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16. Abstract

The evaluation of high-range water reducers on the properties of fresh and hardened concrete under hot and cold weather conditions is described. Four different types of superplasticizers were evaluated: two first generation types and two second generation types. In addition, the effect of superplasticizers on retarding and air-entraining admixtures was investigated. A laboratory testing program consisting of fifteen laboratory mixes and one field mix was used for evaluation of the superplasticizers. The results of the testing program are presented along with recommendations to field engineers.

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EFFECTS OF HIGH-RANGE WATER REDUCERS ON THE PROPERTIES OF FRESH AND HARDENED CONCRETE

by

Ziad Ahmad Zakka
and
Ramon L. Carrasquillo

Research Report Number 1117-3F
Research Project 3-5-87-1117

Guidelines for Proper Use of Superplasticizers and the
Effect of Retempering Practices on Performance and
Durability of Concrete

Conducted for

Texas
State Department of Highways and Public Transportation

In Cooperation with the
U.S. Department of Transportation
Federal Highway Administration

by

CENTER FOR TRANSPORTATION RESEARCH
BUREAU OF ENGINEERING RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

October 1989

There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new and useful improvement thereof, or any variety of plan which is or may be patentable under the patent laws of the United States of America or any foreign country.

PREFACE

The study reported herein is part of a comprehensive study on the use of superplasticizers in concrete construction in Texas. Specifically, this study reports on tests conducted on the effects of the use of superplasticizers on the behavior and durability characteristics of concrete cast under cold weather conditions. Guidelines are presented to be used by the resident engineer on developing a plan for use of superplasticizers in concrete while ensuring adequate performance of the concrete in service.

The work reported herein is part of Research Project 3-5-87-1117, entitled "Guidelines for Proper Use of Superplasticizers and the Effect of Retempering Practices on Performance and Durability of Concrete". The studies described were conducted jointly between the Center for Transportation Research, Bureau of Engineering Research and the Phil M. Ferguson Structural Engineering Laboratory at the University of Texas at Austin. The work was co-sponsored by the Texas State Department of Highways and Public Transportation and the Federal Highway Administration. The study was performed in cooperation with the TSDHPT Materials and Test Division and Bridge Division through contact with Mr. Gerald Lankes and Mr. Berry English, respectively.

SUMMARY

The evaluation of high-range water reducers on the properties of fresh and hardened concrete under hot and cold weather conditions is described. Four different types of superplasticizers were evaluated: two first generation types and two second generation types. In addition, the effect of superplasticizers on retarding and air-entraining admixtures was investigated. A laboratory testing program consisting of fifteen laboratory mixes and one field mix was used for evaluation of the superplasticizers. The results of the testing program are presented along with recommendation to field engineers.

IMPLEMENTATION

The results of this study should be implemented as soon as possible. The differences in performance between the various superplasticizers of the same generation was not significant. Significant difference was however observed between first and second generation superplasticizers. In fact, concrete incorporating Daracem 100 and Rheobuild 716 showed extended workability and better fresh properties compared to first generation superplasticizers Pozzolith 400N and Melment L10. Nevertheless, long term durability of second generation superplasticizers remains questionable due to the short history of their use. Finally, it is recommended that trial batches be performed prior to using superplasticizers in the field to determine their effects on other admixtures, and on fresh and hardened concrete properties for any given mixture.

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CHAPTER 1
INTRODUCTION

1.1 General

High-range water reducers (HRWR), commonly referred to as superplasticizers, are chemical admixtures that can be added to ready-mix concrete to improve its plastic and hardened properties. They are also known as superfluidizers, superfluidifiers and super water reducers[21]. The first superplasticizer was developed in 1964 by Kenichi Hattori in Japan. It was based on formaldehyde condensates of beta-naphthalene sulfonates. Later that same year, a superplasticizer based on sulfonated melamine formaldehyde condensate was introduced in West Germany under the name Melment[16].

High-range water reducers are capable of reducing the water requirement for a given slump by about 30%, thus producing quality concrete having higher strength and lower permeability. They present important advantages compared to conventional water reducers which only allow a reduction of up to 15%. Further, water reduction using water reducers would result in segregation of the fresh mix and a reduced degree of hydration at a later age[27]. Superplasticizers are compatible with almost all other admixtures including air-entraining agents, water reducers, retarders and accelerators. Nevertheless, it is recommended that mixes incorporating different admixtures be tested before usage in the field[27].

The cost of superplasticizer is quite significant at about $5.00 to $6.50 per gallon. This results in an up to a $5.00 per cubic yard increase in the cost of a typical 5 sacks mix. Despite its cost, tremendous savings in labor and production costs can be achieved by using the admixture.

1.2 Justification of Research

As the use of superplasticizers gains widespread acceptance around the world and especially across North America, the need for proper guidelines for its use becomes a necessity. The difficulty in using this admixture results from the fact that its effects on concrete depend on a number of factors including mix proportions, ambient temperature, concrete temperature, time of addition, amount of admixture added and mixing time. In order to produce quality durable concrete such guidelines have to be developed.

1.3 Research Objectives

This research represents a complete study of high-range water reducers, their mode of action, and their effects on plastic and hardened concrete properties. It also provides guidelines for engineers to follow in the field, including the time of addition and the dosage required to achieve the desired properties under cold and hot weather conditions.

1.4 Research Plan

This research includes two parts: cold weather concreting and hot weather concreting. The hot weather concreting part of the study is a continuation of the research conducted by William C. Eckert[6] which specifically addressed the effects of superplasticizers on ready-mix concrete under hot weather conditions. In the course of this study, the following variables were investigated:

a. Cement content
b. Aggregate type
c. Superplasticizer type
d. Extended-life superplasticizer type
e. Retarding admixture dosage
f. Air-entraining dosage

Plastic concrete properties evaluated included:

a. Slump
b. Air content
c. Concrete temperature
d. Unit weight
e. Setting time

Hardened concrete properties evaluated included:

a. Compressive strength
b. Flexural strength
c. Abrasion resistance
d. Deicer-scaling resistance
e. Freeze-thaw resistance
f. Chloride penetration resistance

All tests were performed according to the latest American Society for Testing and Materials (ASTM) specifications and the Texas State Department of Highways and Public Transportation (TSDHPT) specifications where applicable.

1.5 Report Format

A review of the literature addressing the topic of this research is presented in Chapter 2. Chapter 3 includes a detailed description of the materials used as well as the different tests performed. The results of the experimental program are presented in Chapter 4. A discussion of these results is presented in Chapter 5. Chapter 6 includes a summary, conclusions, and guidelines for the use of superplasticizers.

The work described herein is part of research study 3-9-87-1117, titled: "Guidelines for Proper Use of Superplasticizers and the Effects of Retempering Practices on Performance and Durability of Concrete". All tests were performed at the Phil M. Ferguson Structural Engineering Laboratory at the Balcones Research Center of The University of Texas at Austin, under the supervision of Dr. Ramon L. Carrasquillo. The entire research program was sponsored by the Texas State Department of Highways and Public Transportation and the Federal Highway Administration.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

This chapter contains a review of the work conducted by other researchers relating to the subject of this study. It includes a detailed description of the properties and mode of action of superplasticizers, retarding water reducers, and air-entraining admixtures. It also includes the effects these admixtures have on the properties of plastic and hardened concrete under hot and cold weather conditions.

2.2 Definitions

2.2.1 Properties of Fresh Concrete

2.2.1.1 Workability. Workability is defined as "the ease with which concrete can be deformed by an applied stress"[33]. The obtainable deformation depends "on the volume fraction of the aggregate and the viscosity of the cement paste". It is measured by means of the "slump test." Even though many researchers[9,28] have proposed different methods to measure the workability of flowing concrete, including flow table, the slump test remains widely in use. The slump test is a semi-static test that fails to measure the properties of flowing concrete under dynamic conditions. Figure 2.1 illustrates the relationship of both tests[33]. As shown in the figure, the slump test looses its sensitivity and practical use for slumps above 184 mm (7.25 in.). In order to better describe flowing concrete, yield value and viscosity measurements are needed. Yield value is a measure of the extent to which the concrete will flow while viscosity reflects the ease and rate of flow[17,28].

Workability of concrete is affected by many factors including initial slump, type and amount of cement, temperature, relative humidity, mixing criteria (total mixing time, type of mixer, and mixer speed), as well as the presence of chemical and mineral admixtures.

2.2.1.2 Air Content. Air content is the amount of air in the concrete mixture. It is composed of entrapped air and entrained air. Entrapped air is the air that is entrapped in the fresh concrete during casting. While most of the entrapped air is eliminated during consolidation of the concrete into the forms, 1 to 3 percent will remain depending on the maximum aggregate size and shape, the water/cement ratio and other characteristics of the mixture. Entrapped air bubbles are randomly distributed in the concrete. They are large enough to be detected with the naked eye, and usually have a non-spherical shape. Entrained air, on the other hand, is the air that is intentionally entrained in the fresh mixture by means of an air entraining chemical admixture to improve the resistance of concrete to freezing and thawing. Entrained air also improves workability while reducing permeability, segregation, and bleeding[32].

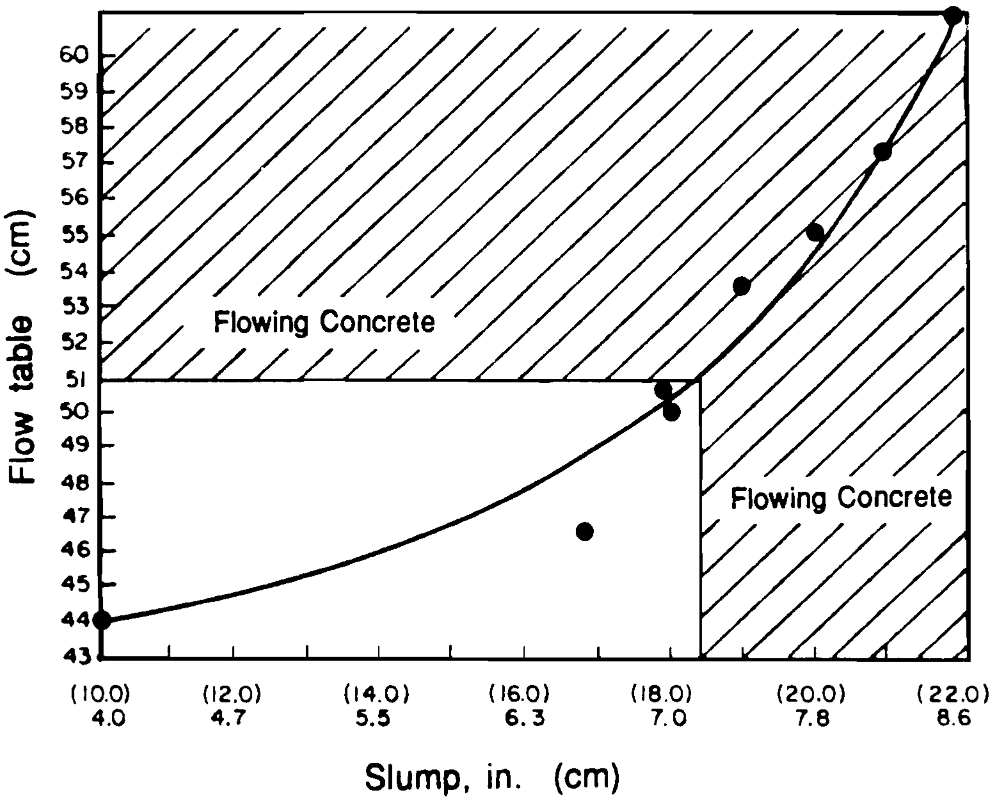


Figure 2.1 The relationship between slump and flow table spread of concrete containing a superplasticizer[33].

Air-entraining agents lower the surface tension of the mixing water producing millions of microscopic air bubbles that are locked into the paste during hardening. The size and number of these bubbles and their spacing determine the characteristics of the air-void system. The resistance of concrete to frost action is mainly dependant on the quality of its air-void system. The volume of air required to achieve optimum frost resistance in concrete is about 9 percent of the volume of mortar in the mixture[23,32]. This represents about 4 to 8 percent of the total volume of the concrete, depending on the maximum size of coarse aggregate used and the resulting mixture proportions. In fact, the use of smaller size aggregates results in a greater surface area of the aggregate. Hence, a larger volume of mortar is required for lubrication of the mixture and a larger amount of air content is required to provide adequate frost resistance.

2.2.1.3 Temperature. The temperature of concrete increases during the hydration of cement. Mixes with finer cement, higher cement content, and mixes incorporating accelerating admixtures experience larger increases in temperature at early ages because of higher rate of hydration. There are many problems associated with an extremely high concrete temperature including: rapid slump loss, early setting time, decreased air content, lower strength, decreased durability, and increased plastic and differential-thermal cracking. High temperature results in a faster hydration of cement, which causes a significant increase in early strength and a reduction in ultimate strength[23]. The amount of additional water needed to achieve a certain slump increases with temperature. As shown in Figure 2.2, an increase from 50 to 100°F (10 to 38°C) requires an additional 33 lb (15 Kg) of water to maintain the same 3-in (76 mm) slump. Such an increase in water content could reduce strength by up to 15 percent[3]. Furthermore, additional water is usually added at the jobsite to offset slump loss. This addition of water represents an increase in the water/cement ratio and therefore a decrease in strength and durability.

2.2.1.4 Segregation and Bleeding. Segregation refers to the separation of the mixture components due to the difference in their specific gravity and size, resulting in a nonuniform mixture. Bleeding is a particular form of segregation where some of the mixing water rises to the surface of the fresh mix[28]. Bleeding increases the water/cement ratio of the upper layer of concrete causing weakness, increased porosity and durability problems. However, limited bleeding is desirable because it allows the excess water to leave the fresh mix and protects against plastic shrinkage cracking. Finally, less bleeding takes place in mixes with low water/cement ratio.

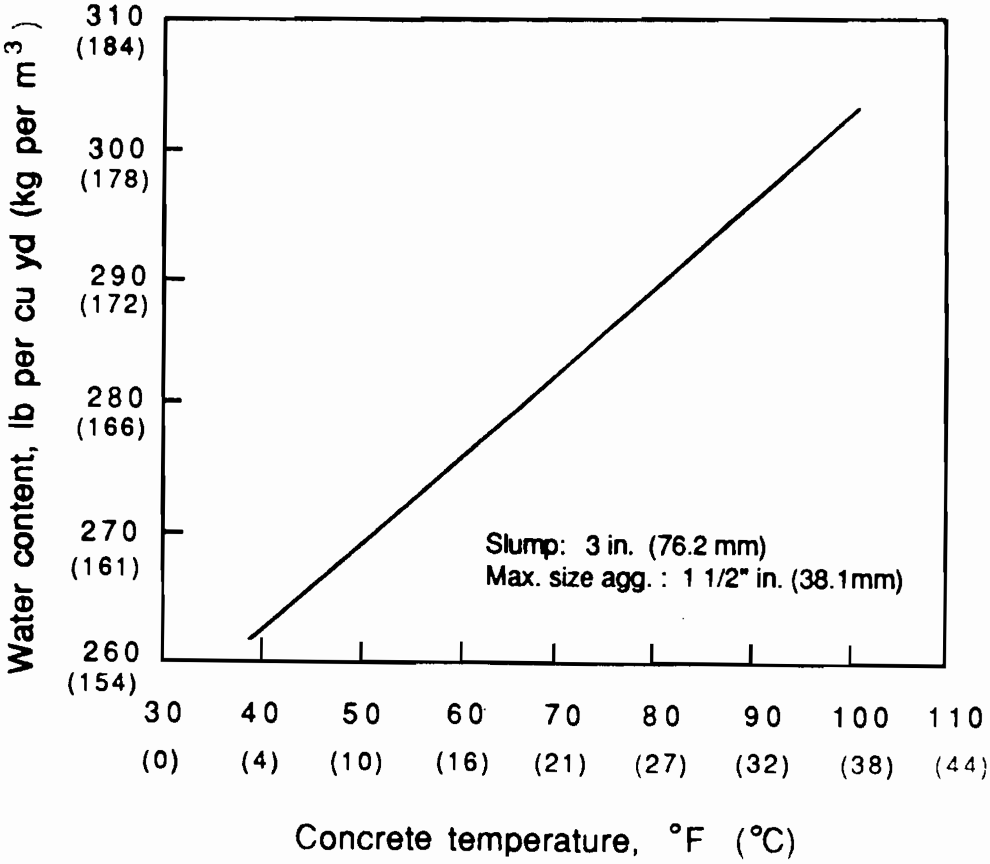


Figure 2.2 The effect of concrete temperature on water content in fresh concrete[3].

2.2.1.5 Finishing. When adequately finished, good quality concrete produces denser, stronger and maintenance- free surfaces. Proper finishing of concrete slabs includes: removing the excess concrete from the surface, floating the surface with flat metal or wood blades, steel-trowelling of the surface to ensure a smooth, dense and wear-resistant surface as desired, texturing of the surface to make it skid resistant, and adding certain chemicals to improve its durability and wear resistance[23].

2.2.1.6 Setting Time. Setting time is determined in terms of initial set and final set. These are arbitrary points between initial water-cement contact and the beginning of strength gain. Initial set is the point in time when the cement paste starts to stiffen considerably. Beyond this point, further mixing of the concrete is harmful. Final set on the other hand, is the point in time when the concrete starts to gain strength. Initial set usually occurs within 2 to 4 hours, while final set takes 5 to 8 hours after initial water-cement contact. There are two main tests for measuring setting times, namely the Vicat needle and the Gillmore needle tests. The primary purpose of determining setting time is for quality control.

2.2.1.7 Unit Weight. The plastic unit weight, or density, of concrete is determined by measuring the weight of concrete in a container of known volume. The unit weight test helps detect any variation between batches of the same mix. It also gives an indication of the air content in the mixture. A decrease in the amount of air in the fresh concrete results in higher unit weight values.

2.2.2 Properties of Hardened Concrete.

2.2.2.1 Air-Void System. In order to produce durable concrete capable of resisting frost action, the concrete should have an adequate air-void system with the following characteristics[23,32]:

1. The spacing factor or maximum distance from the periphery of an air void to any point of the cement paste should not exceed 0.008 in.(0.2 mm). The smaller the spacing factor the more durable the concrete.

2. The specific surface area, which is indicative of the size of the air bubbles, should typically be in the range of 400 to 625 square inches per cubic inch (157 to 246 sq.cm/cu.cm)of air.

3. The number of air bubbles per linear inch should be one and a half to two times the percentage of air content in the concrete.

The air-void system can be determined, according to ASTM C457, by viewing a polished section of the hardened concrete under a microscope to count the air bubbles and calculate the spacing factor.

2.2.2.2 Compressive Strength. The compressive strength of concrete is determined by testing cylinders in uniaxial compression. Compressive strength is mainly affected by the water/cement ratio of the concrete mixture. Strength decreases as the w/c ratio increases. Other factors affecting compressive strength include: age of the concrete, cement type and content, aggregate type, and mineral and chemical admixtures. The ultimate strength of concrete depends on the rate and degree of hydration of the cement. Higher rate of hydration results in higher early strength, but lower ultimate strength. A "more complete" degree of hydration however, results in stronger and denser concrete at later ages[23].

2.2.2.3 Flexural Strength. Concrete is a weak material in flexure. Its flexural strength is usually about 10 percent of its compressive strength. Previous researchers found that the ratio between the two depends on many factors such as the age and strength of the concrete, the type of curing, the type of aggregate, the amount of air-entrainment, and the degree of compaction. Tensile strength is an important indicator of the concrete's tendency to develop cracks, since cracking is primarily a tensile failure. In design however, the tensile strength of the concrete is neglected and all tensile stresses are assumed to be resisted by the reinforcing steel. There are three tests to measure tensile strength: direct tension, splitting tension and flexure[23].

2.2.2.4 Abrasion Resistance. Abrasion resistance is a measure of wear of the concrete surface. It is generally affected by the hardness of the aggregate used. Mixes with harder aggregates show better abrasion resistance. Nevertheless, the effect of aggregate type is less pronounced in high strength concrete. The use of low water/cement ratio in high strength concrete, results in a denser structure with good abrasion resistance[23]. The abrasion resistance of concrete is also affected by the surface finishing and curing procedure. Power finishing and efficient curing result in better abrasion resistance. There are many tests available for determining the abrasion resistance of concrete. The three main ones are: the shotblast test, the dressing wheel test, and the rotating cutter method[6].

2.2.2.5 Freeze-Thaw Resistance. The resistance of concrete to freezing and thawing is one of the most important aspects of durability. Upon freezing, the water in the concrete expands causing cracking of the concrete. Under repeated freezing and thawing cycles, concrete deteriorates quickly both internally and externally. Internal damage is determined by monitoring weight loss and changes in the dynamic modulus of elasticity of the concrete. Changes in the dynamic modulus of elasticity are determined by the fundamental transverse frequency. External damage on the other hand, is determined by visual inspection. It includes large cracks and surface scaling. The concrete resistance to freeze-thaw is tremendously improved by the introduction of entrained air. As mentioned earlier, the air-entraining agents produce millions of small air voids in the cement paste. Upon freezing, water in the concrete can freely expand and occupy these voids. Frost resistance depends on the rate of freezing, the water/cement ratio, time of moist curing, and degree of saturation[23]. The concrete resistance to freeze- thaw can be determined using two different procedures depending on the severity of exposure. The first one is freezing in air and thawing in water, and the other is freezing and thawing in water. Concrete subjected to the second procedure undergoes a much faster deterioration since it is frozen while fully saturated with water.

2.2.2.6 Deicer-Scaling Resistance. The resistance of concrete to the action of deicer-scaling is particularly important for concrete in highways and bridges. During the winter, large amounts of salts are dispensed annually on pavements to prevent them from freezing, thus keeping them open to traffic. These salts will easily penetrate low strength permeable concrete causing considerable damage both to the concrete and the reinforcing steel. On the other hand, mixes with low water/cement ratio and low permeability show good resistance to deicer-scaling.

2.3 Concreting

2.3.1 Hot Weather Concreting. The rate of slump loss is greatly increased under hot weather concreting resulting in a reduction in the time during which concrete can be transported, handled and placed. Additional water is often added at the jobsite to compensate for such a high slump loss. This results in a weaker and less durable concrete, with a higher water/cement ratio. The maximum allowed concrete temperature is usually set at 85 to 90 °F (29 to 32°C) depending on the type of application. Extremely high temperatures have detrimental effects on the properties of fresh and hardened concrete[12].

2.3.1.1 Effects on Fresh Concrete. The effects of hot weather concreting on the properties of fresh concrete include:

- increased water demand
- early and rapid slump loss
- faster rate of setting time
- increased possibility of plastic shrinkage
- increased rate of air loss
- critical need for prompt and early curing

2.3.1.2 Effects on Hardened Concrete. The increase in water/cement ratio due to the addition of water at the jobsite results in the following effects on the properties of hardened concrete:

- decrease in ultimate strength
- decrease in durability

- higher permeability
- nonuniform surface appearance
- increased tendency for drying shrinkage and differential-thermal cracking.

2.3.2 Cold Weather Concreting. Cold weather concreting is defined as the period during which the average temperature is below 40°F (5°C) for three consecutive days, and the highest temperature does not exceed 50°F (10°C) for more than half a day during any 24- hour period. The main concern during cold weather concreting is to protect the concrete from freezing at early ages. The concrete temperature should be as close as possible to the minimum allowable values given in Table 2.1. This table gives the recommended minimum concrete temperatures under various ambient temperatures and section properties. Placing concrete at temperatures below these values or exceeding them by more than 10°F (5°C) is not recommended since that would resultin an increased risk for differential-thermal cracking of the concrete. The period of time during which the concrete needs to be protected against frost action is given in Table 2.2.

Table 2.1 Recommended Concrete Temperatures[2]

Line	Air Temperature	Section size, minimum dimension, in. (mm)			
		< 12 in. (300 mm)	12 - 36 in. (300-900 mm)	36-72 in. (900-1800 mm)	> 72 in. (1800 mm)
Minimum concrete temperature as placed and maintained					
1	- - - -	55 F (13 C)	50 F (10 C)	45 F (7 C)	40 F (5 C)
Minimum concrete temperature as mixed for indicated weather*					
2	Above 30 F (-1 C)	60 F (16 C)	55 F (13 C)	50 F (10 C)	45 F (7 C)
3	0 to 30 F (-18 to -1 C)	65 F (18 C)	60 F (16 C)	55 F (13 C)	50 F (10 C)
4	Below 0 F (-18 C)	70 F (21 C)	65 F (18 C)	60 F (16 C)	55 F (13 C)
Maximum allowable gradual temperature drop in first 24-hr. after end of protection					
5	- - - -	50 F (18 C)	40 F (22 C)	30 F (17 C)	20 F (11 C)

* For colder weather a greater margin in temperature is provided between concrete as mixed and required minimum temperature of fresh concrete in place.

Table 2.2 Protection Recommended for Concrete Placed in Cold Weather*[2]

Service Category	Protection recommended at temperature indicated in Line 1 Table 2.1, days†			
	From damage by freezing‡		For safe strength §	
	Type I or II cement	Type III, accelerator or 100 lb/yd^3 (60 kg/m^3) extra cement	Type I or II cement	Type III, accelerator or 100 lb/yd^3 (60 kg/m^3) extra cement
1. No load, no exposure (See Section 6.1.1)	2	1	2	1
2. No load, exposed (See Section 6.1.2)	3	2	3	2
3. Partial load, exposed (See Section 6.1.3)	3	2	6	4
4. Full Load	3	2	See Chapter 7	

* Weather likely to have a mean daily temperature less than 40 F (5 C) See Sectios 1.3 and 1.4

† Discontinue protection only as instructed in Section 1.10.4.

‡ Unless, in less time, it is assured that the cocnrete including corners and edges, has fully attained a strength of at least 500 psi. However, for protection from thermal cracking, massive concrete will require longer protection, and where cement content is low, it will require longer protection until the concrete reaches a strength of 500 psi (3.5 MPa).

§ These protection periods should be required unless the in-place strength of the concrete has attained a previously established safe strength.

In general, cold weather concrete has fewer problems and results in better quality and more durable concrete as compared to concrete cast in hot weather. It has decreased slump loss, decreased air loss, and extended setting time. This greatly facilitates transportation, placement, and finishing operations. When properly cured, such concrete has a higher ultimate strength, better durability and reduced tendency to develop thermal cracking[2].

2.4 High-Range Water Reducing Admixtures

2.4.1 Properties and Characteristics. Superplasticizers are chemical admixtures capable of improving the workability of concrete without affecting its water/cement ratio. They are classified into four groups[28]:

A: sulfonated melamine-formaldehyde condensate(SMF)

B: sulfonated naphthalene-formaldehyde condensate(SNF)

C: modified lignosulfonates(MLS)

D: other sulfonic-acid esters, and carbohydrate esters

The molecular structure of the first three types is illustrated in Figure 2.3. When properly used, superplasticizers greatly improve workability of concrete without causing any undesirable effects on its fresh and hardened properties. This high workability however, only lasts for about 30 minutes. It is therefore recommended to add the admixture at the jobsite immediately before placement. In order to maintain a high workability for a longer period, redosing is possible, and was not found to be harmful to the concrete[20].

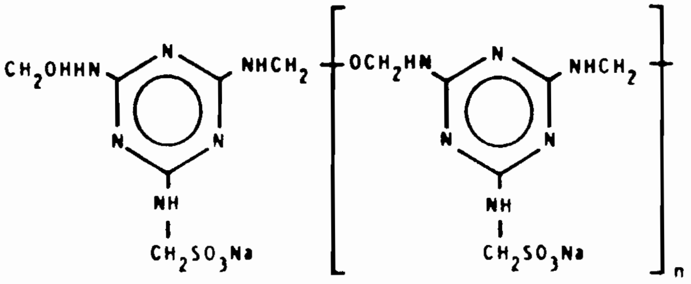
In order to improve workability, especially in hot weather, retarding types of superplasticizers have been developed. They are referred to as extended-life superplasticizers or second generation superplasticizers. They represent a great improvement as compared to conventional superplasticizers. Their effects are extended up to two hours, making it possible to add them to the concrete at the batching plant.

The recommended dosage to achieve the desired properties differs with the superplasticizer's type and manufacturer, the mix design, the temperature as well as the time of addition. Typical dosage rates vary from 10 to 20 fluid ounces per 100 pounds of cement.

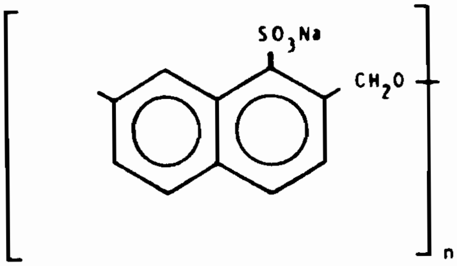
The dispersing action of superplasticizers is not limited to portland cement. They can therefore be advantageously used with other mineral admixtures to produce fly ash concrete, blast furnace slag cement concrete as well as lightweight concrete[28]. Moreover, superplasticizers are compatible with other admixtures such as retarders, accelerators, and air-entraining admixtures.

2.4.2 Chemistry. A study of the rheology, adsorption, and hydration characteristics of cement and cement components is necessary for the understanding of the mode of action of superplasticizers.

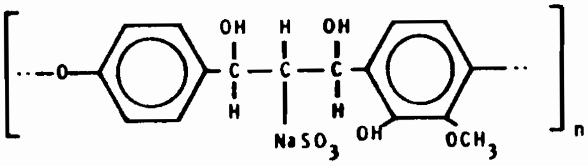
Superplasticizers significantly affect the rheological behavior of the cement paste. In general, the molecules of the superplasticizer align themselves around cement particles forming a watery shell as shown in Figure 2.4. These molecules are attracted to cement particles on one side and water molecules on the other. Thus they create a lubricating film around the cement particles, which reduces both the yield value and the plastic viscosity of the mix. These effects are more pronounced for higher concentrations of superplasticizer. Microscopic examination of cement particles suspended in water shows that large irregular agglomerates of cement particles are dispersed into small particles due to the effect of superplasticizers. As shown in Figure 2.5 [7], the admixture forms needle-like hydration products instead of the large fibrous bundles found in normal concrete. At the age of six months, the concrete incorporating the admixture shows a tighter and more complete structure[28].



SODIUM SALT OF
SULFONATED MELAMINE FORMALDEHYDE
(a)



SODIUM SALT OF
SULFONATED NAPTHALENE FORMALDEHYDE
(b)



SODIUM LIGNOSULFONATE
(c)

Figure 2.3 The molecular structure of commercially available types of superplasticizers[28].

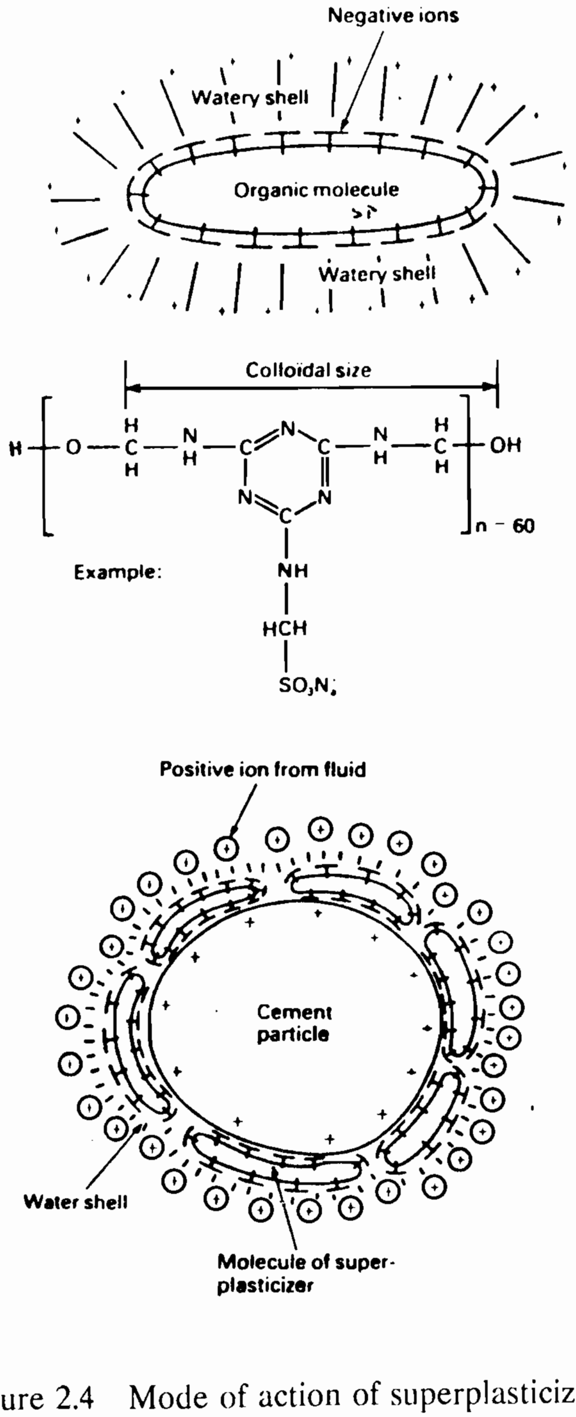


Figure 2.4 Mode of action of superplasticizers[7].

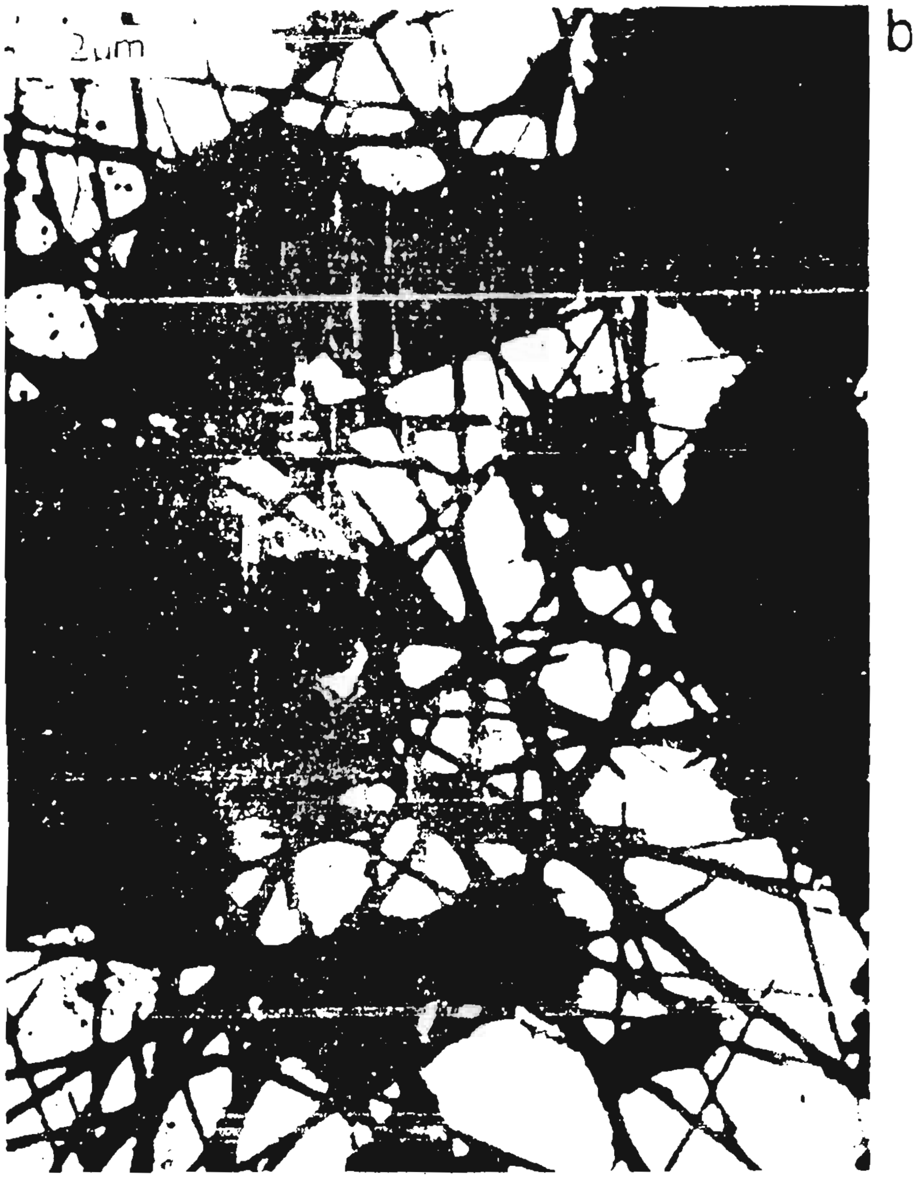


Figure 2.5 Microscopic view of superplasticized concrete[7].

Adsorption is primarily influenced by the type of cement used. It was also found that Type III cement has the highest degree of adsorption followed by Type I and Type II. Figure 2.6 shows the adsorption characteristics of a melamine based superplasticizer (SMF) on cement, C_3A and C_3S in an aqueous solution[28]. The adsorption of superplasticizer on C_3A occurs within seconds. Hexagonal aluminate adsorbs large amounts of superplasticizer, and are not immediately converted to the cubic form in the system C_3A-H_2O-SMF due to the formation of complexes between the SMF and the hydrating C_3A. The mechanism is similar to the hydration of C_3A in the presence of calcium lignosulfonate. For the C_3S on the other hand, limited adsorption occurs on the surface during the first hour. The adsorption is almost nil up to about 4 to 5 hours and then increases continuously. In cement, SMF is adsorbed by the C_3A +gypsum. This adsorption occurs within a few minutes. In order to lower the rate and amount of adsorption, it is recommended to add the admixture 5 to 30 minutes after the beginning of hydration. Delaying the addition of the admixture will therefore leave enough of the admixture in the solution to produce dispersion of the silicate phase and thus, improve workability. Adsorption beyond 5 hours is mainly due to C_3S hydrates in the cement. Adsorption increases as the concentration of superplasticizer added is increased. Due to the adsorption of ions, particles develop charges. The repulsion between particles having identical charges prevents any agglomeration or precipitation, and decreases the viscosity of the system[28]. The large negative potentials resulting from the addition of superplasticizer were found to decrease with time but remain high even after 1200 minutes[22].

Soon after the initial contact between cement and water, cement particles increase in size and reaggregate, causing a reduction in fluidity almost immediately. Continuous mixing of the concrete shears off the hydration products formed on the surface of the cement particles. The combination of elevated temperature and the peeling action increases significantly both the hydration rate and the amount of hydration product formed thus causing a substantial reduction in fluidity[24]. In order to reinstate the fluidity, the superplasticizer should act both on the cement particles and hydration products. Therefore, a higher dosage of superplasticizer is required when the time of addition is delayed[31]. Both melamine and naphthalene based superplasticizers are known to delay the hydration of C_3S and C_3A. As to the effects of these admixtures on the rate of hydration of C_3A+gypsum mixtures, opinions are divided.

2.4.3 Effects on Fresh Concrete

2.4.3.1 Workability. The workability of concrete depends on the following factors: initial slump, type and amount of cement, type and dosage of superplasticizer, time of addition of superplasticizer, temperature, relative humidity, mixing conditions (total mixing time, type of mixer, and mixer speed), and presence of other admixtures. Mixes with lower initial slump require a higher dosage of superplasticizer[28]. The opinions on the effect of initial slump on the rate of slump loss after the addition of superplasticizers are divided. Generally, mixes with higher initial slump were found to have a more gradual rate of slump loss[19]. The opposite was reported by Ramakrishnan[29,30].

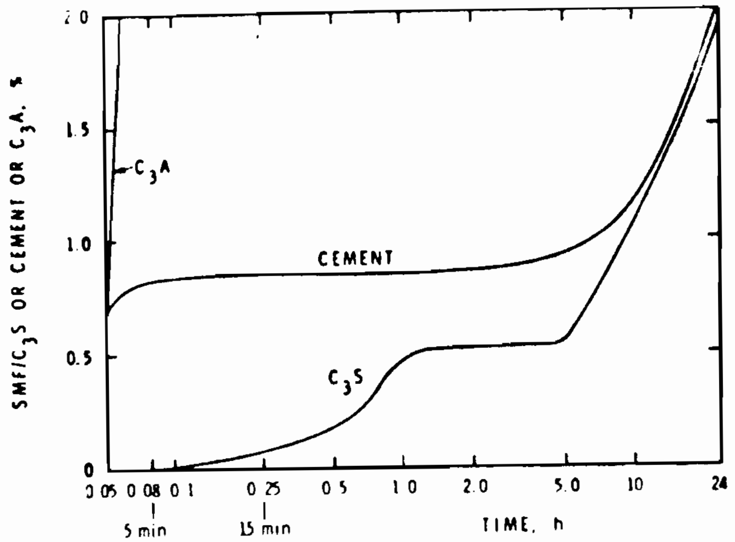


Figure 2.6 The absorptionof superplaticizer on cement, C_3A, and C_3S in an aqueous solution[26].

Workability is also affected by the cement type and cement content of the mix. It was found that to obtain the same workability, a higher dosage of superplasticizer is required for Type I than for Type V cement. Mixes with higher cement content require smaller dosages of superplasticizer to achieve a certain slump[38]. This is expected since mixes with higher cement content are known to be more fluid, even when no admixture is present. Moreover, mixes with higher cement content show a slower rate of slump loss[28].

Superplasticizers differ depending on their type and manufacturer. It was reported that melamine based superplasticizers show a higher rate of slump loss compared to other types of superplasticizers[17,22]. Ramakrishnan[29,30] on the other hand reported that both Melment and Lomar D, two superplasticizers based on melamine and naphthalene respectively, behave identically. Mixes prepared with both admixtures became non workable after 3 hours and went to zero slump after 4 hours. As the dosage of superplasticizer increases, workability increases and the rate of slump loss decreases[22]. The effect of superplasticizer dosage on slump is illustrated in Figure 2.7 [28]. Overdosing the mixture will prolong workability even further, yielding an extremely high slump, but is likely to cause excessive segregation and bleeding. Moreover, workability is improved with the use of a retarding type of water reducer in combination with a superplasticizer[7]. When using a retarder, the dosage of superplasticizer required to achieve a desired slump decreases[39]. Workability is extended

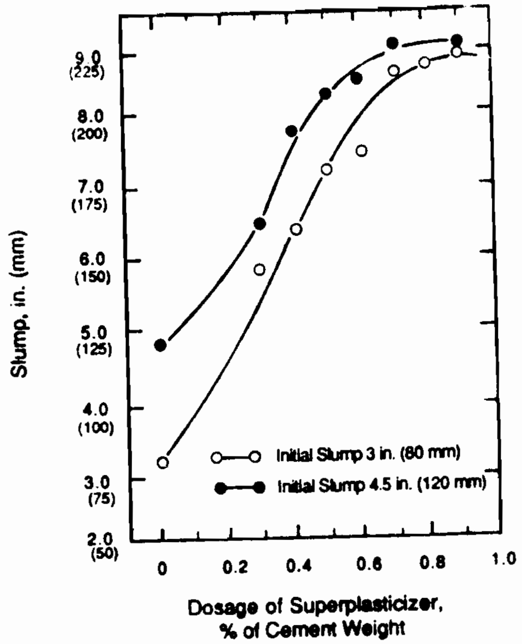


Figure 2.7 The effect of superplasticizer dosage on slump gain[28].

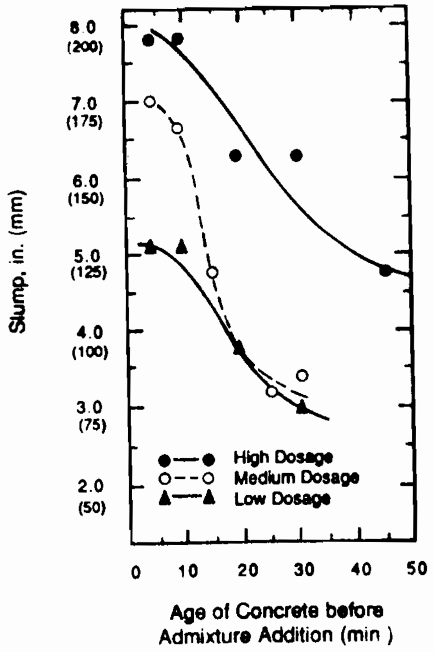


Figure 2.8 The effect of time of addition of superplasticizer on slump gain[28].

even further when using a second generation superplasticizer[10]. The amount of workability retention increasing with the use of a higher dosage of superplasticizer[26,40]

Another factor affecting workability is the time of addition of superplasticizers. As shown in Figure 2.8 [28], the capacity of superplasticizers to improve workability decreases with time. It is, however, recommended to delay the addition for a few minutes until some of the C_3A is removed from the mixture by hydration, as mentioned earlier[7,28]. This reduces slump loss considerably.

At lower temperature, the loss in workability is reduced[19,28], and the dosage required to achieve a desired slump is significantly increased, especially for temperatures below 68°F (20°C)[39]. This is shown in Figure 2.9. Other researchers found no change in the effect of superplasticizers in the temperature range of about 40 to 86°F (5 to 30°C). In order to overcome the problem of rapid slump loss, especially under hot weather, the addition of repeated dosages of superplasticizer was found to be effective[28].

Workability can be reinstated by repeated dosing with superplasticizers. Generally, repeated dosage does not deteriorate the concrete, but may result in loss of entrained air[20], and thus an increase in the plastic unit weight. Repeated dosage improves workability for an extra 25 to 45 minutes regardless of the slump achieved after the first dosage. The

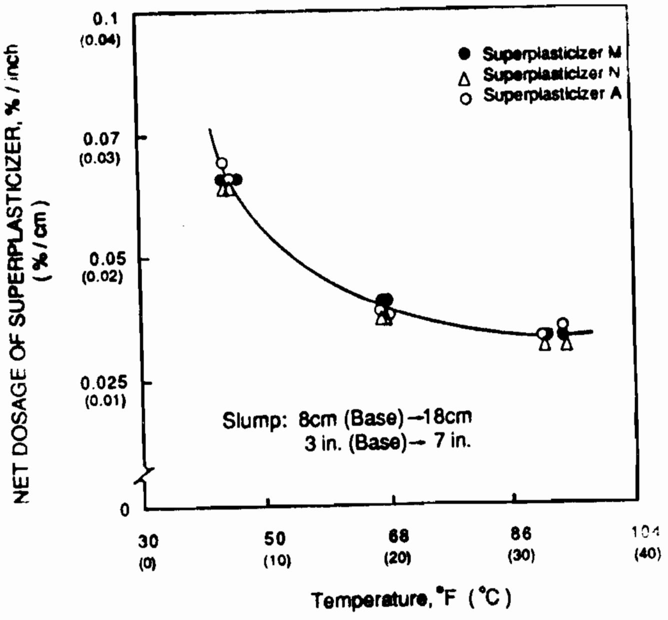


Figure 2.9 The effect of temperature on superplasticizer dosage[39].

effectiveness of superplasticizers in improving workability decreases with the number of repeated dosages, and the rate of slump loss increases after each repeated dosage[29]. Other researchers found that the amount of the second and third dosages are equal to the initial one[28]. Mailvaganam[19] even reported that the slump obtained after repeated dosing with superplasticizer exceeded the slump obtained after the first dosage, and showed a more gradual rate of slump loss.

2.4.3.2 Air Content. The incorporation of superplasticizer lowers the viscosity of the fresh concrete mixture, thus facilitating the escape of air from it. Typically, 1 to 3 percent of the air is lost due to the addition of the admixture. Gebler[9] estimated the loss as being about 35 to 40 percent of the initial air content. This loss is accentuated even further with redosage[29], high temperature, delay in casting, prolonged mixing time[8], higher initial air content[30], use of higher water/cement ratio[35] and use of higher dosage of retarding admixtures. Some superplasticizers have air-entraining admixtures as their components. In fact, in some instances, the air content of fresh concrete was found to increase immediately after the addition of superplasticizers[28,39]. Foam stability is generally improved when naphthalene or melamine based superplasticizers are used with Vinsol Resin air-entraining agent[8].

When using second generation superplasticizers, the air content was found to remain unchanged or to decrease slightly, unless the superplasticizer is added at the same time as the air-entraining agent. When both admixtures were added at the same time, the air content increased because of the increase in fluidity of the mixture[36].

2.4.3.3 Temperature. The use of superplasticizers reduces the rate of temperature rise in the concrete, thus reducing slump and air loss while delaying setting time[30]. The degree of reduction depends on the type of superplasticizer used. Use of Lomar D, a superplasticizer based on naphthalene formaldehyde, was reported to result in a lower temperature rise when compared to the use of Melment, a melamine based superplasticizer[29].

2.4.3.4 Segregation and Bleeding. Superplasticized concretes show increased bleeding compared to regular concretes with the same water/cement ratio. This is due to the delayed setting time[36]. Compared to flowing concrete prepared without the admixture, however, superplasticized concrete shows much lower bleeding[9]. In order to avoid segregation and excessive bleeding in flowing concrete, the mixture should contain sufficient fines. The use of 4 to 5 percent more sand in the mixture is recommended. According to the Canadian Standards Association guidelines (A266.5.M 1981), the minimum recommended fine aggregate content passing the sieve 300 x10-6 m is 674, 758, and 843 lb/cu.yd (400, 450, and 500 kg/m^3) for mixes with a maximum aggregate size of 1.5, 0.75, and 0.5 in. (40, 20, and 14 mm) respectively[28]. In order to avoid segregation and bleeding problems in flowing concrete, adequate inspection should be provided during placing, consolidating and finishing operations, especially when using conveyor belt systems[22]. Finally, due to the delay in setting time in cold weather, bleeding has more time to occur[39].

2.4.3.5 Finishing. The finishing of superplasticized flowing concrete is not as simple as it may seem. The reason being that such concrete tends to have a relatively high volume of mortar on the surface. Thus, the surface becomes sticky and tends to shear or tear under the action of the trowel. This problem can be solved by using a mix with coarser fine aggregates and/or a larger amount of coarse aggregates. Another way to solve this problem is to delay the finishing operation until the concrete looses its stickiness and becomes easier to finish[6].

2.4.3.6 Setting Time. Generally, superplasticizers delay both the initial and final setting time of concrete[9]. This is expected since superplasticizers were found to delay the hydration of cement as discussed earlier. The extent of the retardation depends on the type and dosage of superplasticizer used. Finally, when used in combination with other admixtures, superplasticizers may have opposing effects on setting time. It is therefore necessary to study the effect of these admixtures before using them in the field. At the recommended dosage, melamine was found to have the least effect on setting time compared to other superplasticizers[17,22].

2.4.3.7 Unit Weight. The plastic unit weight of concrete increases after the addition of superplasticizers. This is mainly due to the loss of air that usually occurs during the addition of the admixture[29]. The increase in unit weight is also due to better consolidation of the concrete after the addition of superplasticizer.

2.4.4 Effects on Hardened Concrete.

2.4.4.1 Air-Void System. The incorporation of superplasticizers results in a lower quality air-void system in the concrete[38]. As shown in Figure 2.10[28], the spacing factor is affected by the dosage of superplasticizer used. It increases as the dosage of superplasticizer increases reaching a maximum value near the dosage rate of 0.40 to 0.50 percent by weight of cement, and then decreases. It is therefore essential to determine the effects of a given admixture dosage on the spacing factor, before using it in the field, especially when frost resistance is desired. The bubble size is also affected by the addition of superplasticizer[34]. In fact, microscopic examination of superplasticized concrete showed that the air bubbles were two to three times larger than the size of air bubbles in concrete not incorporating a superplasticizer. The increase in both spacing factor and bubble size due to the addition of superplasticizer results in fewer air bubbles per linear inch than required by ASTM C-457.

2.4.4.2 Compressive Strength. The strength of concrete with superplasticizer was found to be greater or at least equal to the strength of the same concrete made without the admixture. Strength is increased even further with sequential dosages. This strength gain was found to be around 10 percent at the age of 28 days. At an earlier age, the difference is even greater. When used with superplasticizers, Type I cement behaves like a high early strength cement, even exceeding a Type III cement. The increase in the rate of strength gain is explained by some researchers as a result of using a greatly reduced water/cement ratio in concrete incorporating superplasticizers, and not to an improvement in the rate of

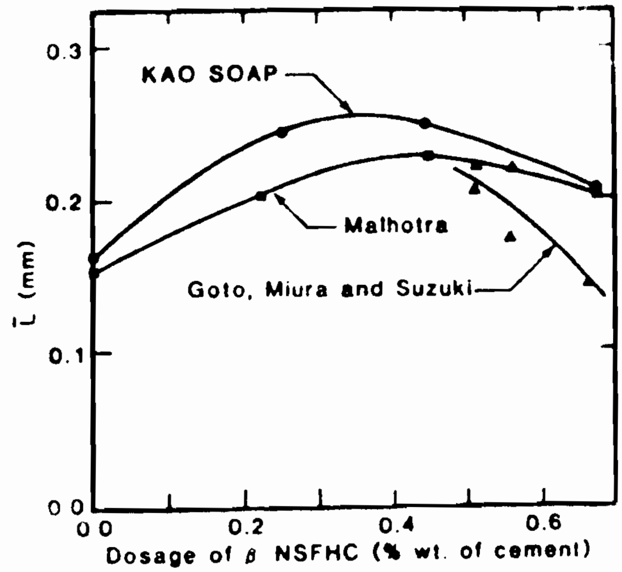


Figure 2.10 The effect of superplasticizer dosage on the spacing factor of concrete[28].

hydration[23]. In fact, Malhotra and Malanka[22] reported that the cylinders cast right before adding superplasticizer had the same compressive strength as the ones cast immediately after the addition. Other researchers reported that the high rate of strength gain was due to a loss of air in the concrete[29,30]. Nevertheless, most researchers agree that the addition of superplasticizers increases the rate and degree of hydration of cement because of a better dispersion of the hydrating products, thus causing an increase in strength both at earlier and later ages, while maintaining the same water/cement ratio[17]. The increase in the rate and degree of hydration of cement at early ages results in higher early strength. On the other hand, the increase in the final degree of hydration achievable due to a good dispersion of hydrating products is responsible for the increase in strength at later ages.

Concrete incorporating a melamine based superplasticizer was reported to show higher compressive strength when compared to the control at all ages. Naphthalene based superplasticizers, however, showed lower strength at early ages and a similar strength at ninety days. In general, second generation superplasticizers were found to slightly increase compressive strength. Nevertheless, some researchers reported that, when sampled just after the addition of superplasticizer, flowing concrete showed a compressive strength at less than 90 percent of the control[26]. Yamamoto and Takeuchi[40] also reported lower compressive strength due to the addition of second generation superplasticizers.

2.4.4.3 Flexural Strength. Unlike their effects on compressive strength, superplasticizers were found to cause only a slight increase in the flexural strength of concrete[9]. According to Johnson and Gamble[17], this is due to the fact that failure in flexure is governed mainly by the strength of the paste-aggregate bond, while compression failure is primarily controlled by the strength of the cement paste itself.

2.4.4.4 Abrasion Resistance. The abrasion resistance of concrete was found to increase due to the incorporation of superplasticizers. In fact, the use of superplasticizers allows a production of high strength concrete with a good consolidation and surface finish. Therefore, when properly finished, superplasticized concretes show better abrasion resistances compared to regular concrete.

2.4.4.5 Freeze-Thaw Resistance. In order to have a good freeze-thaw resistance, the concrete paste should have enough entrained air, and an adequate air-void system as mentioned in section 2.2.2.1. Both the spacing factor and the size of air bubbles in superplasticized concrete however, exceed the required values. This is particularly true for melamine and naphthalene based superplasticizers. Nevertheless, superplasticized concretes show acceptable resistance to freeze and thaw action[5, 17, 27]. It was also reported that entraining 0.5 percent more air than in normal concrete, will even better improve freeze-thaw resistance[39]. Other researchers found that superplasticized concrete had a lower frost resistance than regular concrete[34]. Regarding the long term durability, superplasticized concrete, this remains questionable due to the relatively short history of its use.

2.4.4.6 Deicer-Scaling Resistance. Superplasticized concrete was found to have acceptable resistance to deicer-scaling[28]. This is due to its greater strength, lower permeability and better surface finishing. As mentioned earlier, the delay in setting time due to the use of superplasticizers allows more time for placing and finishing the concrete properly.

2.4.4.7 Resistance to Chloride Penetration. Previous researchers reported that for the same slump, superplasticized concrete is less permeable than regular concrete. However, superplasticized concrete is more permeable than regular concrete, both having the same water/cement ratio[9].

2.4.5 Applications. Despite the cost associated with the use of superplasticizers, overall cost savings in terms of manpower and accelerated construction time are possible. Moreover, the admixture allows the production of a high strength and durable concrete having a reduced permeability and shrinkage, and an improved surface finish. There are three main applications for superplasticizers[28]

1. Superplasticizers are used to produce a flowing concrete while maintaining the same cement content and water/cement ratio. Flowing concrete, also referred to as self- levelling or self-compacting concrete, is concrete having a slump of

8 inches (203 mm) or more, and bearing no signs of segregation and excessive bleeding. The advantages of such a concrete are numerous. It is ideal for placing in areas of congested reinforcement without incurring segregation or honeycombing. Besides, the ease of placing it and the need for only a minor vibration makes it suitable for casting floors, foundation slabs, bridges, pavements, roof decks, etc. The only practical limitation on the use of flowing concrete is that it may not be used to cast slopes exceeding 3 degrees to the horizontal.

2. The second practical use of superplasticizers in concrete is in the reducing of the amount of water required by up to 30 percent while keeping the same workability. This allows a significant decrease in the water/cement ratio and therefore an increase in strength. Concrete having a water/cement ratio as low as 0.28 and a strength of up to 14.5 ksi (100 MPa) were achieved. Ultra high strength of the order of 21.75 ksi (150 MPa) at 100 days for mixes incorporating silica fume has also been achieved[28].

3. The third use of the admixture is to produce concrete with reduced cement content while maintaining the same water/cement ratio. This use of the admixture is particularly popular in North America because of the important reduction in cost associated with it.

Superplasticizer's high rate of strength gain makes it ideal for use in precast industry applications. Strengths in the order of 5.8 Ksi (40 MPa) are achieved in 8 to 18 hours at lower curing temperature and/or curing time, and therefore at lower cost. Superplasticizers have also been advantageously used to produce concrete having excellent pumping characteristics. The use of the admixture reduces pumping pressure and line pressure loss by about 30 percent. Because of its lower water/cement ratio and higher early compressive strength, superplasticized concrete has been used to produce shrinkage compensating concretes containing lower amounts of expansive agents. Finally, superplasticizers have been used for spray applications and where special shapes are desired as in architectural work. The first major project involving the use of precast superplasticized concrete was the Montreal Olympic Stadium. It is composed of segmental precast units with a design compressive strength of 6 ksi (42 MPa) at 28 days and a required minimum slump of 6 in. (150 mm) for the heavily reinforced precast units[28]. By using superplasticized concrete, it was possible to successfully meet both strength and workability requirements.

2.5 Retarding Admixtures

2.5.1 Properties and Characteristics. The first retarding admixture, or retarder, was developed in the 1930's. It was based on naphthalene sulfonic acids. Since then, retarding admixtures have been extensively used. Retarding admixtures are water reducing admixtures that extend workability and setting time, by decreasing the degree of hydration at early ages. They extend the plasticity of fresh concrete, allowing more time for transportation, handling and placing of the concrete. They also delay both the initial and final setting time. Retarding admixtures are useful for hot weather concreting because of the tremendous decrease in the working window at higher temperatures. While a small retardation is possible using a retarding type superplasticizer, proper retarding admixtures are required when a longer retardation is desired[39]. Retarders can be divided into four categories based on their chemical composition[23, 28]:

1. Lignosulfonic acids and their salts
2. Hydroxy-carboxylic acids and their salts
3. Carbohydrates
4. Other compounds

All retarding admixtures have water reducing properties[6]. Thus, they can be classified as both retarding and water reducing admixtures. They are capable of reducing the required mixing water by up to 15 percent without affecting the workability of the mix. This results in a higher strength concrete with lower shrinkage. The water reduction depends on the type and manufacturer of the retarder, dosage used, procedure followed in adding it, water/cement ratio, cement type and content, type of aggregate, air content, and other mineral admixtures. The water reducing effect of the admixture is lower in mixes with low slump values, and higher cement content. The effect of retarding admixtures is greater, however, for air-entrained mixes, and mixes with low alkali and C_3A cement. When normal or accelerated setting time is desired, the retarding effect of retarding admixtures is offset by the addition of an accelerator, such as triethanolamine that shortens the setting time, and calcium chloride, formate or other salts that shorten setting time and accelerate early hardening[28].

Lignosulfonates were developed in the 1930's. They are the most widely used retarding admixtures. Hydroxy-carboxylic acids were developed in the 1950's. Their use has increased tremendously, but remains much less than lignosulfonates. Gluconic acid is the most widely used type of lignosulfonates. Carbohydrates on the other hand include natural compounds such as glucose and sucrose, or hydroxylated polymers. Other compounds include other organic compounds such as glycerol, polyvinyl alcohol, and sulfanilic acid. Finally, sodium gluconate was found to be more effective in improving workability and reducing water than glucose and lignosulfonates[28].

The degree of retardation is proportional to the amount of retarder used. Overdosing, however, is detrimental to the concrete. In fact, if the dosage used exceeds a certain critical point, the hydration of C_3S is stopped at stage 2 (see Figure 2.11)[23] indefinitely and the cement paste will never harden[28].

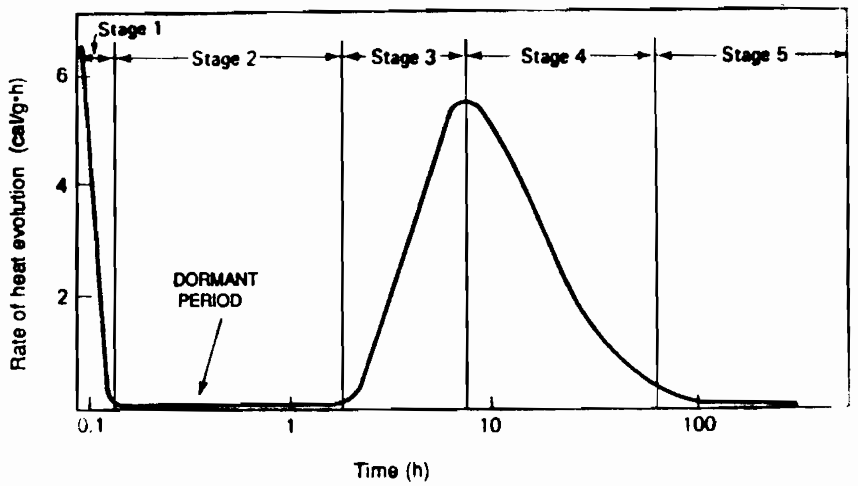


Figure 2.11 The calorimetric curve of portland cement[23].

Retarding admixtures perform best when added at the end of the mixing time. This is difficult, however, since it usually results in the admixture being non-uniformly dispersed in the mix, especially in large mixes. In order to assure good performance, it is recommended to mix the cement, aggregate and half of the mixing water for 15 to 30 seconds before the addition of the retarder. The retarder should then be added to the mix dissolved in 25 percent of the mixing water[28].

The admixture is usually in aqueous solution form. It has an extremely long shelf-life. In one study, a retarding admixture stored for 10 years showed no signs of deterioration with the exception of a minor separation of the solid products in the solution. Nevertheless, retarding admixtures should be stored at moderate temperatures. In fact, extremely hot temperatures may cause separation and solidification of the admixture. The recommended dosage is in the range of 3 to 6 fluid ounces per 100 pounds of cement. It is, however, recommended that trial mixes be made to determine the exact dosage of retarder needed to obtain the desired properties. Overdosing the mix with the admixture results in extremely long retardation and a significant decrease in compressive strength at early ages, especially in cold weather. It may even cause the mix to remain in the plastic state for several days[28].

Retarding admixtures may be used with other chemical and mineral admixtures. When used with a superplasticizer, retarders allow a reduction in the dosage of superplasticizer needed to achieve a given workability[39]. When retarders are used with an air-entraining agent, the two admixtures should not be mixed and need to be added separately. In fact, when added together, the air-entraining admixture looses its effectiveness in entraining air into the mixture. The retarding admixture, on the other hand, is not affected. In some instances however, air-entraining agents are combined with retarders forming one admixture having both a retarding and air-entraining effect.

2.5.2 Chemistry. The effect of retarders is greatly influenced by the C_3A, and alkali and sulfate content of the cement used. Retarders were found to extend the length of the dormant period in the cement hydration process (see Figure 2.11), thus slowing the rate of early hydration of C_3S. However, the rate of subsequent hydration in stages 3 and 4 may be accelerated due to the use of retarding admixtures.

The effect of retarders on the hydration of C_3A on the other hand, is very complex. It was found that while the overall hydration of C_3A is retarded due to the admixture, the initial reaction between C_3A and water may be accelerated. It was also found that retarders may interact with the hydrating products during formation producing C_3A-Admixture compounds. Therefore, mixes incorporating a cement with higher C_3A content require higher dosage of retarder[23, 28].

The retarding properties of the admixture are also affected by the SO3 content of the cement. Depending on the amount of SO3 present in the cement, it was found that retarders may cause abnormal retardation or early stiffening. In fact, cement with low sulfate (gypsum) content experience an extremely great retardation due to retarding admixtures. If noticed during trial batches, this problem can be easily solved either by increasing the amount of gypsum in the cement or reducing the dosage of retarder used[6]. Another problem that could arise from the use of retarding admixtures is a delay in setting time, but not the time during which the concrete is workable. It was reported that the effectiveness of retarders is influenced by the content of alkali oxides in the cement. The reason for this observation is not exactly known[23]. Finally, as the second hydration of C_3A begins around 24 hours after the initial water-cement contact, the concentration of retarder in the solution drops sharply. The formation of more ettringite adsorbs large amounts of the admixture, allowing the hydration of C_3S to proceed[6].

2.5.3 Effects on Fresh Concrete.

2.5.3.1 Workability. Retarding admixtures allow a reduction in water content of the concrete without affecting its workability. The extent of reduction is even higher for mixes with higher slump values. In fact the incorporation of a given dosage of a retarding admixture increased the slump by 1.18 in.(30 mm) in a mix with a slump of 0.78 in.(20 mm). When added to a mix with 2.75 in.(70 mm) slump, the same dosage of admixture increased the slump by 3.15 in.(80 mm)[27].

At a given slump value, the use of retarding admixtures increases flow and decreases the rate of slump loss of regular and superplasticized concrete especially at high temperatures[19]. As mentioned earlier however, the type of cement used and the time of addition have a tremendous effect on the behavior of retarding admixtures. In fact, when used with certain types of cements, retarders are capable of increasing the rate of slump loss, while delaying the setting time. Even when the rate of slump loss is increased however, the slump of the concrete made with the retarder remains higher than the slump of the control[28]. Finally, the effect of retarders on workability is improved, when the addition is delayed for a few minutes after the initial contact between cement and water. In fact, a delay of about 10 minutes was found to produce optimal retardation. Further delay, decreases the effectiveness of the admixture, and its capability to delay setting time is completely lost 2 to 4 hours after initial water-cement contact[23]. Concrete incorporating the admixture shows a greater flow and lower slump loss than plain concrete with the same slump. In some instances however, the retarding admixtures are capable of increasing slump loss. Despite this, the slump of the concrete made with the retarder remained higher than the slump of the control even after two hours[28].

2.5.3.2 Air Content. Some retarding admixtures like lignosulfonates have air-entraining properties. When added at the manufacturer's recommended dosage, they are capable of entraining 2 to 3 percent air[28]. The use of higher dosages can entrain up to 7 percent air, especially in mixes with high slump values. It is important to note however, that retarding admixtures reduce the surface tension in the mix, allowing some of this entrained air to escape. This air loss is further increased with the use of higher retarder dosages[39]. Therefore, it is more efficient to use a proper air-entraining agent to entrain the desired amount of air. Finally, it was found that the dosage of air-entraining agent required to obtain the desired air content is decreased due to the presence of retarders[28].

2.5.3.3 Temperature. The rise in concrete temperature is lower in concrete incorporating a retarding admixture. Previous researchers reported that retarding admixtures result in lower concrete temperature at one day. At 3 days, it was reported that the temperature of concrete incorporating the admixture was the same as the control. After 3 days, the mixes with the admixture had a higher temperature. Mixes containing accelerating admixtures showed opposite results. Finally, due to their relatively low cost, retarding admixtures are more efficient than ice in controlling the temperature of concrete[28].

2.5.3.4 Segregation and Bleeding. Concretes containing retarding admixtures are more cohesive and therefore, less likely to experience segregation. The degree of bleeding however was found to depend on the type of retarder used. For a given slump value, retarding admixtures containing hydroxy-carboxylic acids were found to increase the rate of bleeding. The rate is however reduced with lignosulfonate and especially glucose use. The rate of bleeding of a particular retarder should be investigated before using it in the field in order to prevent plastic cracks due to high rate of evaporation especially under hot and windy weather conditions[33].

2.5.3.5 Finishing. The extended plasticity in concrete due to the use of retarding admixtures facilitates the placing operation. The concrete can be adequately vibrated, thus reducing the risk of air pockets and cold joints from occurring. Due to an extended setting time, a reduction in the number of finishers is possible, and largerslabs can be finished at one time. This is particularly important in hot weather conditions where setting time is very short[28]. Howard[14] however, reported that concrete incorporating a retarding admixture was stickier and harder to finish than plain concrete.

2.5.3.6 Setting Time. Generally, retarding admixtures delay both initial and final setting time[28]. The amount of retardation depends on the dosage of admixture used, the type of cement used, the amount of mixing water, and the temperature of the concrete. A higher dosage of retarding admixture increases the delay in setting time[39]. The effect on cement of the amount of retardation can only be determined by trial batches. These tests should be performed on concrete mixes identical to the ones to be used in the field. In general, it was found that the retarding effects of the admixture are more pronounced in mixes with pozzolanic and slag cements compared to portland cement. Finally, when specific retardation under extremely high concreting temperature is desired, overdosing is possible. In some instances however, this results in acceleration of the initial setting time. This may be avoided by delaying the addition of the admixture for a few minutes as mentioned earlier[28].

2.5.3.7 Unit Weight. For the same air content, retarding admixtures were found to increase the unit weight of concrete[28]. This is due to lower water content. In fact, water being the lightest material in the mixture, any reduction in water results in increased unit weight. The increased unit weight is also due to increased fluidity which allows better consolidation of the concrete.

2.5.4 Effects on Hardened Concrete

2.5.4.1 Air-Void System. The air-void system of concrete incorporating retarding admixtures is adequate. However, the literature addressing this topic is limited.

2.5.4.2 Compressive Strength. The use of water reducers allows a reduction in the amount of water in the mixture, and therefore a decrease in the water/cement ratio and an increase in compressive strength. However, this increase in strength is not only due to a reduction in water content, but also to a greater degree of hydration at later ages. This was concluded by other researchers since even at identical water/cement ratios, mixtures incorporating retarding admixtures showed a higher ultimate strength. Ultimate strength is however decreased when a large overdose of retarder is added[27]. Finally, the rate of strength gain after one day is also increased due to the use of retarding admixtures. Thus, even though the retarder causes a slight decrease in strength at one day, both the concrete incorporating the admixture and the control show a similar strength at seven days[23].

2.5.4.3 Flexural Strength. Flexural strength is slightly increased due to the use of retarders[23]. The increase in flexural strength was found to be about 10 percent after 7 days[28]. Previous researchers reported that the relationship between compressive and flexural strength is not affected by retarding admixtures composed of lignosulfonates and hydroxy-carboxylic acids[33]. It was found, however, that other types of retarding admixtures cause a slight change in this relationship.

2.5.4.4 Abrasion Resistance. The abrasion resistance of concrete is generally improved due to reduced water content when using a retarder. The resistance to abrasion is further improved due to the retarding effects of the admixture. In fact, better finishing is possible due to delayed setting time, especially under hot weather conditions[28].

2.5.4.5 Freeze-Thaw Resistance. The use of retarding admixtures improves the resistance of concrete to freezing and thawing. The reason for this being that the admixture reduces air loss as mentioned earlier. Wallace and Ore[37] reported that the resistance of air-entrained concrete to frost action was improved by 39 percent due to the addition of retarding admixtures.

2.5.4.6 Deicer-Scaling Resistance. The concrete's resistance to deicer-scaling is improved due to the use of retarding admixtures. This is due to a better permeability, and use of a lower water/cement ratio.

2.5.5 Applications. Retarding admixtures are used to prolong the plasticity of fresh concrete in hot weather, and when an unavoidable delay between mixing and placing is expected. The admixture is also used in pouring of mass concrete, since its use eliminates the need for cold joints between successive lifts. The concrete remains plastic long enough to allow these lifts to be blended together by vibration. Retarders also help prevent a cracking of the concrete due to form deflection, when pouring large slabs[23]. The admixture is also beneficial in improving the pumping characteristics of concrete mixes. A reduction in pumping pressure of up to 30 percent was achieved with a retarder based on lignosulfonate[28]. Finally, it is recommended that trial batches incorporating retarding admixtures be prepared to investigate the behavior of these admixtures in the presence of various cements prior to their use in the field.

2.6 Air-Entraining Admixtures

2.6.1 Properties and Characteristics. Air- entraining agents are chemical admixtures added to the fresh concrete mixture to improve the durability of the concrete at later ages. The addition of the admixture produces millions of small air bubbles which are dispersed throughout the cement paste. The effect of the admixture is similar to that of household detergents with the exception that the bubbles produced using the air-entraining agent are smaller in size, and much more stable[23]. The admixture is added to the concrete with the mixing water. When the concrete is subjected to frost action at later ages, these air voids allow for the expansion of the frozen water, thus protecting the concrete from cracking. The air content recommended by the American Concrete Institute (ACI) for adequate durability is shown in Table 2.3.

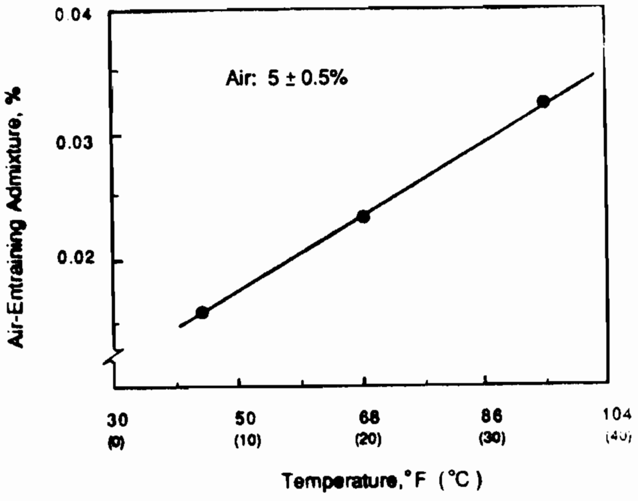


Figure 2.12 The effect of temperature on the dosage of air-entraining admixtures[39].

Table 2.3 Approximate Mixing Water and Air Content Requirements for Different Slumps and Maximum Sizes of Aggregates#

Slump, in.	Percent Water for Indicated Maximum Size of Aggregates							
	3/8 in.	1/2 in.	3/4 in.	1 in.	1-½ in.	2 in.*	3 in.*	6 in.*
	Non-Air-Entrained Concrete							
1 to 2	21	20	19	18	16	15	14	12
3 to 4	23	22	20	19	18	17	16	14
6 to 7	24	23	21	20	19	18	17	- - -
	Approx. amount of entrapped air in non-air-entrained concrete, percent							
	3	2.5	2	1.5	1	0.5	0.3	0.2
	Air-Entrained Concrete							
1 to 2	18	18	17	16	15	14	13	12
3 to 4	20	19	18	17	16	16	15	13
6 to 7	22	20	19	18	17	17	16	- - -
	Recommended Average Total Air Content, percent							
	8	7	6	5	4.5	4	3.5	3

These quantities of mixing water are maxima for reasonable well-shaped angular coarse aggregates graded within limits of accepted specifications.

* The slump values for concrete containing aggregates larger than 1-½ in. are based on slump tests made after removal of particles larger than 1-½ in. by wet screening.

This table gives the amount of air required as a percentage of the total volume of concrete, depending on the maximum size of coarse aggregate and severity of exposure. At the recommended dosage, all commercial air- entraining admixtures were found to produce an adequate air-void system. As the dosage is decreased, the air content decreases, and both the bubble size and spacing factor increase. The dosage of air-entraining admixtures is not affected by the presence of superplasticizers[8]. Nevertheless, it is affected by the temperature as seen in Figure 2.12. The required dosage of air- entraining admixture increases linearly as the temperature increases[39]. It also increases when a finely divided mineral admixture such as fly ash is added to the mixture. In order to be effective, the admixture should be thoroughly mixed. Inadequate mixing results in air void clusters in the hardened concrete (Figure 2.13). Some cement manufacturers grind the air-entraining agent with the cement, thus producing air-entrained concrete without the need for any admixture. Such cements are designated IA, IIA, etc.

The most common air-entraining agent used is neutralized vinsol resin, which has been selected as a reference for all other air-entraining admixtures[23]. It is a registered trademark of Hercules Inc., that is commercially available in a transparent dark yellow-brown solution. The pH of the solution is usually between 11.5 and 12. "Settling out of a very viscous gummy- like mass" may occur if the pH drops below 10[32]. Some air-entraining admixtures have water reducing properties. They are referred to as air-entraining water reducing agents. The main advantage of these admixtures is that they entrain air into the concrete without affecting its compressive strength. They are capable of entraining up to 3 percent air in the concrete mix without causing any reduction in compressive strength, or requiring any modification of the mix design[33]. Air-entraining admixtures should be stored in closed containers separately from other chemical admixtures in order to avoid contamination. In fact, air-entraining admixtures are easily contaminated with calcium chloride or calcium lignosulfonate.

The recommended dosage of air-entraining admixture is very small. It is usually one fluid ounce per hundred pounds of cement. Therefore, it is very important to dispense the admixture uniformly. The addition of other chemical admixtures, such as retarding admixtures, makes the air-entraining agent more efficient[31]. Nevertheless, the two admixtures should be added separately. As mentioned earlier, the air-entraining agent looses its effectiveness when added together with a retarding admixture.

2.6.2 Chemistry. Air-entraining admixtures contain surface-active agents which concentrate at the interface of air and water. They lower the surface tension of water helping air bubbles to form and stabilize. Surface- active agents are molecules having one end that tends to dissolve in water, or hydrophilic (water-loving), and another end that is repelled by water or hydrophobic (water-hating). As seen in Figure 2.14[23], these chemical molecules will tend to align themselves at the interface with one end in the water, and the other in the air. The hydrophilic end is composed of carboxylic acid or sulfuric acid, while the hydrophobic end is made of aliphatic or aromatic hydrocarbons.

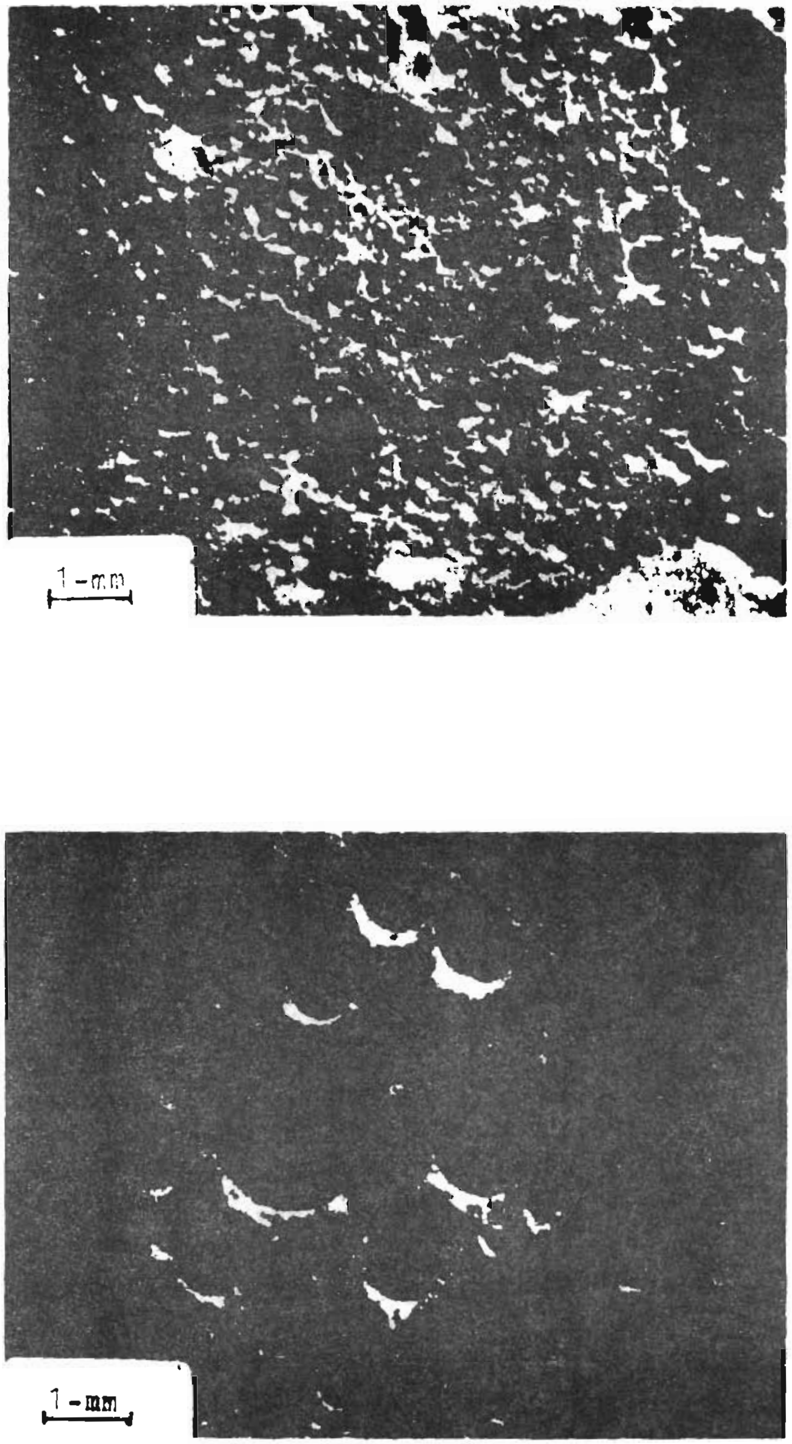


Figure 2.13 The effect of superplasticizers on the air-void system in concrete[32].

2.6.3 *Effects on Fresh Concrete*

2.6.3.1 Workability. The addition of entrained air improves the workability and cohesiveness of the fresh mix. In fact, the addition of 5 percent entrained air increases the slump by about 0.5 to 2 in.(12.7 to 50.8 mm). Even at the same slump, air-entrained concrete is more workable, and easier to place and consolidate. The main reason being that air bubbles act as low friction, elastic, fine aggregates, reducing the interaction between the coarse aggregates in the mixture. The escape of entrained air from the mix during transportation, especially in hot weather, is one of the reasons for slump loss. When slump loss is not excessive, the air lost may be recovered along with the slump upon retempering. When retempering fails to recover the lost air, it is possible to add a second dosage of air-entraining agent at the jobsite. This is not recommended however, since it may result in a non-uniform concrete having large amounts of air-void clusters[32].

2.6.3.2 Air Content. In order to have adequate durability, the concrete should possess the right amount of air. It was found that while low air content decreases durability, excessive air content reduces both strength and durability. The air content of concrete increases with an increasing air-entraining dosage. The air content in concrete is also affected by the fineness of sand, gradation and shape of the coarse aggregate, cement

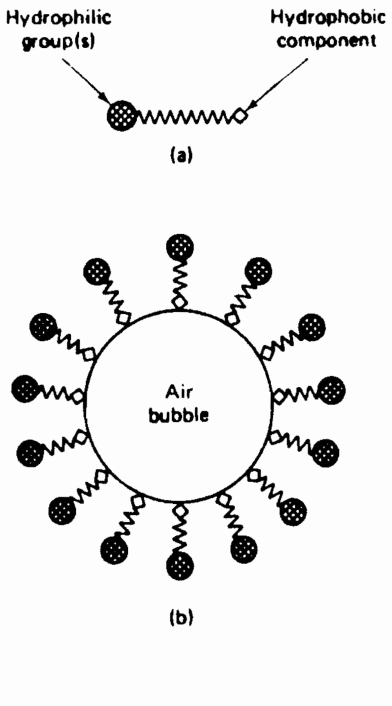


Figure 2.14 The mdoe of action of air-entraining admixtures[23].

addition of mineral admixtures such as fly ash. The air content decreases as the sand in the mixture gets finer. It also decreases with finer cement and higher cement content. The opposite is true for mixes with higher water/cement ratio. As the mixing time of concrete increases, the air content increases to a maximum value and then gradually decreases during extended mixing. The effect of temperature on air content is significant. As mentioned in section 2.6.3.3, higher air loss is observed at higher temperatures[32]. The air content can be reduced below the recommended values given in Table 2.3, when the mixture has a high cement content and a low water/cement ratio. This is because higher strength concrete has lower permeability, and improved resistance to cracking caused by internal stresses[23]. When naphthalene or melamine based superplasticizers are used with vinsol resin air-entraining agent, foam stability is generally improved[8].

2.6.3.3 Temperature. At higher temperatures, air-entraining admixtures are less effective in entraining air in the concrete. That is due to higher air loss at the higher temperature[32]. It was reported that an increase in temperature from 10 to 38°C (50 to 100°F), results in decreasing the air content by half[23]. This is even more pronounced at higher slump values. In fact, a temperature increase of 59°F (39°C) was found to reduce the air content by 1 percent in a 7 in.(177.8 mm) slump mix, while showing no effects on a 1 in.(25.4 mm) slump mix[28].

2.6.3.4 Segregation and Bleeding. Entrained air reduces segregation and bleeding considerably, both at low and high slump[23, 32]. Due to their large number and small size, air bubbles increase the cohesiveness and homogeneity of the concrete. In fact, by attaching themselves to the surface of the solids in the mix, the air bubbles help the aggregate "remain in suspension" thus reducing the possibility of segregation especially in flowing concrete. Bleeding, on the other hand, is also reduced since the incorporation of air bubbles decreases the permeability of the concrete. Thus, water molecules are attracted to the air bubbles and cannot find their way to the surface. In order to avoid shrinkage cracks due to reduced bleeding, the surface of the concrete should be moist cured until the concrete starts to gain strength.

2.6.3.5 Finishing. Finishing of air-entrained concrete seems difficult to inexperienced finishers. It feels sticky and does not bleed enough. Experienced finishers however, find air-entrained concrete easier to finish compared to non air- entrained concrete. In order to ensure a good durable finish, magnesium or aluminum floats should be used, and the finishing operation should be delayed until the concrete looses some of its stickiness[28].

2.6.3.6 Setting Time. Setting time of concrete was not found to be affected by the incorporation of air-entraining admixtures[28].

2.6.3.7 Unit Weight. The addition of air- entraining admixtures in the concrete causes an increase in the volume of voids. This results in a decrease of the unit weight of concrete.

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2.6.4 *Effects on Hardened Concrete*

2.6.4.1 Air-Void System. Generally, all commercially available air entraining agents produce adequate air-void systems satisfying the parameters stated in section 2.2.2.1. At a given air content, an increase in the water/cement ratio results in increased bubble size, increased spacing factor and therefore a lower quality air-void system[23]. Ray[32] considers that only the air content and the limitation on the spacing factor are significant in determining the durability characteristics of concrete. The other parameters are not as important, and are too complicated to determine.

2.6.4.2 Compressive Strength. The addition of entrained air has a tremendous effect on strength. Usually, every 1 percent increase in air content results in a 3 to 5 percent loss in compressive strength. A part of this strength loss can be offset however, by using a lower water/cement ratio. In fact, the water/cement ratio needed to achieve a certain workability is lower for air-entrained concrete compared to non air-entrained concrete[32].

2.6.4.3 Flexural Strength. Previous researchers found that entrained air decreases flexural strength. The amount of strength reduction being approximately the same as for compressive strength.

2.6.4.4 Abrasion Resistance. The abrasion resistance of air-entrained concrete was found to be lower than non air-entrained concrete. When adequate resistance to abrasion is desired, Ray[32] recommends that the air content in the concrete be less than 4 percent.

2.6.4.5 Freeze-Thaw Resistance. In order for concrete to have adequate freeze-thaw resistance, the air content should be about 9 percent of the volume of mortar in the concrete[32]. Damage due to freeze-thaw generally starts with the finished surface flaking off. Then, larger parts of the concrete flake off and finally, large cracks develop across the full thickness of the member[32].

2.6.4.6 Deicer-Scaling Resistance. The resistance of concrete to deicer-scaling is improved due to entrained air. The main reason being that air-entrained concrete is less permeable and therefore more resistant to deicing salts.

2.6.5 Applications. Air-entrained concrete is required when the concrete is expected to resist frost action and chemical attacks. It has been used where there is a need for watertight impermeable concrete. Water-retaining structures and construction below grade, are common examples of such applications. Air-entrained concrete is also advantageously used for pumping application because of its reduced tendency to segregate. The use of aluminum pipes is not recommended however, since the mix will react with the aluminates in the pipes entraining large amounts of air.

CHAPTER 3

MATERIALS AND EXPERIMENTAL PROGRAM

3.1 Introduction

This chapter contains a detailed description of all the materials used in the experimental program, as well as the procedures followed in conducting the various tests. The experimental program was divided into two parts: cold and hot weather concreting. The first part included eight mixes, which were batched from January to March 1988. The second part consisted of eight mixes, seven of them were batched in June and one in August of that same year.

3.2 Materials

3.2.1 Portland Cement. The portland cement used was a commercially available ASTM Type I cement, meeting ASTM C150-86, Standard Specification for Portland Cement. The physical and chemical properties of the cement used are listed in Appendix A1.

3.2.2 Coarse Aggregate. Two types of coarse aggregates were used during the course of this research program: natural gravel and crushed limestone. The natural gravel was from the Colorado River, while the crushed limestone was from Georgetown, Texas. Both were normal weight, and had a 3/4 inch nominal maximum size conforming to ASTM C33-86, Standard Specification for Concrete Aggregates. The limestone aggregate had a bulk specific gravity at SSD of 2.54 and the river gravel aggregate had a bulk specific gravity at SSD of 2.62.

3.2.3 Fine Aggregate. The fine aggregate used in all the mixes was a natural sand from the Colorado River. It meets the specification of ASTM C33-86, Standard Specification for Concrete Aggregates. Its bulk specific gravity at SSD was 2.62, and its fineness modulus ranged from 2.88 to 3.21.

3.2.4 Water. The water used in all mixes was tap water conforming to ASTM C94-86b, Standard Specification for Ready- Mixed Concrete.

3.2.5 High-Range Water Reducers. Four types of commercially available superplasticizers were investigated.

MB 400N is a superplasticizer based on naphthalene sulfonate formaldehyde, produced by Master Builder Inc. The manufacturer's recommended dosage is 10 to 20 fl.oz per 100 lb (650 to 1300 ml/100 Kg) of cement. It conforms to ASTM C494-86, Standard Specification for Chemical Admixtures for Concrete, Types A and F admixtures, Type A being water-reducing admixtures, and Type F high range water-reducing admixtures.

Melment L-10 is a superplasticizer based on melamine sulfonate formaldehyde produced by Gifford-Hill Chemicals, Inc. The manufacturer's recommended dosage is 16 to 18 fl.oz per 100 lb (1040 to 1170 ml/Kg) of cement. It also meets the requirements of ASTM C494-86, Standard Specification for Chemical Admixtures for Concrete, Types A and F admixtures.

Rheobuild 716 is a second generation superplasticizer produced by Master Builders Inc. The manufacturer's recommended dosage is 12 to 18 fl.oz per 100 lb (780 to 1170 ml/100 Kg) of cement. It conforms to ASTM C494-86, Standard Specification for Chemical Admixtures for Concrete, Types A, F and G admixtures. Types A and F are described above. Type G are high range water- reducing and retarding admixtures.

Daracem 100 is a second generation superplasticizer produced by W. R. Grace Co., Inc. The manufacturer's recommended dosage is 10 to 15 fl.oz per 100 lb (650 to 975 ml/kg) of cement. It meets the requirements of ASTM C494-86, Standard Specification for Chemical Admixtures for Concrete, Types A, F and G admixtures.

3.2.6 Retarding Admixtures. MB 300R was used in this research program. It is a retarding water reducing admixture produced by Master Builders, Inc., which conforms to ASTM C494-86, Standard Specification for Chemical Admixtures for Concrete, Type B and D admixtures. Type B being retarding admixtures, and type D water-reducing and retarding admixtures. It is based on a calcium salt of lignosulfonic acid, which is approved for use by the Texas SDHPT. The manufacturer's recommended dosage is 3 to 5 fl.oz per 100 lb (195 to 325 ml/100 kg) of cement.

3.2.7 Air-Entraining Admixtures. One type of air- entraining admixture was used throughout this program. It is a neutralized vinsol resin produced by Master Builders Inc. It conforms to ASTM C260-86, Standard Specification for Air- Entraining Admixtures for Concrete. The use of this admixture is approved by the Texas SDHPT. In this study, the needed dosage of air-entraining admixture to achieve a 4 to 6 percent air content was added. It varied from 0.64 to 1.38 fl.oz per 100 lb of cement, depending on the ambient temperature and mix characteristics.

3.3 Mix Proportions

The mix proportions of all mixes are listed in Appendix A2.

3.4 Mix Variations

3.4.1 Temperature. During the first part of this program, the effects of superplasticizer on cold weather concreting were investigated. The concrete temperature was held in the range of 54 to 68°F. For the second part of this program, the effects of superplasticizers on hot weather concreting were investigated for concrete temperatures between 85 and 88°F. Thus, in this report, cold weather concreting and hot weather concreting refer to concrete temperatures in the range of 54 to 68°F and 85 to 88°F, respectively.

3.4.2 Cement content. The effect of superplasticizers in improving the properties of fresh and hardened concrete was studied using two different cement contents. A cement content of 5 sacks (470 pounds) per cubic yard, and a higher cement factor of 7 sacks (658 pounds) per cubic yard were used. The 5-sack mixes meet the specification for Texas SDHPT Class A regular concrete, while the 7 sacks mixes meet the requirements of the Texas SDHPT Class C-C special concrete. Class A concrete is specified for general application, while class C-C concrete is specified when designing bridge slabs, and high strength concrete incorporating superplasticizers.

3.4.3 Coarse Aggregate. The effects of coarse aggregates on fresh and hardened properties of concrete were investigated using crushed limestone and natural river gravel type aggregates. River gravel has a smooth surface texture, and rounded regular shape. They improve workability, finishing and abrasion resistance. However, the angular shape of crushed limestone causes an increase in the bond between the aggregate and the mortar, thus they are preferred in the production of high strength concrete. The two aggregates were supplied by different batching plants. The crushed limestone coming from a plant located further away from the laboratory than the plant supplying the river gravel. This generally resulted in an increased transportation time and delay in time of addition of the admixture for the mixes containing crushed limestone.

3.4.4 High-Range Water Reducer.

3.4.4.1 Type and Manufacturer. The effects of four types of superplasticizers on fresh and hardened concrete were investigated in this study. The four superplasticizers studied included two conventional types and two second generation superplasticizers.

The conventional types included a naphthalene-based and a melamine-based superplasticizer. The advantages and problems associated with their use were evaluated. These effects included workability, slump loss, air loss, finishability, setting time, strength and durability. It also included the effect on concrete cost in order to achieve the desired properties.

Two second generation superplasticizers were investigated primarily because they allow extended workability and can be added at the batching plant. This represents tremendous advantages since it possibly reduces the air loss that is likely to occur in low slump mixes in hot weather during transportation. Moreover, the long lasting effects of this type of superplasticizers eliminate the need for a second and third dosage. In fact, by the time the slump of concrete incorporating a second generation of superplasticizer returns to its initial value, the concrete is too old to be used. Most specifications, including the one used by the Texas SDHPT prohibits the use of concrete that is more than two hours old.

3.4.4.2 Time of Dosage.

3.4.4.2.1 FIRST GENERATION. The time of addition of the conventional types of superplasticizers was about 60 minutes after the initial water- cement contact. Due to fluctuation in transportation time depending on traffic and plant location, the addition was sometimes delayed for another 15 minutes. A repeat dosage, however, was always made when the slump of the concrete dropped to its initial value prior to the addition of the first dosage. However, for the last mix of the series conducted in hot weather, the superplasticizer was added at the batching plant 15 minutes after the initial water-cement contact. This was done to reduce the amount of air lost during transportation and to study the effect of early addition of the admixture on the properties of concrete.

3.4.4.2.2 SECOND GENERATION. The second generation superplasticizers were added at the batching plant 15 minutes after the initial water-cement contact. A repeat dosage was not required.

3.4.5 Retarder Dosage. The effect of a retarder dosage on superplasticized concrete was investigated using dosages of 0, 3, and 5 fl.oz per 100 lb (0,195,325 ml/kg) of cement. Retarding admixtures have some water reducing properties and therefore reduce the dosage of superplasticizer required to achieve a certain slump. Furthermore, they improve the properties of fresh concrete by reducing slump loss and delaying setting time, especially in hot weather.

3.5 Mixing Procedure

All mixes were inspected and tested at the batching plant, to make sure that the desired types and amount of ingredients were put in the mixing truck in the proper sequence. Before the concrete truck was loaded, its drum was inspected to make sure it had been thoroughly washed and dried. The truck was then loaded in the following sequence; the aggregates were added first, followed by the cement, and then the water. The chemical admixtures, including air-entraining agents and retarders, were added last to prevent them from being absorbed by the aggregates. During the addition of the aggregates, samples of fine and coarse aggregates were taken. Immediately after batching, air and slump tests were conducted at the plant. Concrete with lower than desired slump values was retempered with water and sampled again. The amount of added water was about 1 gallon per yard of concrete for every one-inch increase in slump. Concrete with higher slump values and/or an air content other than desired was not accepted and was immediately rejected.

The procedure for mixes 1 through 13 was as follows: The concrete with the desired slump and air content was then sent to the laboratory, where the rest of the tests were conducted. During days of warm temperatures, the driver was asked to add a total of two gallons of water per truck load before leaving the plant to balance water evaporation during transportation, and thus minimize slump loss.

At the laboratory, a second team was ready to receive the truck and start the various tests at once, avoiding any delays. Just after the truck arrival, the time, ambient temperature and relative humidity were recorded. Then, two wheelbarrow loads of concrete were discarded and a third one was used to conduct slump, air content, and unit weight tests. Each wheelbarrow has a capacity of 2.5 cubic feet (0.07 m3). The reason for the foregoing discarding of concrete is to ensure that the concrete tested is representative of the mixture. As soon as the slump and air content tests were finished and the desired values obtained, that is 1 to 3 inches of slump and 4 to 6 percent air, the first set of specimens was cast, and a wheelbarrow load of concrete was sieved in preparation for the setting time test.

Meanwhile, the superplasticizer was added to the concrete mixture, which was about one hour old. The dosage needed to produce an 8 to 10 inches slump, was estimated for each mix, depending on its cement content, initial slump and coarse aggregate type. Before the addition of superplasticizer, the truck driver was asked to rotate the drum backward allowing the concrete to rise to the top. The drum was then stopped and the admixture added directly on to the concrete using a 5-gallon bucket. A water hose was used to spray loose any admixture stuck to the drum. The concrete was then mixed for five minutes. At the end of mixing, two wheelbarrow loads of concrete were discarded, and slump and air content tests were performed on the third. Whenever the desired slump was not obtained, a second and sometimes third dosage of superplasticizer was added following the exact same procedure. After the proper slump was obtained, a unit weight test was conducted, one wheelbarrow load was sieved, and the second series of specimens was cast. Every 15 minutes thereafter, one wheelbarrow load of concrete was discarded, and another was used to perform a slump and air content test. When the slump dropped to its initial value of 1 to 3 inches, the concrete was dosed again with superplasticizer. The same procedure was followed as in the first dosage, and the third series of specimens was cast.

All specimens were cast in accordance with ASTM specifications. Immediately after placing and rodding the concrete in the molds, wooden trowels were used to remove the excess concrete and level the surface of the specimens. The finishing operation, using aluminum trowels, was not started until some of the bleeding was gone, and the concrete had lost some of its stickiness. The specimens were then surrounded with wet burlap and covered with plastic sheets. The next day, the molds were stripped and the specimens were put in a curing chamber conforming to ASTM C511-85. The compressive and flexural strength specimens were cured until tested at 7 and 28 days. Freeze thaw specimens were cured for 28 days, while deicer- scaling specimens were removed from the chamber at the age of 14 days, and dry cured at 75°F ± 3°F for another 14 days. At 28 days, both deicer-scaling and freeze-thaw specimens were placed in a freezer at 0°F until they were tested.

The procedure for mixes 14 and 15 was as follows: After the slump and air content of the fresh concrete were measured at the batch plant, a second generation superplasticizer was added following the same procedure used in adding conventional superplasticizers. At that time, the concrete was 15 minutes old. After the addition, the concrete was mixed for 5 minutes. Two wheelbarrow loads of concrete were then discarded and a new slump test was performed to determine if the slump was well in the desired range of 8 to 10 inches. The concrete was then sent to the laboratory where the rest of the tests were conducted.

The procedure for mix 16 (field mix) was as follows: For this mix, all tests on freshly mixed concrete were conducted at the batching plant. The specimens were cast and consolidated in the back of a pick-up truck. The identical procedure was followed as in laboratory mixes except that no unit weight or setting time tests were conducted. The cast specimens included only compressive strength cylinders and freeze-thaw prisms. Five series of specimens were cast. The first series was cast immediately after the concrete was mixed. The second series was cast right after the addition of the first dosage of superplasticizer. The third series was cast when the slump dropped to 6 inches. The fourth was cast when the slump dropped to its initial value of 3 inches, just before adding the second dosage of superplasticizer. The fifth and final series was cast immediately after the second dosing. The specimens were consolidated and finished in the same way as the laboratory cast specimens. The specimens were protected against drying with wet burlap and a cover of plastic sheets. They were transported to the laboratory on the following day. In order to minimize vibration and impact during transportation, the pick-up truck was driven at a very low speed, and the specimens were separated with pieces of wood. The specimens were then demolded and cured in the same way as laboratory mixes.

The procedure followed in casting, consolidating and curing the specimens of all mixes was in accordance with ASTM C192-81, Standard Method of Making and Curing Concrete Test Specimens in the Laboratory.

3.6 Test Procedure

3.6.1 Fresh Concrete Tests

3.6.1.1 Slump. The slump test was performed according to ASTM C143-78, Standard Test Method for Slump of portland Cement Concrete, and Tex-415-A, Slump of Portland Cement Concrete.

3.6.1.2 Air Content. The air content test was performed according to ASTM C173-78, Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method, and Tex-416-A, Air Content of Freshly Mixed Concrete.

3.6.1.3 Temperature. The concrete temperature was taken using a thermometer having a range from 25°F to 125°F with 1°F gradations.

3.6.1.4 Setting Time. This test was conducted on mortar in cylindrical containers having a depth of 6 inches and a diameter of 10 inches. It was performed according to ASTM C403-85, Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance.

3.6.1.5 Unit Weight. This test was carried out according to ASTM C 138-81, Standard Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete and Tex-417-A, Weight per Cubic Foot and Yield of Concrete.

3.6.2 Hardened Concrete Tests

3.6.2.1 Compressive Strength. The test was conducted at the age of 7 and 28 days. It was performed on 6 x 12 inch cylinders using unbonded neoprene pads. The strength was taken as the average of three specimens and the standard deviation and coefficient of variation were computed. The test was performed according to ASTM C39-86, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens, and Tex-418-A, Compressive Strength of Molded Concrete Cylinders.

3.6.2.2 Flexural Strength. Flexural strength was determined by performing a modulus of rupture test on 6-in x 6-in x 20-in beams. The beams were tested in flexure using the third point loading method. The test was conducted at the age of 7 and 28 days during the first part of the research program and only at 7 days during the second part. The strength was determined as the average of three specimens and the standard deviation and coefficient of variation were computed. The test was performed in accordance with ASTM C78-84, Standard Test Method for Flexural Strength of Concrete.

3.6.2.3 Abrasion Resistance. After the beams were tested in flexure at 7 days, one-half of each beam was saved and tested for abrasion resistance on the following day. The test was only conducted during the first part of this research program. The test was performed on the finished surface of the specimens in accordance to ASTM C944-80, Standard Test Method for Abrasion Resistance of Concrete or Mortar Surfaces by the Rotating Cutter Method.

3.6.2.4 Freeze-Thaw Resistance. All sixteen mixes cast during cold and hot weather were tested for freeze-thaw resistance. In addition, nine mixes cast during a related study were also tested. These nine mixes were cast by William C. Eckert[6] in the course of a study specifically addressing the effects of superplasticizers on ready-mix concrete under hot weather. The mixing proportions and properties of these specimens are tabulated in appendix A3. The tests were performed on 3-in x 4-in x 16-in prisms according to ASTM C666-84, Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing, procedure A for freezing and thawing while fully saturated in water. It is also in accordance with Tex-423-A, Resistance of Concrete to Rapid Freezing and Thawing.

3.6.2.5 Deicer-Scaling Resistance. The test was performed on slabs that were moist cured for 14 days and then air cured for 14 days. At 28 days, the specimens were placed in a freezer at 0°F until they were tested. In preparation for the test, a thick layer of silicone gel was placed around the perimeter of the finished surface, forming a half inch deep water tight dike. The preparation was done at the age of 26 days, two days before the specimens were placed in the freezer. The test consisted of subjecting concrete slabs, with 4 percent calcium chloride solution covering their finished surface, to 50 cycles of freezing and thawing in accordance with ASTM C672-84, Standard Test Method of Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals. The deterioration was determined by visual inspection, and a rating from 0 to 5 was considered with 0 being best and 5 worst. The photograph used as a reference in rating the specimens is presented in appendix D. The specimens were flushed and a new solution was added every 5 cycles. The rating was conducted at cycle 0, 5, 10, 25, and 50. At the end of the fiftieth cycle, one specimen out of every set of three was used to conduct a chloride penetration test.

3.6.2.6 Chloride Penetration Resistance. This is a rapid chloride content determination test that was used in lieu of the titration test which takes a much longer time to perform. The test conducted consists of drilling 3 holes, 3/4 in. diameter, in the finished surface of the deicer-scaling slabs, and collecting the dust obtained at various depths. The dust collected up to a depth of 1/2 inch was discarded since it was determined from previous tests that the concentration of chloride ions in the top layer was affected to a great extent by how well the specimens were flushed with water during the deicer-scaling test. The dust at depths of 1/2 to 3/4 inch and 1 to 1 1/4 inch were collected. For each depth, two samples were taken. Each sample was then diluted in 10 ml of 15 percent acetic acid solution. The concentration of chloride ions in each solution was determined using an electrometer, and the average was used to determine the chloride content in each layer.

CHAPTER 4

EXPERIMENTAL RESULTS

4.1 Introduction

The results of all the experimental tests conducted during this phase of the research program are presented in this chapter. These results are discussed in Chapter 5.

This chapter is divided into two sections dealing with the effects of superplasticizers on the properties of fresh and hardened concrete. Fresh concrete properties include slump, air content, temperature, setting time and unit weight. Hardened concrete properties include compressive and flexural strength, abrasion resistance, freeze-thaw resistance, deicer-scaling resistance and chloride penetration resistance. Mix 16 was the only mix cast in the field. In this mix, fresh properties included slump, air content and temperature, and hardened concrete properties were limited to compressive strength and freeze-thaw resistance. The purpose behind this mix was to study the effect of air loss on the freeze-thaw resistance and compressive strength of concrete incorporating superplasticizers.

Cold weather mixes were cast during the first part of the study, and are designated as mixes 1 to 8. Hot weather mixes were cast during the second part of the study. They are numbered from 9 to 16. In all mixes except 4, 14, 15, and 16, the first set of specimens designated as "No Super", was cast without superplasticizer. The set cast after the first addition of superplasticizer is designated as "Dose #1", and "Dose #2" designates the specimens cast after the second addition of superplasticizer. In each set, three specimens were cast and these are designated as A, B, and C.

In mix 4, the slump remained above three inches for more than one hour after the addition of the first superplasticizer dosage. Thus, a second dosage of superplasticizer was not added, and the third set represents the specimens cast from the same concrete as "Dose #1" (see above), but one hour and ten minutes later. At the time of casting the third set, the concrete was two hours and thirty minutes old, its slump had dropped to 2-3/4 inches, its air content had decreased by 4 percent, its unit weight had increased by 5 lb/cu.ft, and its temperature had increased by 3°F. The purpose for casting these specimens was to investigate the effect of delay in casting fresh concrete on strength and durability properties. Mixes 14 and 15 were cast using a second generation superplasticizer added at the batching plant. These mixes included only one set each that was cast immediately after the concrete truck arrived at the laboratory.

Finally, mix 16 includes five sets. The first set was cast before the addition of superplasticizer, the second set was cast immediately after adding superplasticizer, and the third set was cast 50 minutes later. After an additional 90 minutes, the fourth set was cast.

The fifth and last set was cast after adding a second dosage of superplasticizer. At that time, the concrete was three hours and fifteen minutes old.

Typical test results are shown in this chapter. Test data for all of the specimens are presented in Appendices B1 to B11.

4.2 Fresh Concrete Tests

4.2.1 Workability. Workability was determined using slump tests. The slump of the first set of specimens was always in the range of 1 to 3 inches. After the addition of superplasticizers, the slump increased to the range of 8 to 10 inches, and it gradually decreased with time due to slump loss. The second addition of superplasticizer was added when the slump dropped below its initial value of 1 to 3 inches. As mentioned earlier, this second dosage was added for all mixes except mixes 4, 14, and 15. The results of the mixes cast during the first and the second part of the study are presented in Tables 4.1 and 4.2 respectively. The results of typical mixes are illustrated in Figures 4.1 through 4.5. The time of addition, number of additions and dosage of superplasticizer used in each addition are shown in these Figures.

4.2.2 Air Content. The air content of the fresh concrete at the batching plant was in the range of 4 to 6 percent for mixes 1 through 15. Most of the entrained air was lost during transportation. In mix 16, however, the initial air content was 8.75 percent, and the loss due to transportation was eliminated since all tests were carried out at the batching plant. Air content was measured every 15 minutes for all mixes. Its variation with time is presented in Tables 4.1 and 4.2 for cold and hot weather respectively. The results of typical mixes are shown in Figures 4.6 through 4.9. The time of addition, number of additions and dosage of superplasticizer used in each addition are shown in these Figures.

4.2.3 Temperature. The temperature of fresh concrete was recorded every 15 minutes. The temperature of concrete for mixes 1 through 8 cast in cold weather was in the range of 54 to 68°F, while the hot weather mixes had temperatures between 85 and 88°F. The variation in temperature with time is presented in Table 4.1 and 4.2 for cold and hot weather mixes respectively. The results of typical mixes are shown in Figures 4.10 through 4.14. These figures also show the time of addition, number of additions and dosage of superplasticizer used in each addition.

4.2.4 Setting Time. Setting time of concrete before the addition of superplasticizer and after each redosage was determined for mixes 1 through 13. The setting time of mixes 14 and 15 was only determined for mortar after adding the superplasticizer. The test was not performed on mix 16. The results of typical mixes are shown in Figures 4.15 to 4.20. These figures show initial and final setting time. Initial set is defined as the time corresponding to a penetration resistance of 500 psi, while final set is the point in time when the cement paste achieve a penetration resistance of 4000 psi.

Table 4.1 Change in slump, air content, and concrete temperature with time for cold weather mixes.

	ELAPSED TIME FROM INITIAL WATER:CEMENT CONTACT IN MINUTES									
Mix #1	55	70	85	100	115	125	140	155	170	185	N/A
Slump (in.)	1.5	8	4.5	3.25	2	8.25	6	4.5	3.25	2.25	"
Air (%)	4.5	3.75	3.25	3.25	2.5	2	1.75	2.25	2	2	"
Temp. (^{o}F)	57	58	59	60	63	63	64	65	66	68	"
Mix #2	57	72	87	102	117	132	142	157	172	187	N/A
Slump (in.)	0.75	1.75	8	6.5	4.75	3.75	8.75	8.75	8	5.25	"
Air (%)	3.25	N/A	2	1.75	2	2.25	1	1	1.25	1.5	"
Temp. (^{o}F)	62	66	68	68	68	68	70	69	68	68	"
Mix #3	60	72	87	102	117	132	147	160	N/A	N/A	N/A
Slump (in.)	1	9.75	9.5	8.5	8	7.75	5	9.5	"	"	"
Air (%)	3	N/A	2.5	2.75	2.25	2.5	2.25	2.5	"	"	"
Temp. (^{o}F)	68	69	69	69	69	68	68	69	"	"	"
Mix #4	63	75	88	103	118	133	150	N/A	N/A	N/A	N/A
Slump (in.)	1.25	9.5	9.25	7.75	6	5	2.75	"	"	"	"
Air (%)	3	N/A	6	5.25	N/A	3.25	2	"	"	"	"
Temp. (^{o}F)	54	55	54	56	56	56	57	"	"	"	"
Mix #5	51	66	78	66	96	106	121	136	151	166	181
Slump (in.)	1.25	4.75	5.5	6.5	7.25	8	5.5	3.75	8.75	6	4.75
Air (%)	5	N/A	N/A	N/A	N/A	3.25	3	3	2	2.25	2.25
Temp. (^{o}F)	57	61	62	64	66	68	68	68	70	71	71
Mix #6	50	70	85	100	115	130	145	160	175	190	N/A
Slump (in.)	1.75	8.5	8.5	8.25	7.5	6.75	6.25	3.5	2	8.25	"
Air (%)	N/A	4.75	4.125	3.5	4.25	4	4.25	4.5	4	2.25	"
Temp. (^{o}F)	62	64	63	63	63	63	64	64	64	67	"
Mix #7	67	86	101	117	132	147	162	N/A	N/A	N/A	N/A
Slump (in.)	0.5	9	6.5	2.25	8.25	2.75	0.75	"	"	"	"
Air (%)	1	3	2.75	1.5	2	1	0.25	"	"	"	"
Temp. (^{o}F)	67	71	70	70	71	71	70	"	"	"	"
Mix #8	73	N/A	104	119	134	151	164	179	199	N/A	N/A
Slump (in.)	1.5	"	9	8.5	7.25	5.25	4.75	2.5	9.5	"	"
Air (%)	3.75	"	7	8	8	8	N/A	6.75	N/A	"	"
Temp. (^{o}F)	63	"	62	63	61	62	62	62	62	"	"

N/A: Not Available

Table 4.2 Change in slump, air content, and concrete temperature with time for hot weather mixes.

	ELAPSED TIME FROM INITIAL WATER:CEMENT CONTACT IN MINUTES											
Mix #9	60	80	95	110	125	140	155	170	N/A	N/A	N/A	N/A
Slump (In.)	0	4	8.5	6.25	3.5	9.25	9	8	"	"	"	"
Air (%)	1.5	N/A	2.5	2.75	2	1.25	1.5	1.5	"	"	"	"
Temp. (°F)	91	92	93	93	93	94	95	94	"	"	"	"
Mix #10	62	82	97	112	127	142	157	172	"	"	"	"
Slump (In.)	3.5	8.25	7.5	6.5	5.5	4.5	2.5	9.25	"	"	"	"
Air (%)	3.75	2.5	2.25	2.25	2.25	2.5	1.5	1.25	"	"	"	"
Temp. (°F)	89	92	92	90	93	94	94	97	"	"	"	"
Mix #11	73	96	111	126	141	156	171	186	201	"	"	"
Slump (In.)	1	3	8	4	2.75	9.5	5.25	3	1.25	"	"	"
Air (%)	1.75	N/A	1.5	2	1.75	1	1.25	1.5	1.5	"	"	"
Temp. (°F)	90	92	93	94	94	95	92	95	94	"	"	"
Mix #12	69	84	99	114	129	144	159	174	N/A	"	"	"
Slump (In.)	2	10	9.5	9	8.5	8	8	8	"	"	"	"
Air (%)	2	3.25	2	3	2	2	2	1.75	"	"	"	"
Temp. (°F)	89	89	88	87	88	90	88	86	"	"	"	"
Mix #13	62	82	97	112	127	142	157	172	184	"	"	"
Slump (In.)	0	8.5	6	6	5.5	4.25	3.5	2.5	8.5	"	"	"
Air (%)	2.25	2.25	2.25	2.5	2.5	2	1.75	N/A	1.5	"	"	"
Temp. (°F)	91	94	953	95	95	94	96	94	97.5	"	"	"
Mix #14	9	20	54	69	89	104	119	134	149	"	"	"
Slump (In.)	1.75	9.25	7.5	7.25	6	4	3	2	1	"	"	"
Air (%)	5	N/A	5.5	4.75	3.5	3.5	3.5	3.25	3	"	"	"
Temp. (°F)	87	88	89	89	90	91	90	92	94	"	"	"
Mix #15	11	21	56	76	86	101	116	131	146	"	"	"
Slump (In.)	1.25	9	7.75	7	6.25	4.75	3.25	2.75	1.75	"	"	"
Air (%)	4	N/A	5	4.5	4	3.75	3.25	2.75	2.25	"	"	"
Temp. (°F)	87	88	89	89	90	90	91	92	93	"	"	"
Mix #8	25	40	60	75	90	105	120	135	150	165	170	195
Slump (In.)	3.5	9.5	8.75	7.75	7.5	7	6.5	6.5	6.25	6.5	7.5	7
Air (%)	8.75	5.5	5.25	5.25	5	5	5	5	4.5	4	2.75	2.25
Temp. (°F)	88	88	86	88	88	88	90	90	90	91	94	96

N/A: Not Available

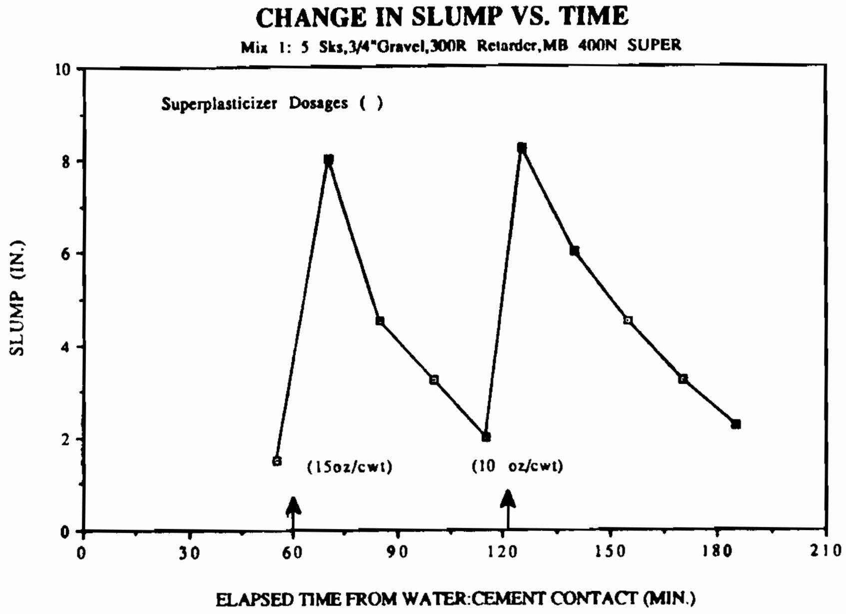


Figure 4.1 Change in slump with time data for mix 1 cast in cold weather.

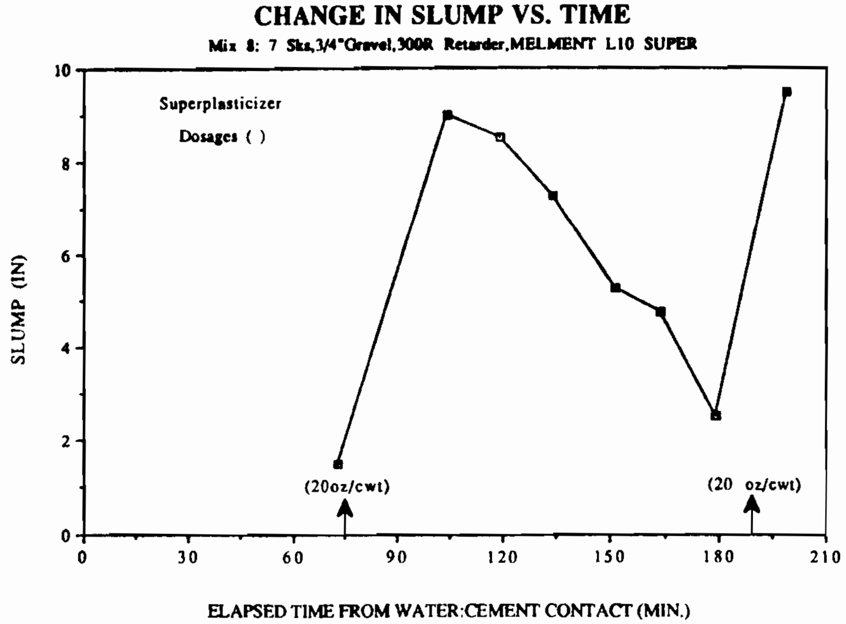


Figure 4.2 Change in slump with time data for mix 8 cast in cold weather.

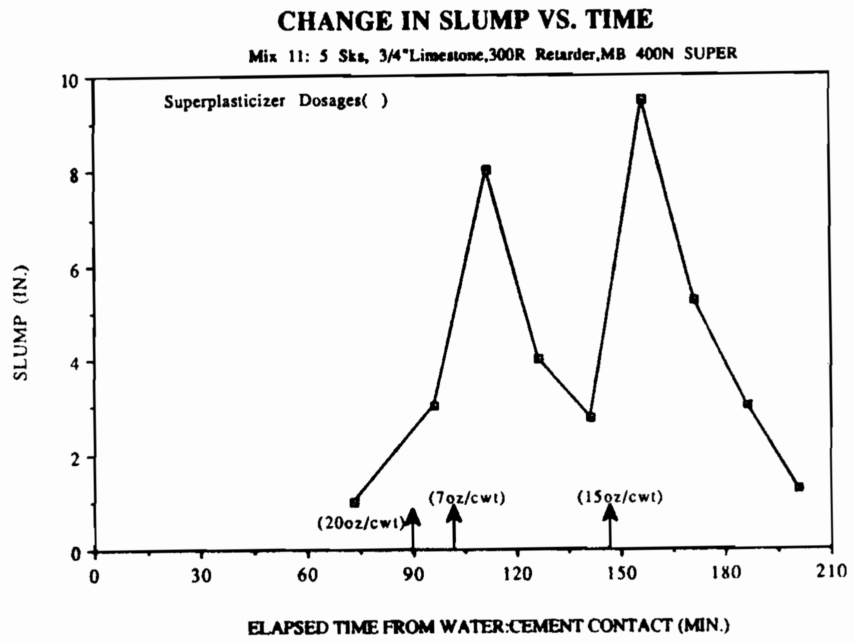


Figure 4.3 Change in slump with time data for mix 11 cast in hot weather.

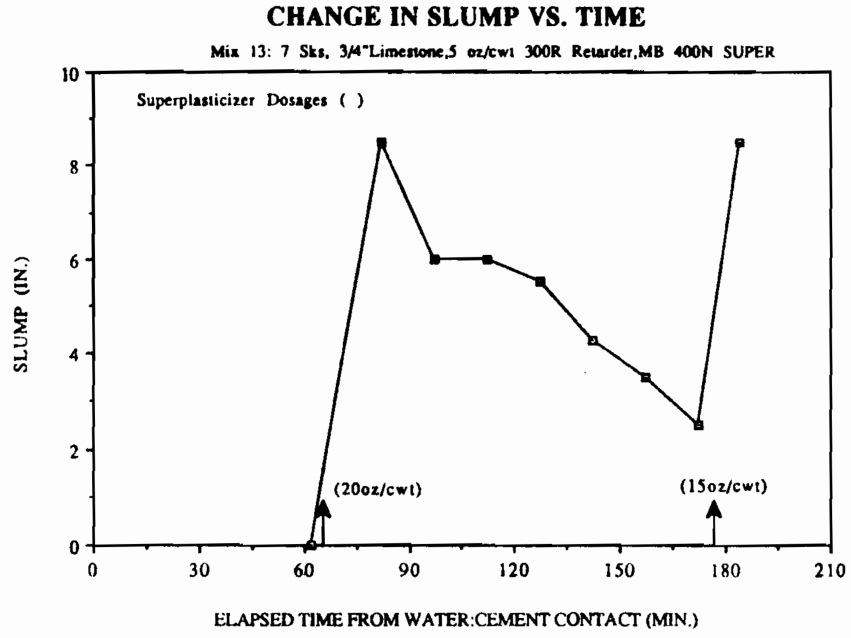


Figure 4.4 Change in slump with time data for mix 13 cast in hot weather.

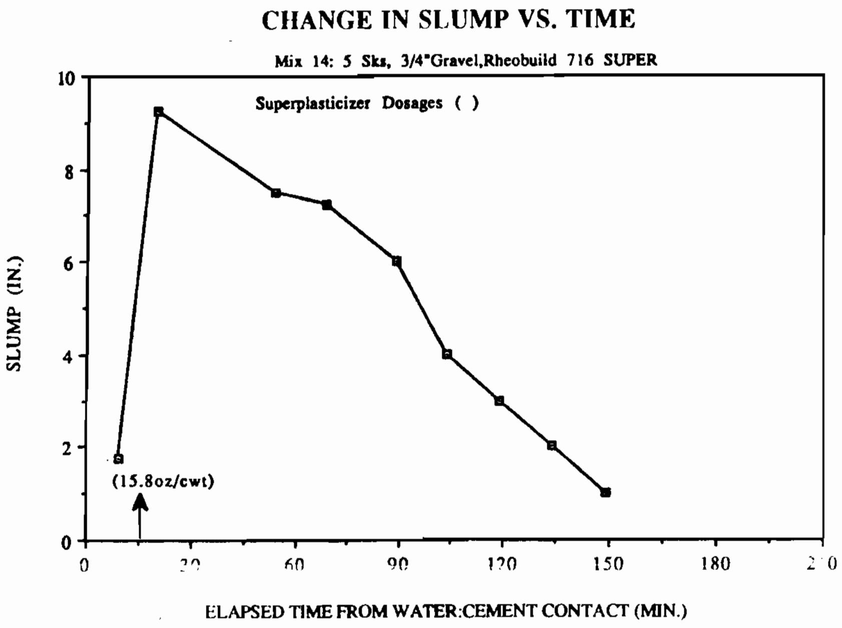


Figure 4.5 Change in slump with time data for mix 14 cast in hot weather.

4.2.5 Unit Weight. Unit weight tests were conducted on fresh concrete before adding the superplasticizer and after each addition for mixes 1 to 13. The results of typical mixes are shown as bar graphs in Figures 4.21 and 4.22. For mixes 14 and 15 however, the test was only carried out after the addition of superplasticizer, and the results of both mixes are shown in Figure 4.23. This test was not conducted on mix 16.

4.3 Hardened Concrete Tests

4.3.1 Compressive Strength. Compressive strength tests were conducted at 7 and 28 days on all mixes. All test results are tabulated in Appendix C1. These tables include the experimental test results of three cylinders for each set as well as the standard deviation and coefficient of variation for each set. Typical results for mixes with conventional superplasticizers are shown in Figures 4.24 and 4.25. The results of mixes 14 and 15 incorporating second generation superplasticizers are presented in Figure 4.26, and the results of mix 16 are shown in Figure 4.27.

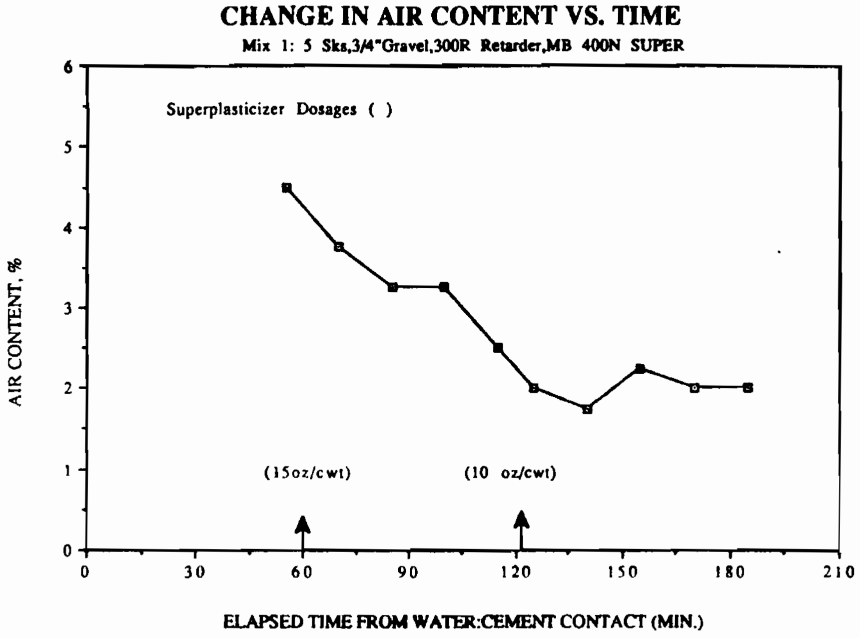


Figure 4.6 Change in air content with time test data for mix 1 cast in cold weather.

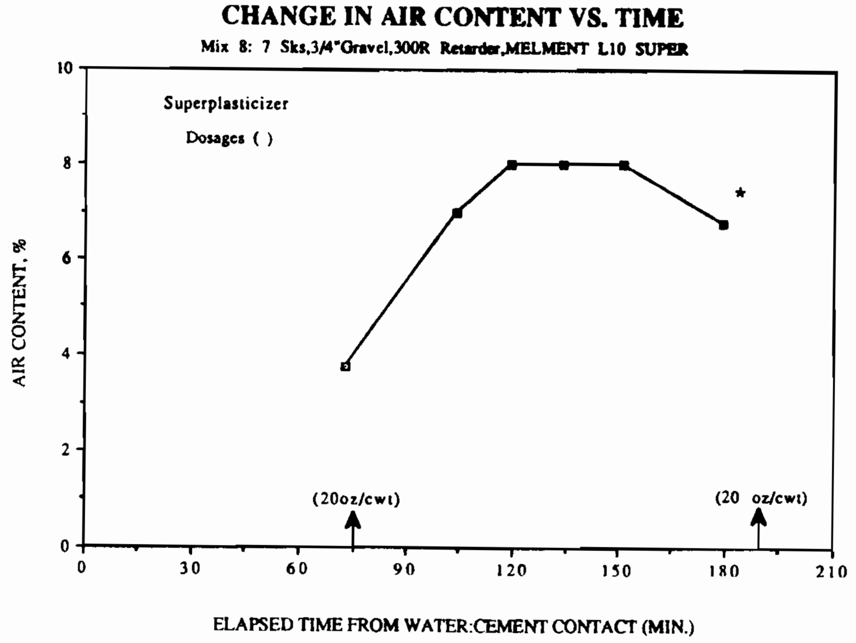


Figure 4.7 Change in air content with time test data for mix 8 cast in cold weather.

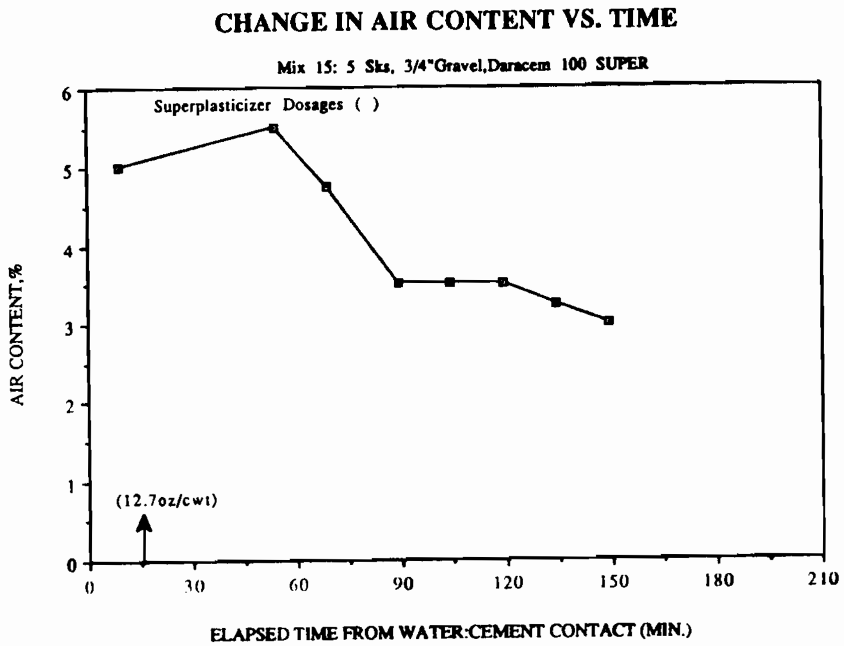


Figure 4.8 Change in air content with time test data for mix 15 cast in hot weather.

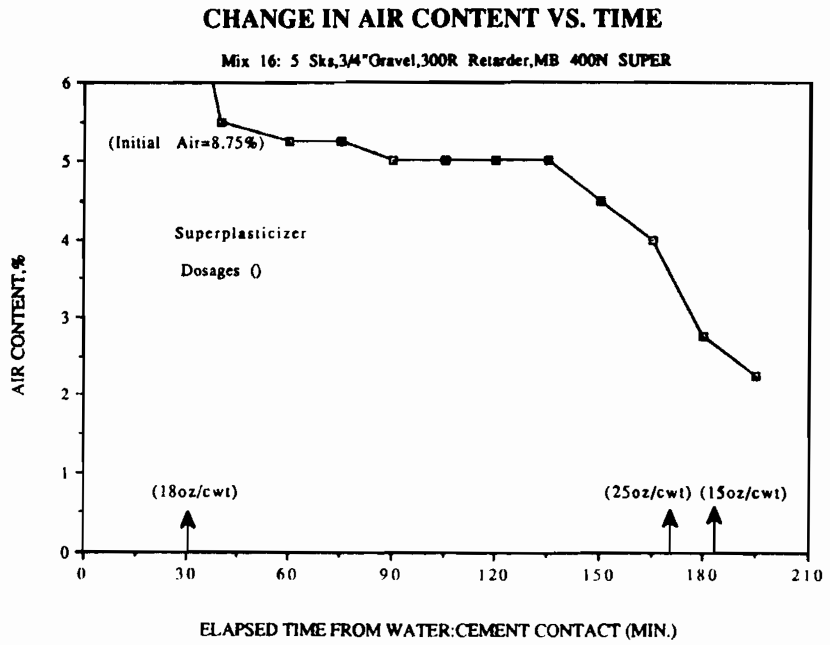


Figure 4.9 Change in air content with time test data for mix 16 cast in the field, under hot weather.

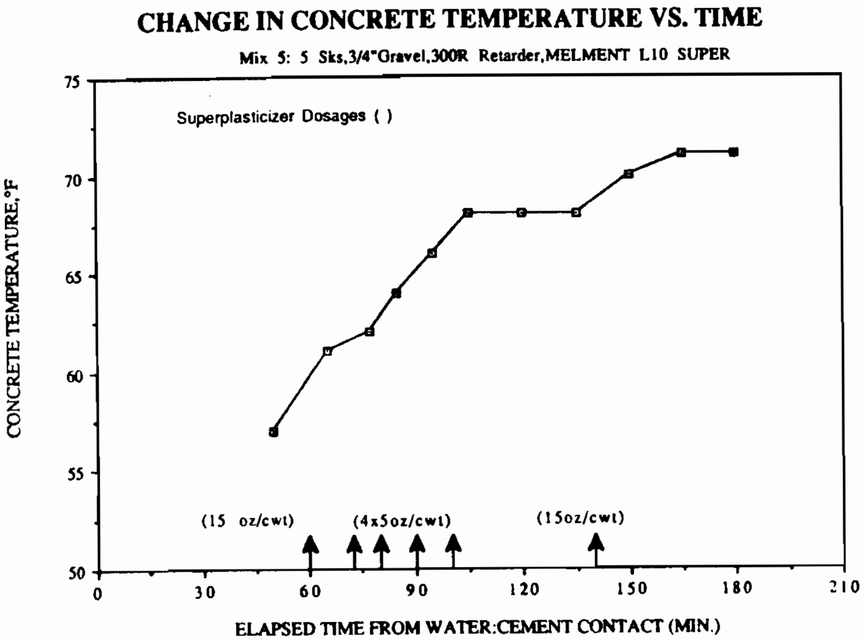


Figure 4.10 Change in concrete temperature with time data for mix 5 cast in cold weather.

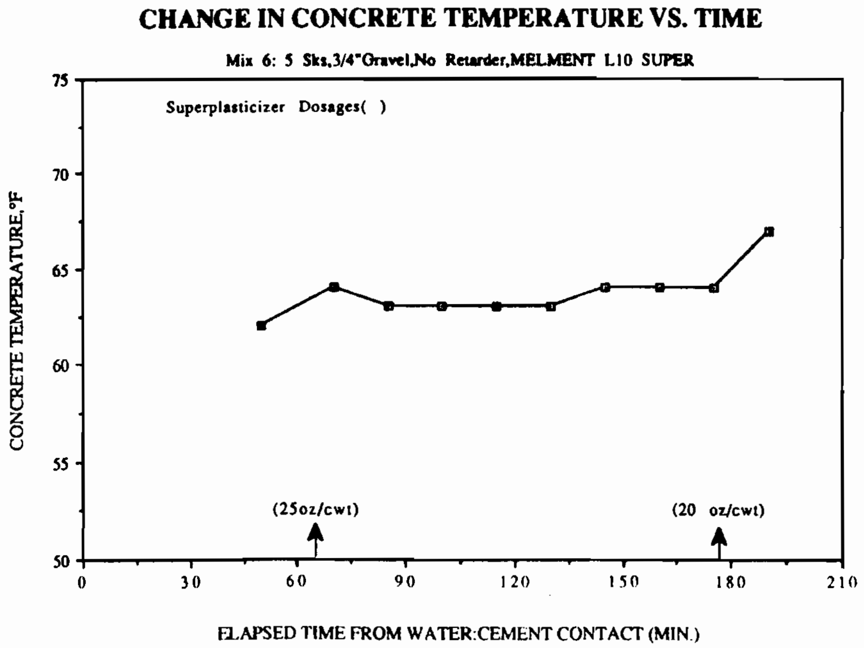


Figure 4.11 Change in concrete temperature with time data for mix 6 cast in cold weather.

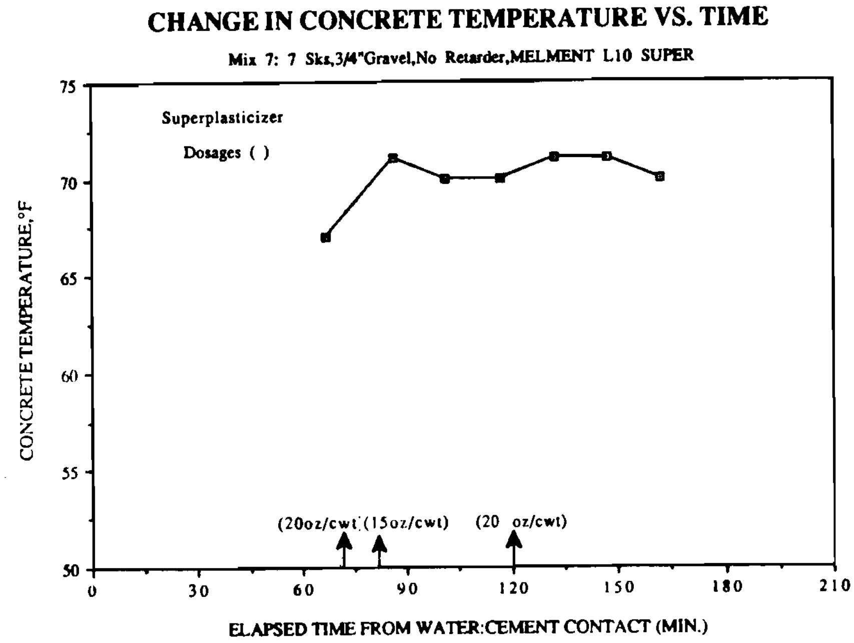


Figure 4.12 Change in concrete temperature with time data for mix 7 cast in cold weather.

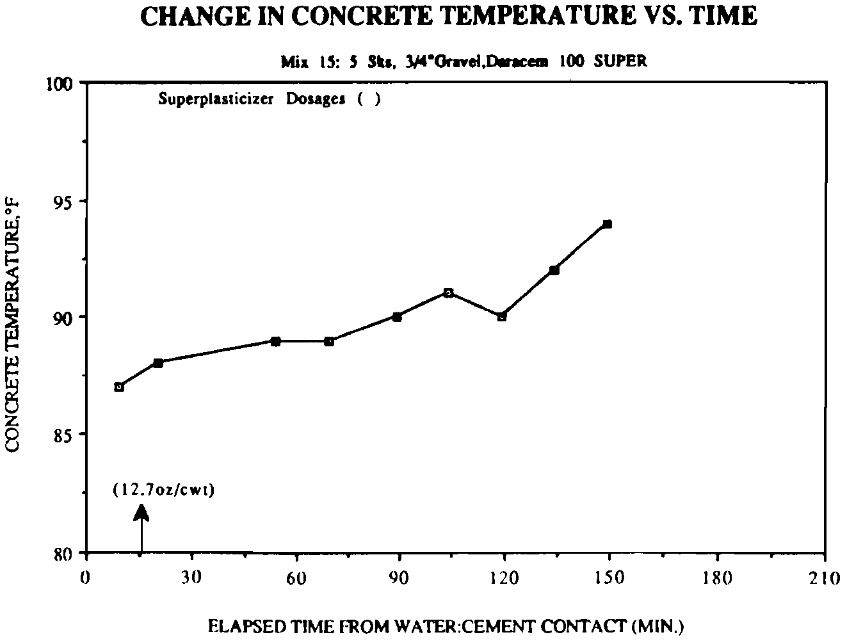


Figure 4.13 Change in concrete temperature with time data for mix 15 cast in hot weather.

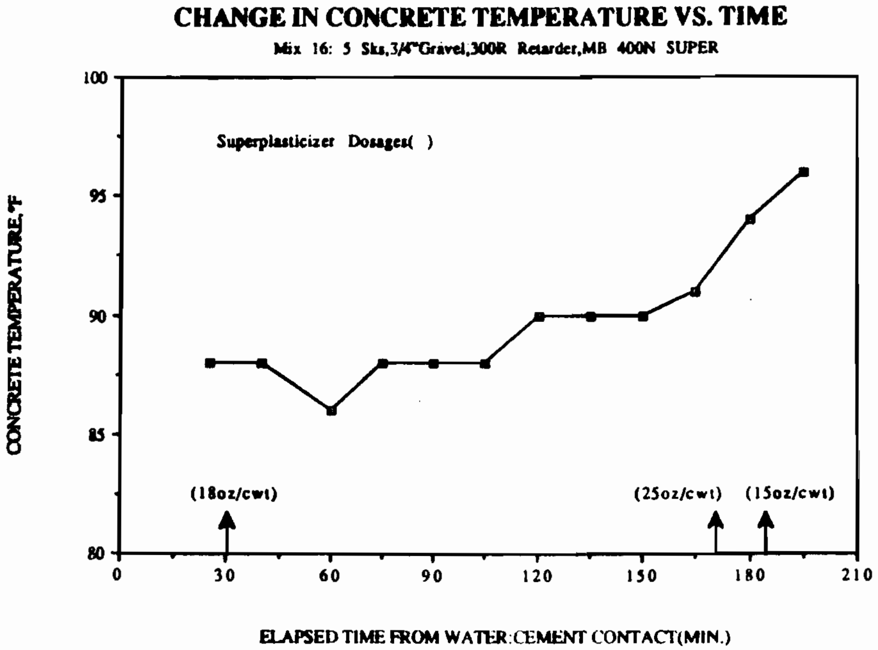


Figure 4.14 Change in concrete temperature with time data for mix 16 cast in the field, under hot weather.

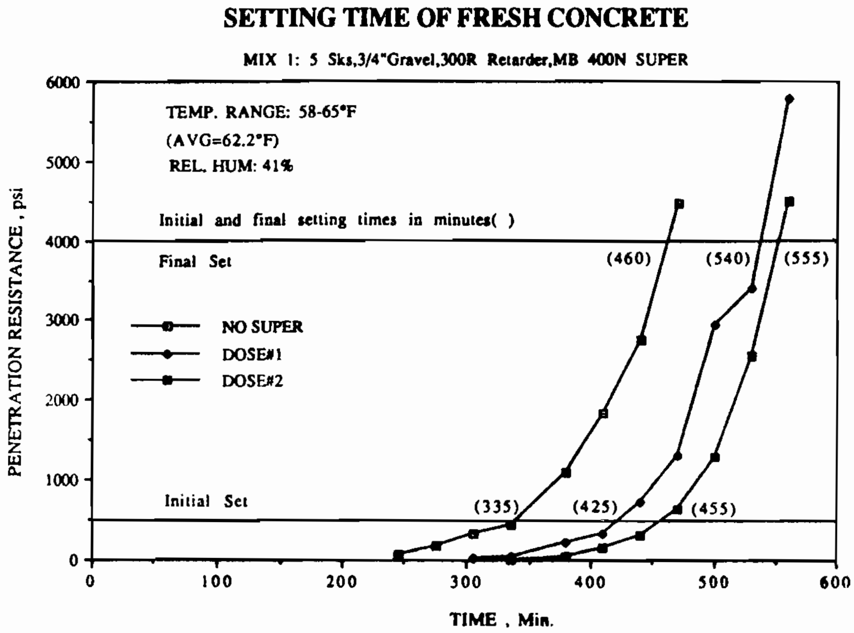


Figure 4.15 Setting time data for mix 1 cast in cold weather.

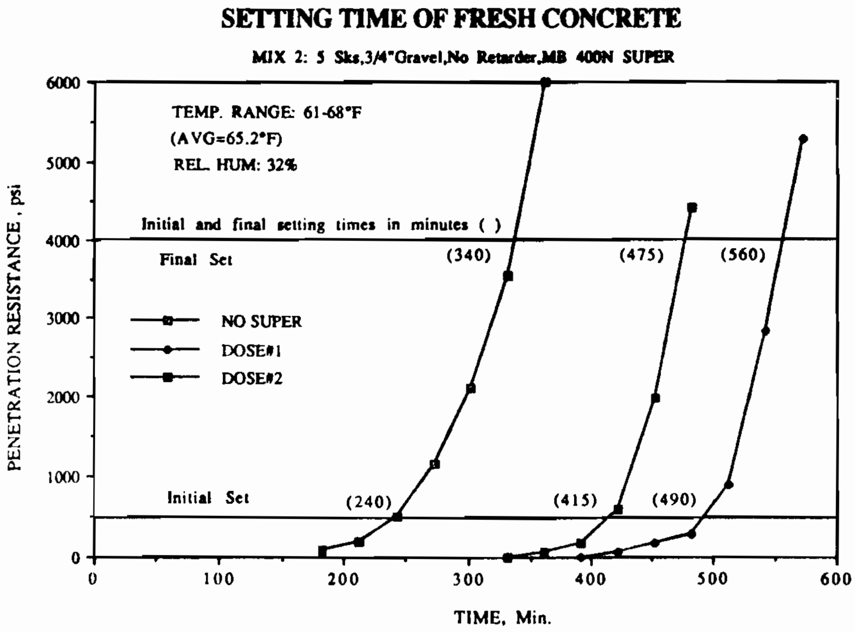


Figure 4.16 Setting time data for mix 2 cast in cold weather.

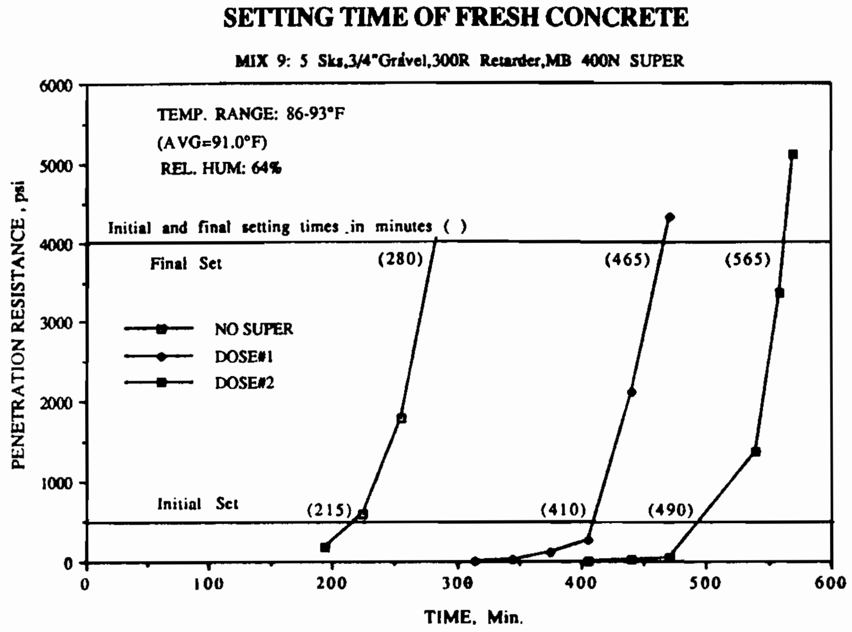


Figure 4.17 Setting time data for mix 9 cast in hot weather.

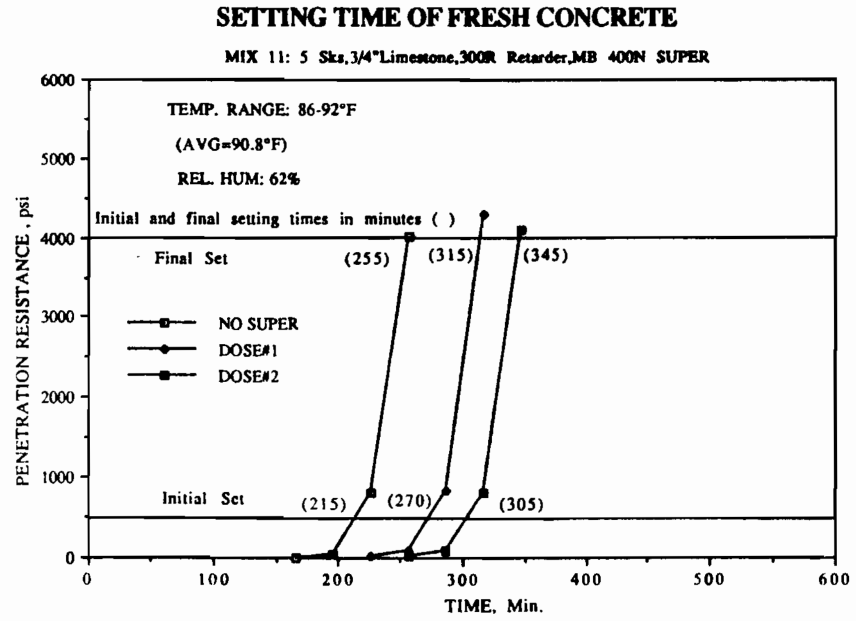


Figure 4.18 Setting time data for mix 11 cast in hot weather.

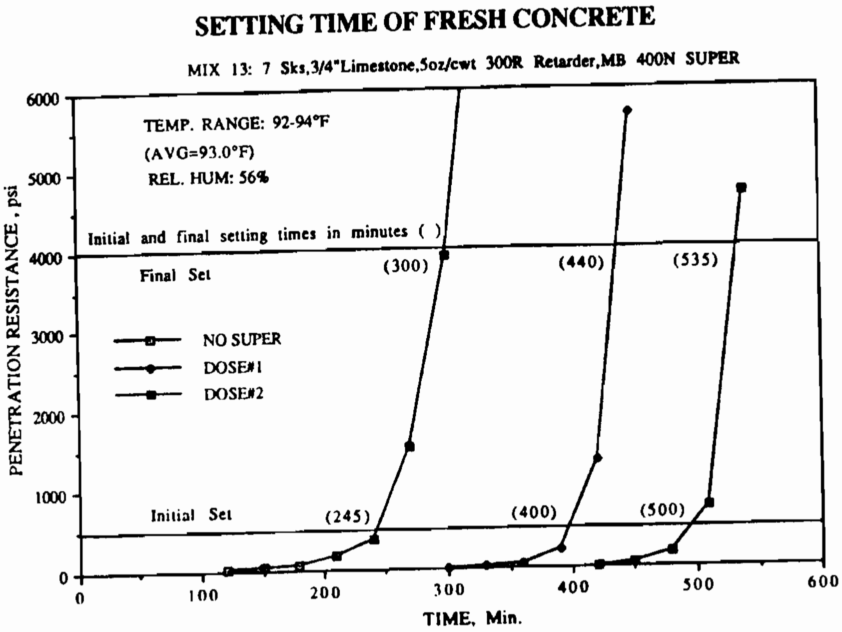


Figure 4.19 Setting time data for mix 13 cast in hot weather.

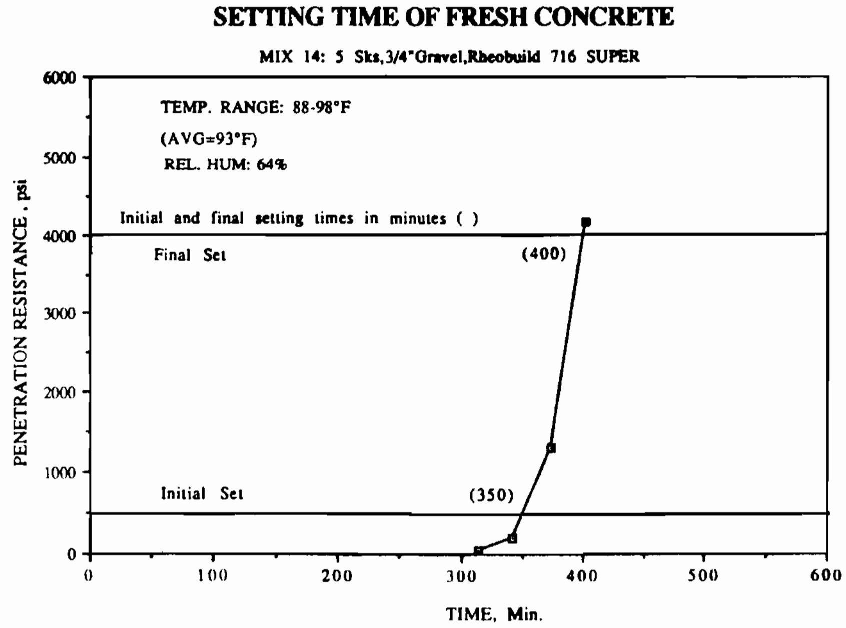


Figure 4.20 Setting time data for mix 14 cast in hot weather.

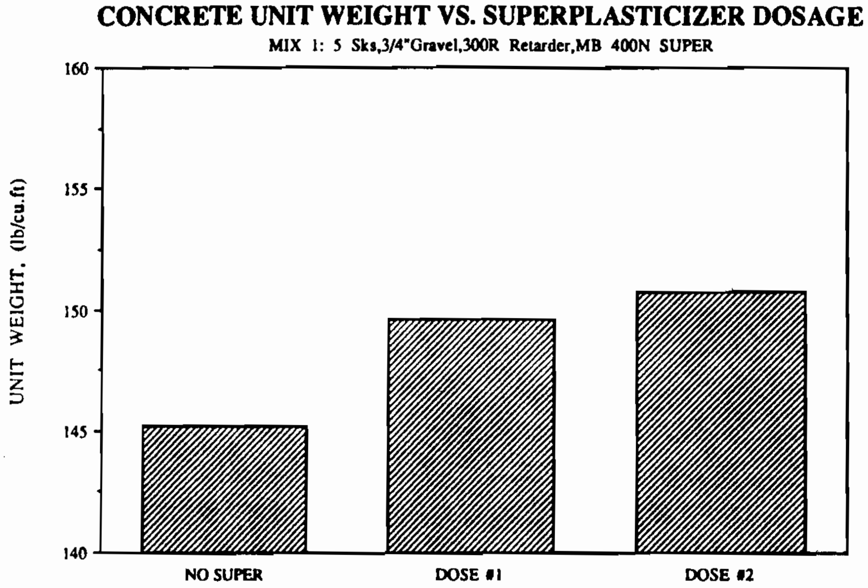


Figure 4.21 Unit weight data for mix 1 cast in cold weather.

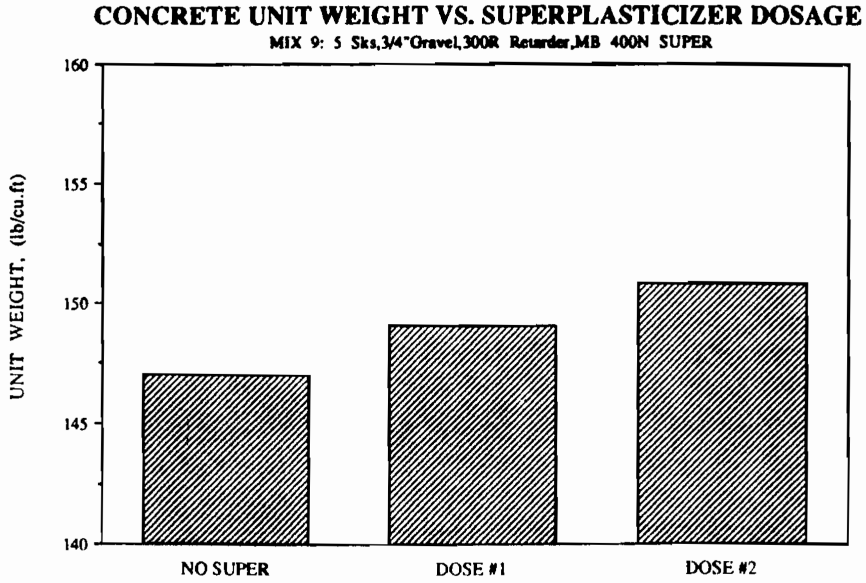


Figure 4.22 Unit weight data for mix 9 cast in hot weather.

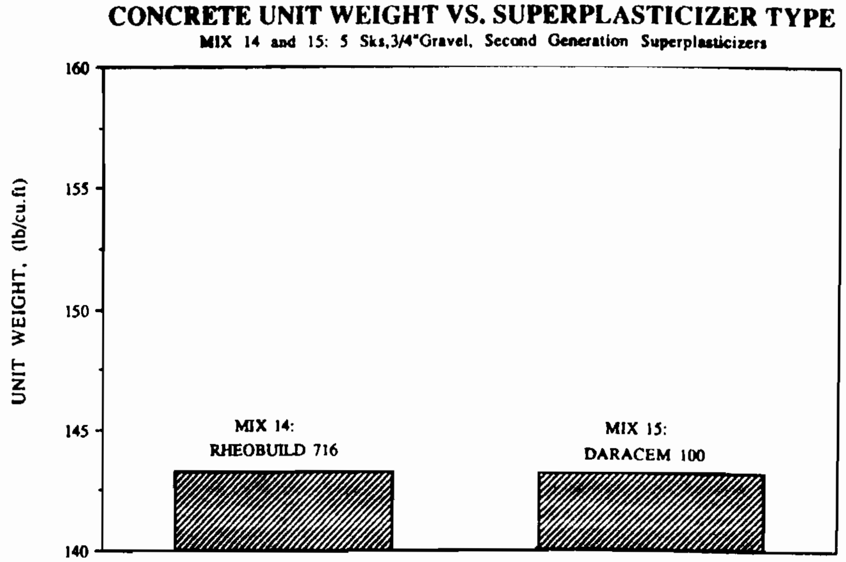


Figure 4.23 Unit weight data for mixes 14 and 15 cast in hot weather.

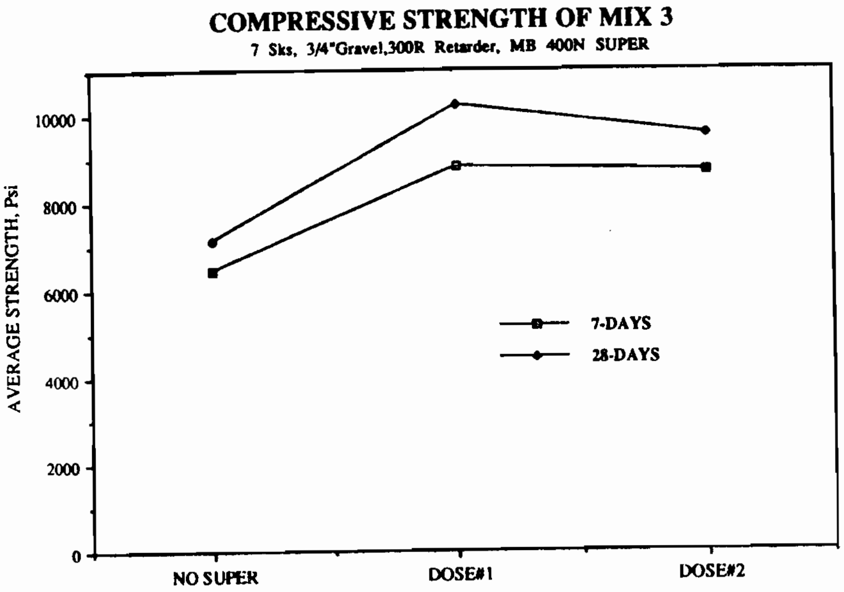


Figure 4.24 Compressive strength data for mix 3 cast in cold weather.

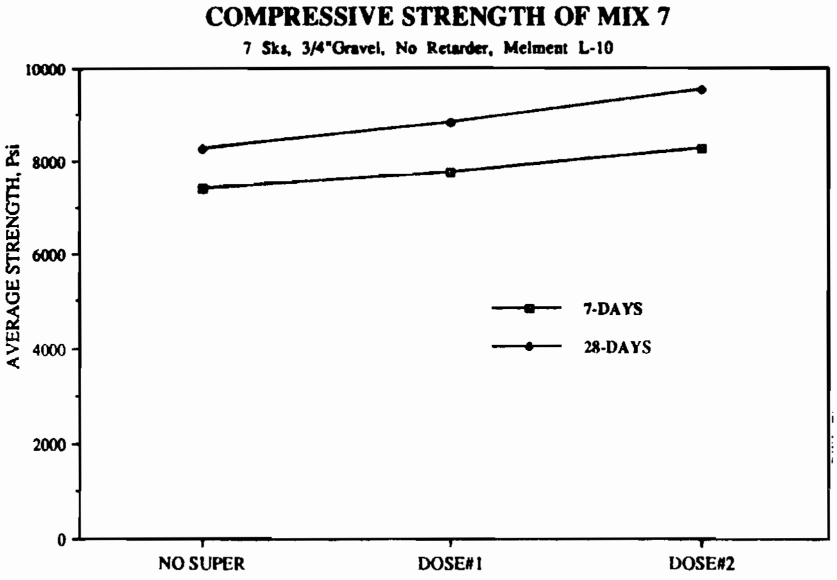


Figure 4.25 Compressive strength data for mix 7 cast in cold weather.

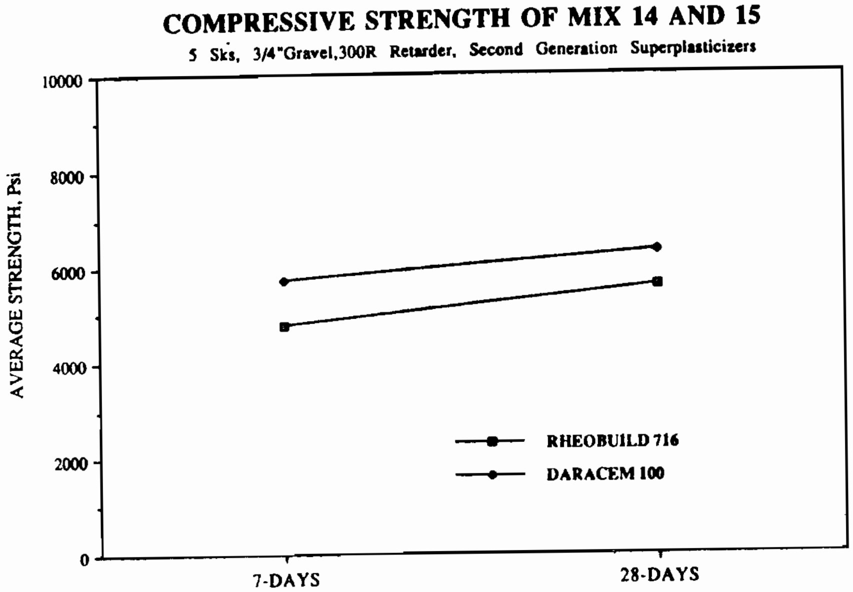


Figure 4.26 Compressive strength data for mixes 14 and 15 cast in hot weather.

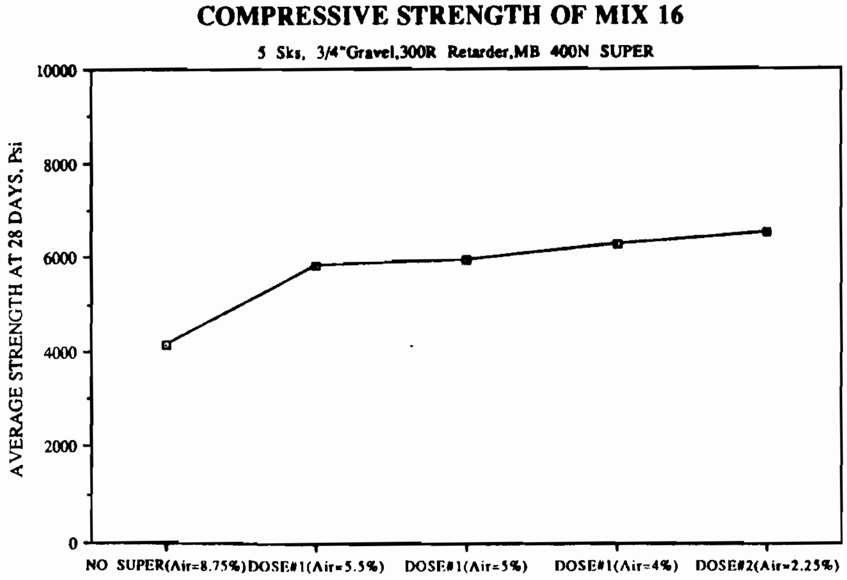


Figure 4.27 Compressive strength data for mix 16 cast in the field, under hot weather.

4.3.2 Flexural Strength. Flexural strength tests were conducted for all mixes except mix 16. They were conducted at 7 and 28 days during the first part of this study, and only at 28 days for the second part. The results at 7 and 28 days are tabulated in Appendix C2. The tables also include the standard deviation and coefficient of variation for each set of specimens. Typical results of the mixes with conventional superplasticizers are shown in Figures 4.28 to 4.30, while the results of mixes 14 and 15 incorporating second generation superplasticizers are presented in Figure 4.31.

4.3.3 Abrasion Resistance. Abrasion resistance tests were conducted during the first part of the study. The tests were conducted at 8 days on beam halves from the flexure tests at 7 days. Typical results are shown in Figures 4.32 and 4.33.

4.3.4 Freeze-Thaw Resistance. The results of the freeze-thaw tests are presented in Appendix C3. Typical results are illustrated in Figures 4.34 through 4.38.

The results of the freeze-thaw tests conducted on mixes L1 through L9 cast during a related study by William C. Eckert[6] are presented in Appendix C4. Typical results of these mixes are shown in Figures 4.39 and 4.40.

4.3.5 Deicer-Scaling Resistance. This test was conducted for all mixes except mix 16. Typical test results are shown in Figures 4.41 to 4.43.

4.3.6 Chloride Penetration Resistance. This test was conducted on one specimen from each set of three. The specimen chosen was the most representative of each set. Typical test results are shown in Figures 4.44 and 4.45.

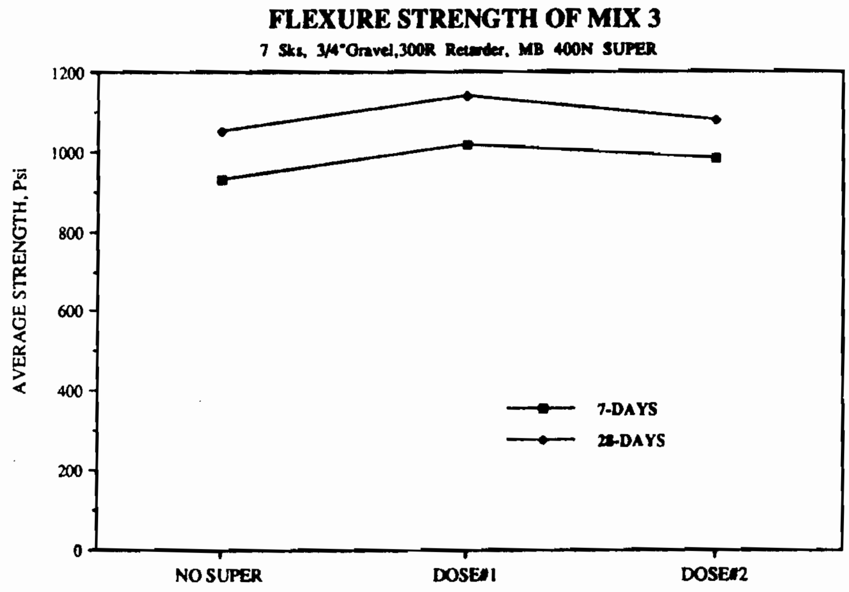


Figure 4.28 Flexural strength data for mix 3 cast in cold weather.

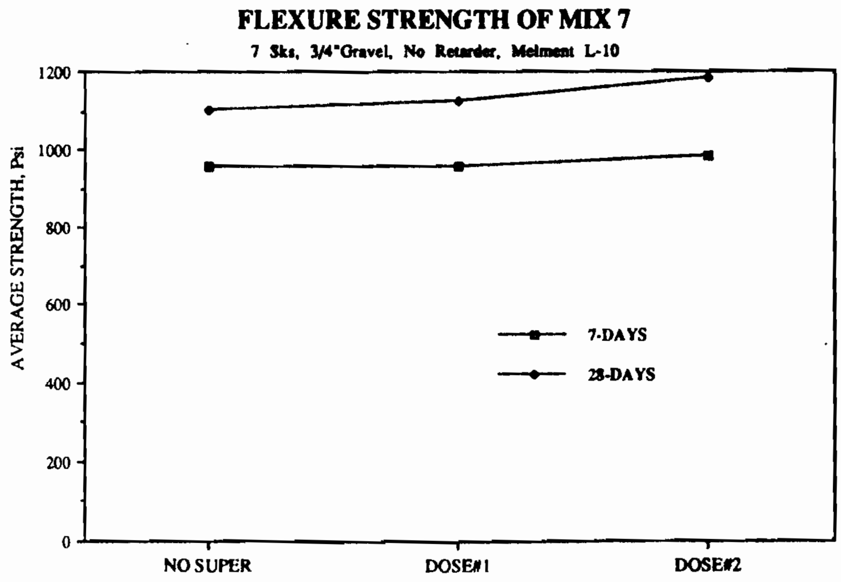


Figure 4.29 Flexural strength data for mix 7 cast in cold weather.

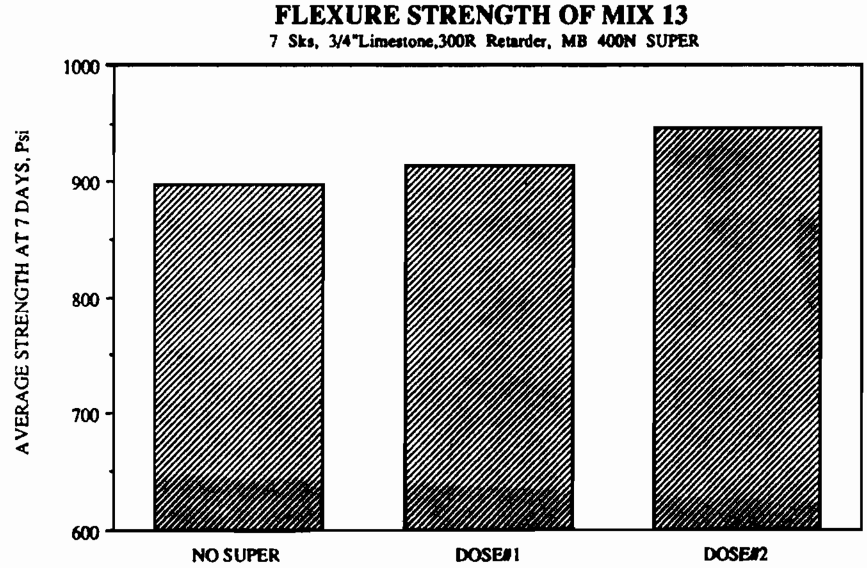


Figure 4.30 Flexural strength data for mix 13 cast in hot weather.

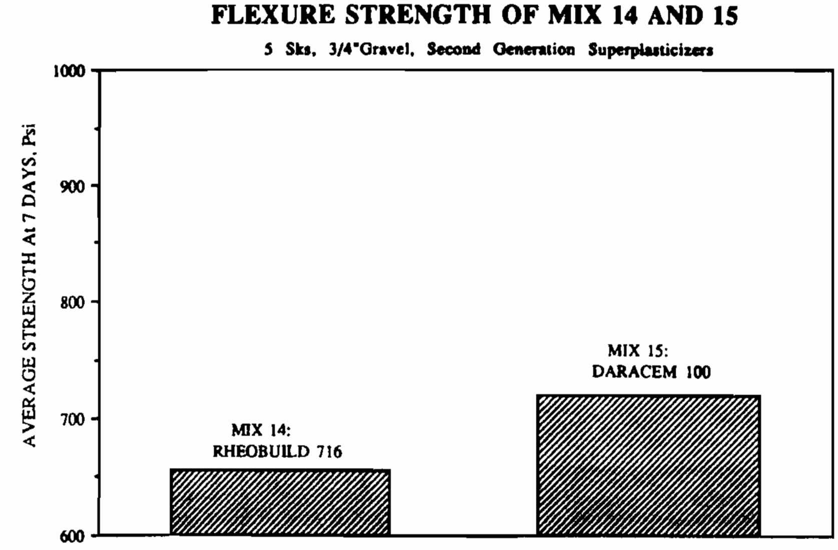


Figure 4.31 Flexural strength data for mixes 14 and 15 cast in hot weather.

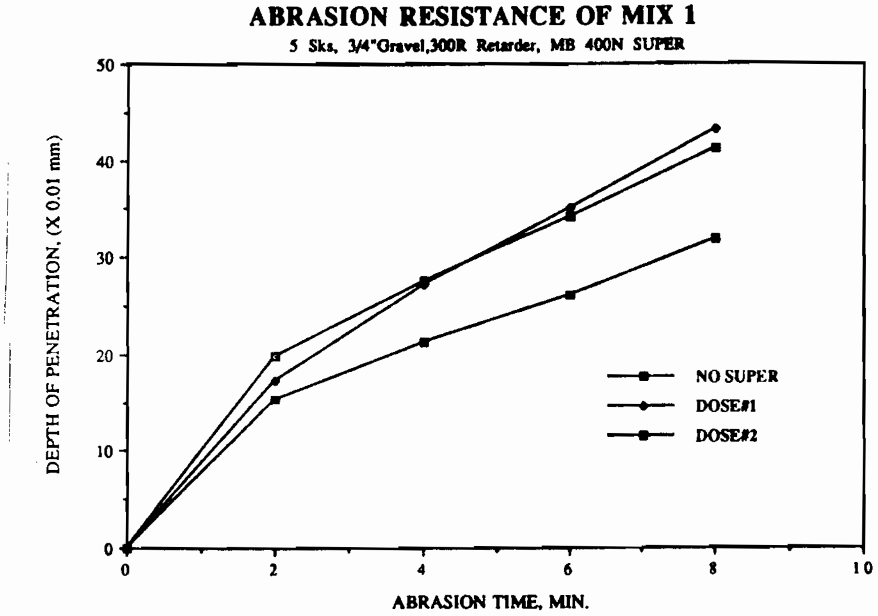


Figure 4.32 Abrasion test data for mix 1 cast in cold weather.

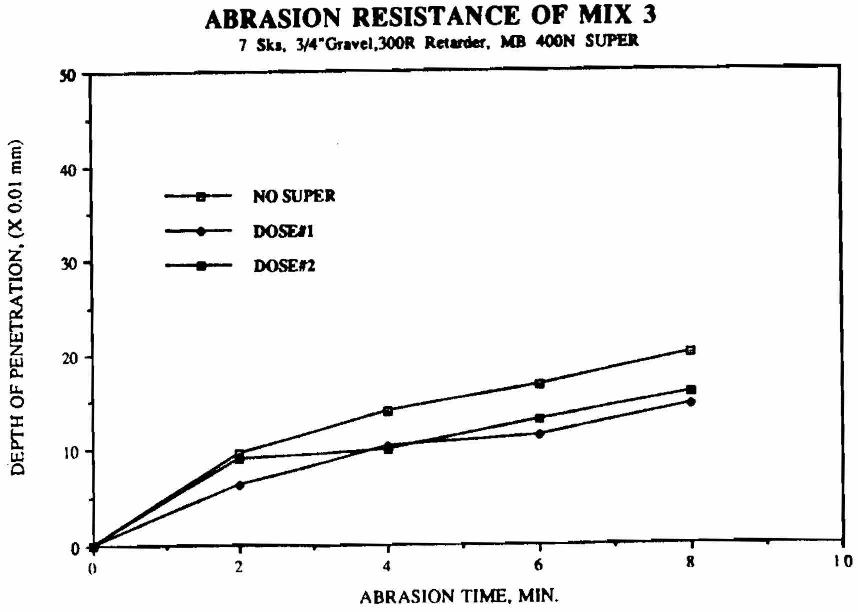


Figure 4.33 Abrasion test data for mix 3 cast in cold weather.

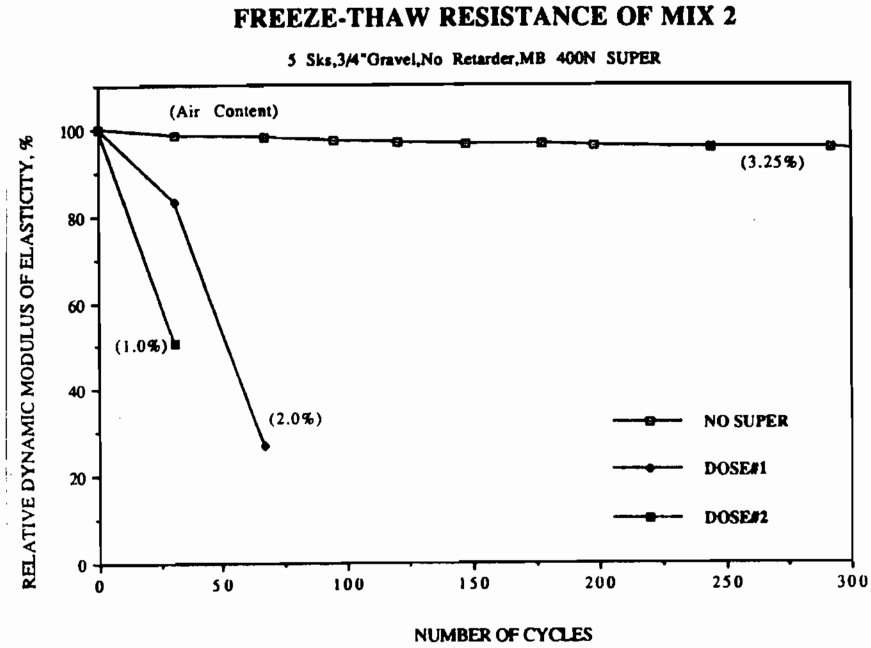


Figure 4.34 Freeze-thaw test data for mix 2 cast in cold weather.

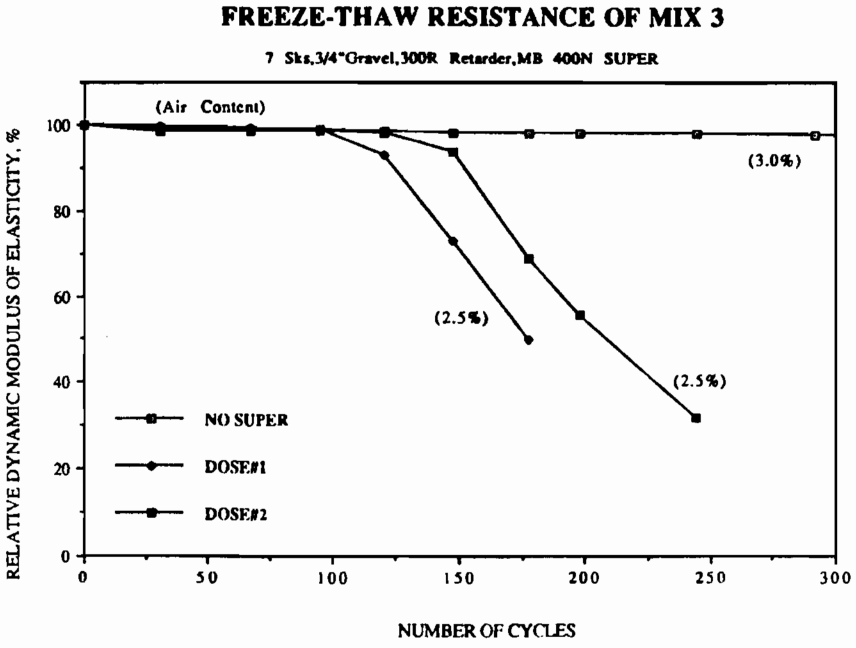


Figure 4.35 Freeze-thaw test data for mix 3 cast in cold weather.

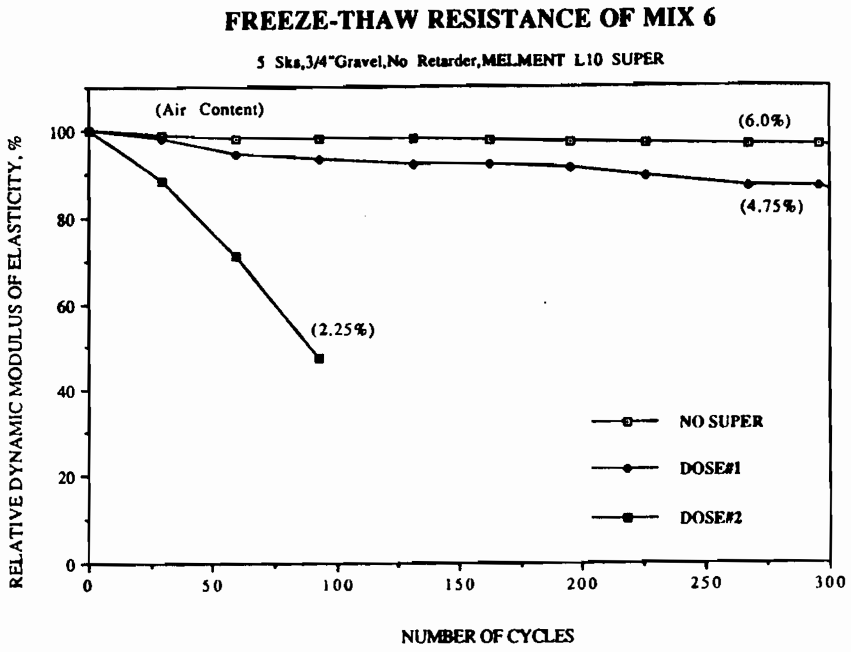
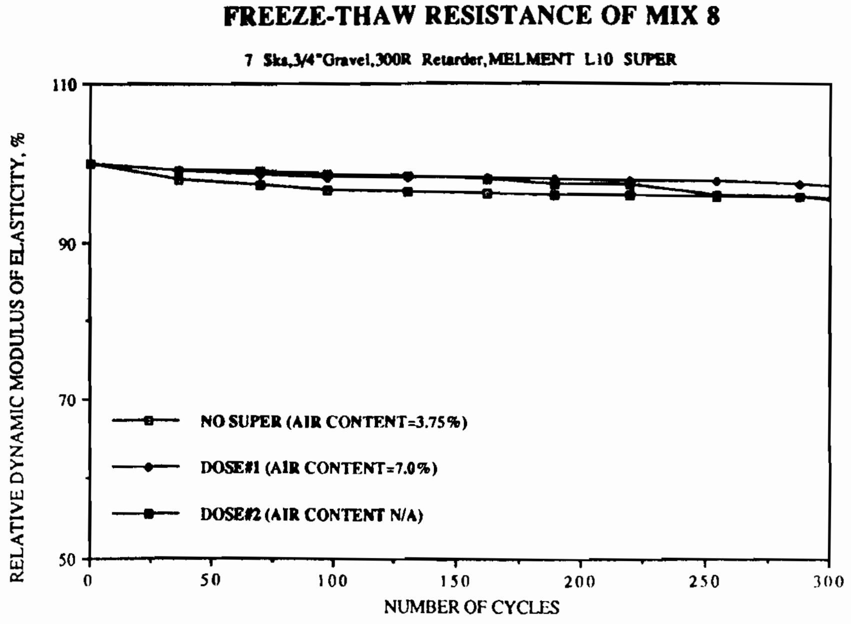


Figure 4.36 Freeze-thaw test data for mix 6 cast in cold weather.



N/A: Air content was 6.75% just before redosage.
It was not measured after redosage.

Figure 4.37 Freeze-thaw test data for mix 8 cast in cold weather.

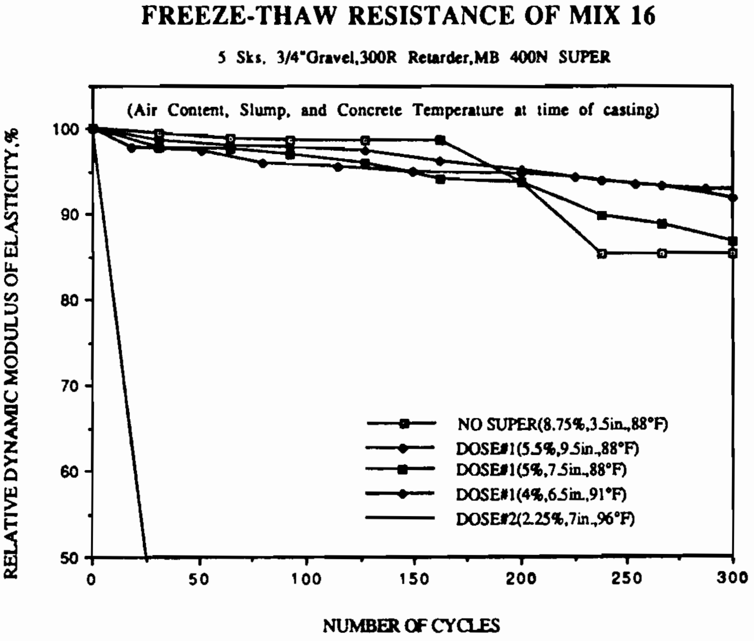


Figure 4.38 Freeze-thaw test data for mix 16 cast in the field, under hot weather.

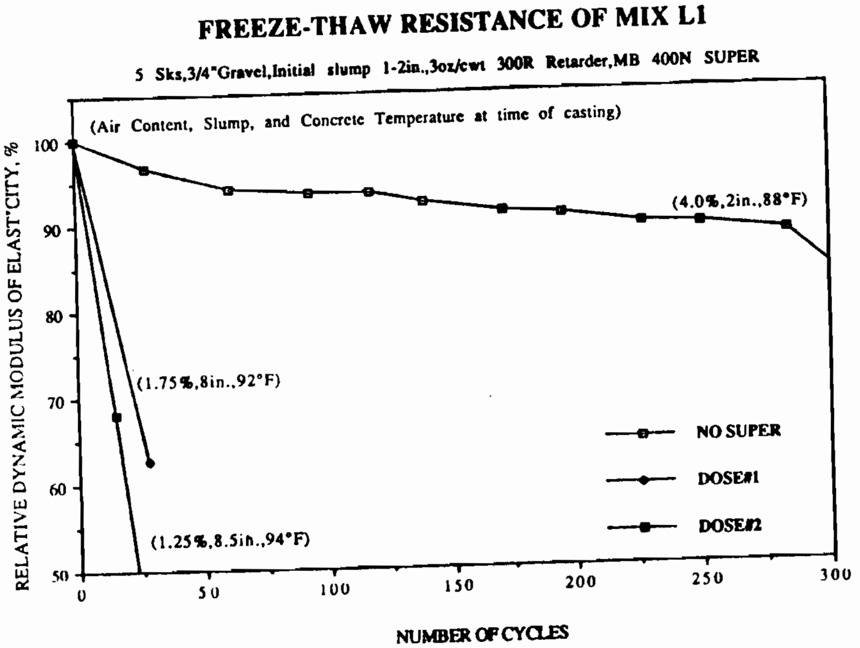


Figure 4.39 Freeze-thaw test data for mix L1 cast in hot weather.

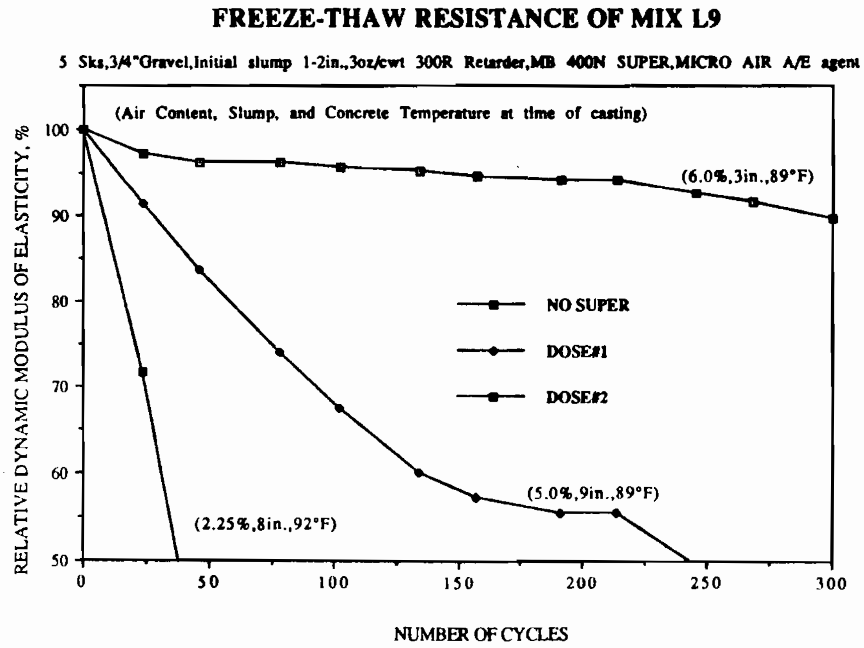


Figure 4.40 Freeze-thaw test data for mix L9 cast in hot weather.

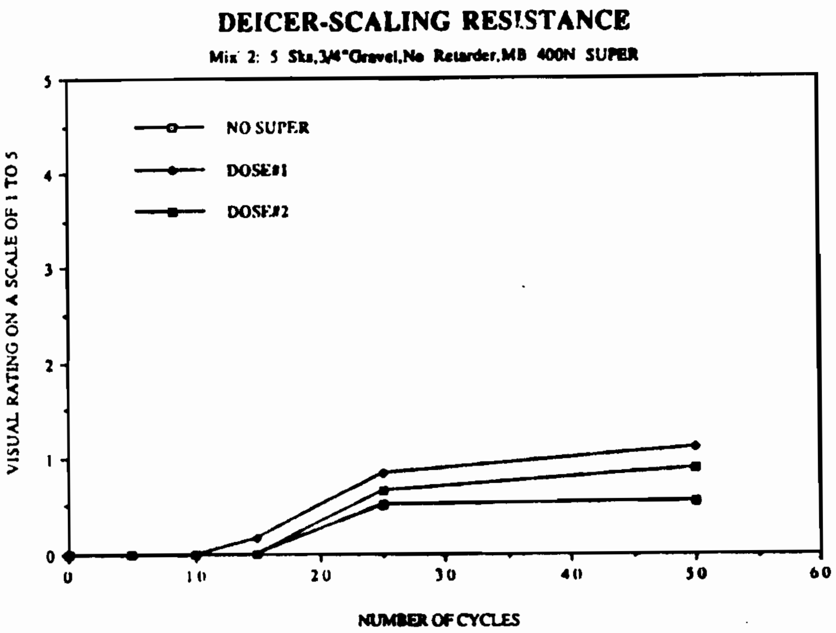


Figure 4.41 Deicer-scaling test data for mix 2 cast in cold weather.

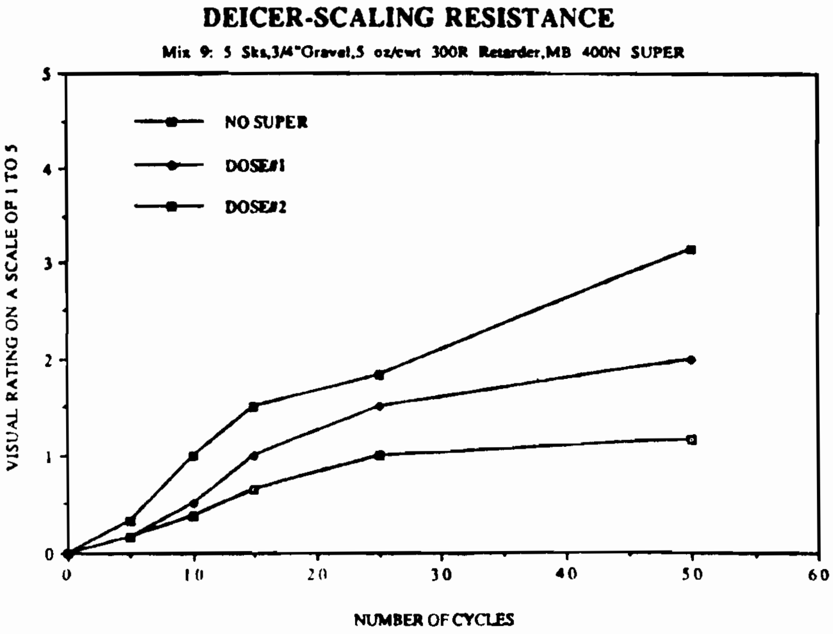


Figure 4.42 Scaling test data for mix 9 cast in cold weather.

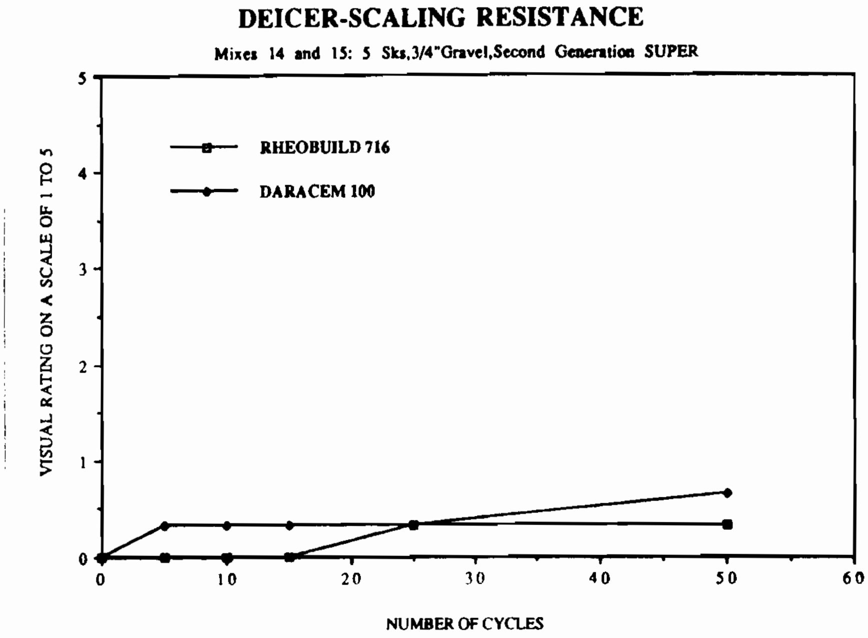


Figure 4.43 Deicer-scaling test data for mixes 14 and 15 cast in hot weather.

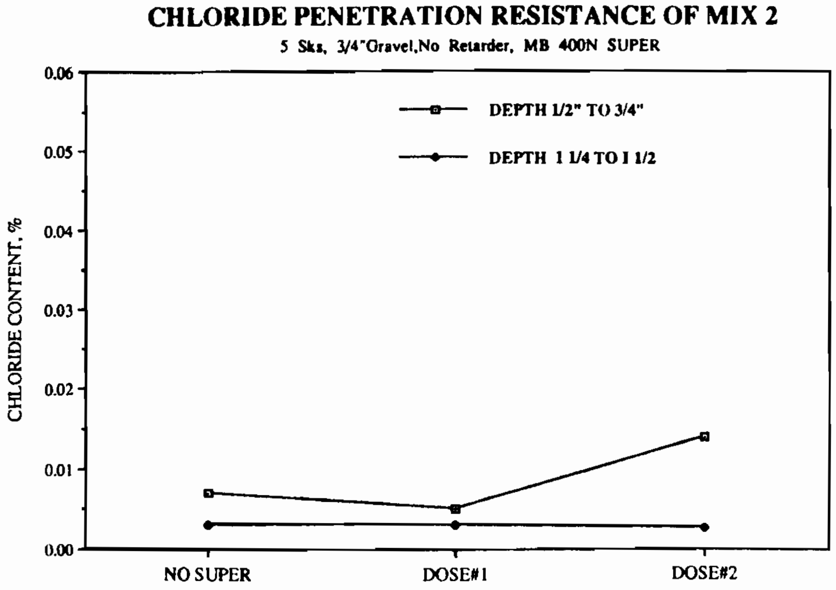


Figure 4.44 Chloride penetration test data for mix 2 cast in cold weather.

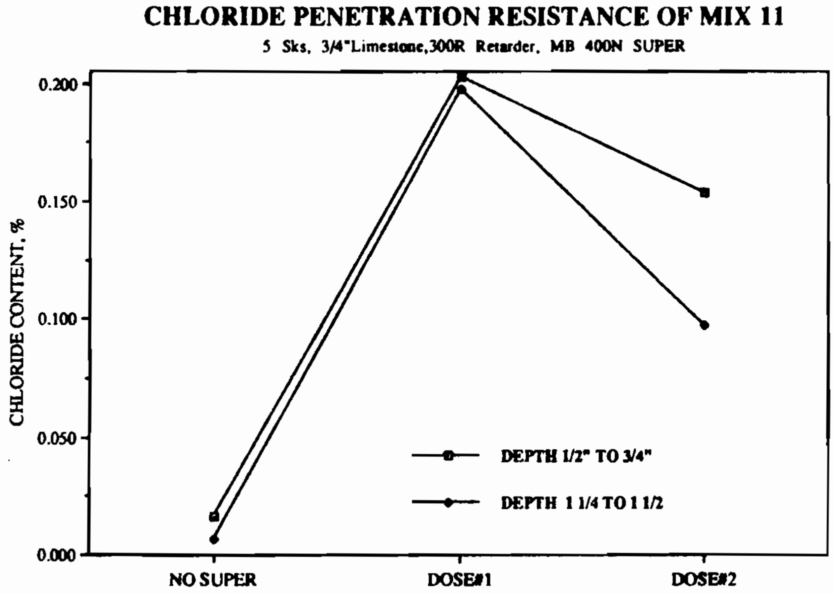


Figure 4.45 Chloride penetration test data for mix 11 cast in hot weather.

CHAPTER 5
DISCUSSION OF EXPERIMENTAL RESULTS

5.1 Introduction

The experimental results presented in Chapter 4 are discussed in this chapter. The effects of superplasticizers on the properties of fresh and hardened concrete, under both cold and hot weather condition are examined herein.

5.2 Effects Of Superplasticizers On Fresh Concrete

5.2.1 Workability. The effect of superplasticizer on workability is determined by studying the rate of slump gain, and the rate of slump loss of concrete after each addition of superplasticizer.

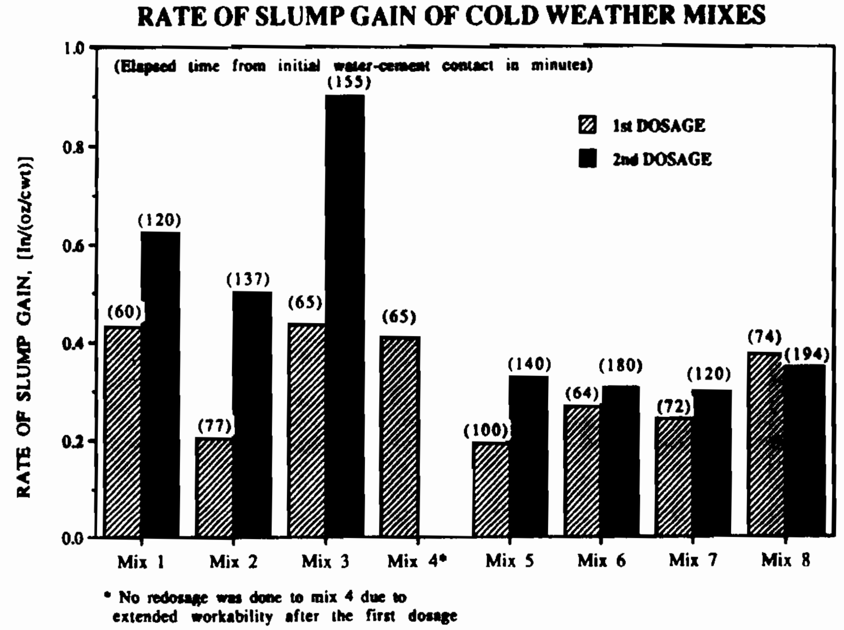
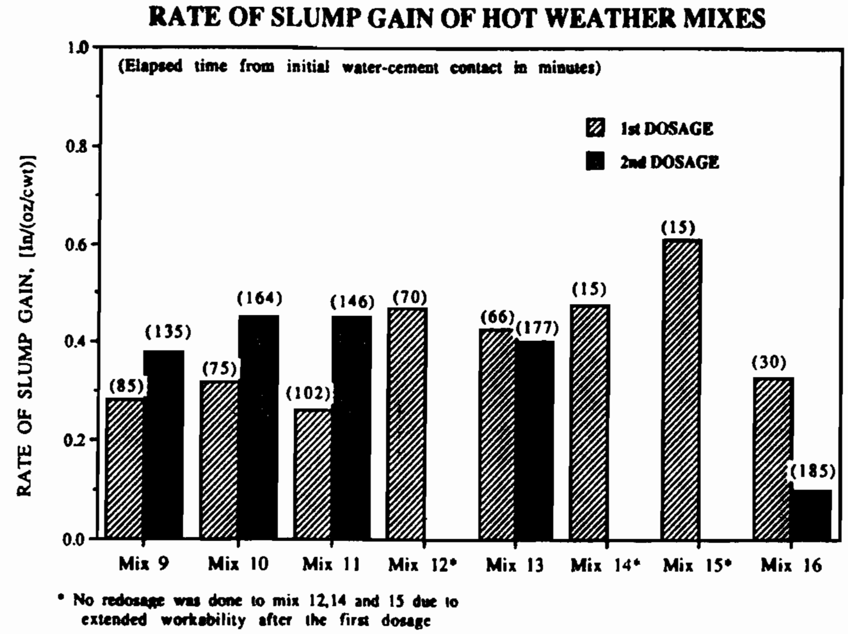


Figure 5.1 Rate of slump gain for cold weather mixes.

The rate of slump gain is defined as the increase in slump per dosage of superplasticizer added. It is affected by the number of additions of superplasticizer, time of addition, superplasticizer type, use of retarding admixtures, temperature, and cement content. The rate of slump gain of cold and hot weather mixes is shown in Figures 5.1 and 5.2 respectively.

As shown in these figures, the rate of slump gain increased after the second addition of superplasticizer in all except mixes 8,13,16. Mailvaganam[19] reported similar results. The lower rate of slump gain after the second dosage in mixes 8, 13, and 16 is explained by the delayed time of redosage which was done at 194, 177, and 185 minutes respectively.

The rate of slump gain was affected by the type of superplasticizer used. As shown in Figure 5.3, Daracem 100 showed the highest rate of slump gain followed by Rheobuild



* No redosage was done to mix 12,14 and 15 due to extended workability after the first dosage

Figure 5.2 Rate of slump gain for hot weather mixes.

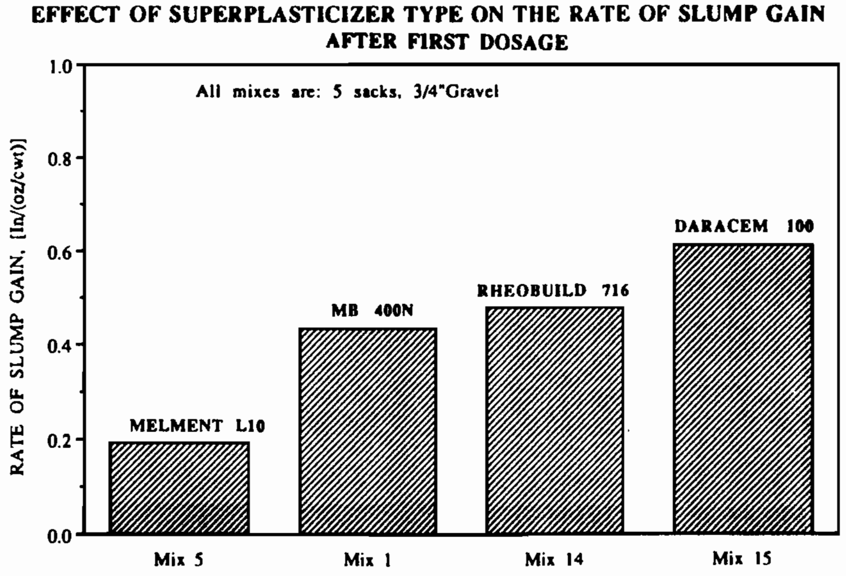


Figure 5.3 Effect of superplasticizer type on the rate of slump gain.

716, Pozzolith 400N and Melment L10. The rate of slump gain after the first and second dosage was affected by the addition of retarding admixtures as shown in Figures 5.4 and 5.5. In fact when the addition of superplasticizer was performed at the same time, the mixes incorporating retarding admixtures showed a higher rate of slump gain.

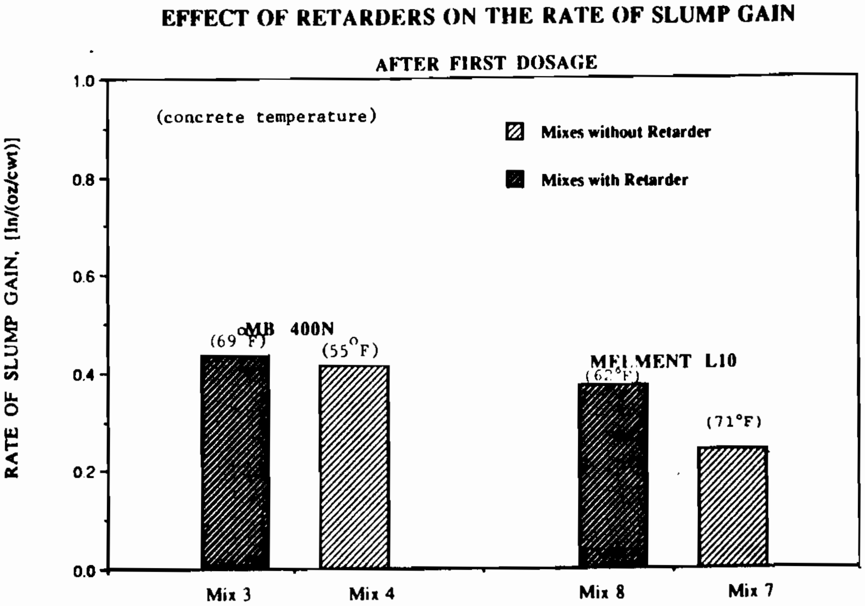


Figure 5.4 Effect of retarder on the rate of slump gain after first dosage of superplasticizer.

The rate of slump gain decreased when the temperature increased as shown in Figure 5.6. This was expected since an increase in temperature results in higher rate of cement hydration and therefore lower slump gain.

Finally, the rate of slump gain was affected by the cement content in the mixture. As shown in Figure 5.7, the mixes with higher cement content showed higher rates of slump gain after the addition of superplasticizer. Furthermore, a lower dosage of superplasticizer was needed to improve workability in mixes with higher cement content, except for mix 3.

The rate of slump loss of all mixes cast in cold and hot weather are shown in Figures 5.8 and 5.9, respectively. The rate of slump loss is defined as the decrease in slump with time. It is mainly affected by temperature, initial slump, cement content, superplasticizer type and use of retarding admixtures.

At higher temperature all mixes experienced higher slump loss. Similar results were reported by many researchers[28,30,32]. Mix 7, which experienced the highest slump loss after the addition of superplasticizer had a very high slump and air loss during transportation from the batching plant to the laboratory. Slump loss during transportation was also reported by other researchers[2,32]. The effect of higher temperature on slump loss is shown in Figure 5.10, where mixes 3 and 10 had a slump loss about 23 percent higher than mixes 1 and 9. Mailvaganam[19] reported that slump loss increased tremendously above 32°C, while extended workability is obtained at temperatures below 22°C.

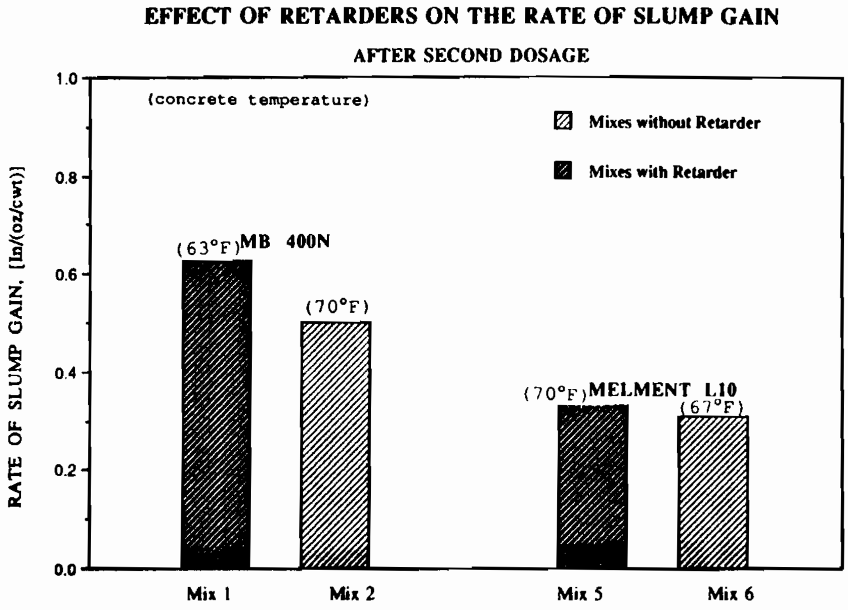


Figure 5.5 Effect of retarder on the rate of slump gain after the second dosage of superplasticizer.

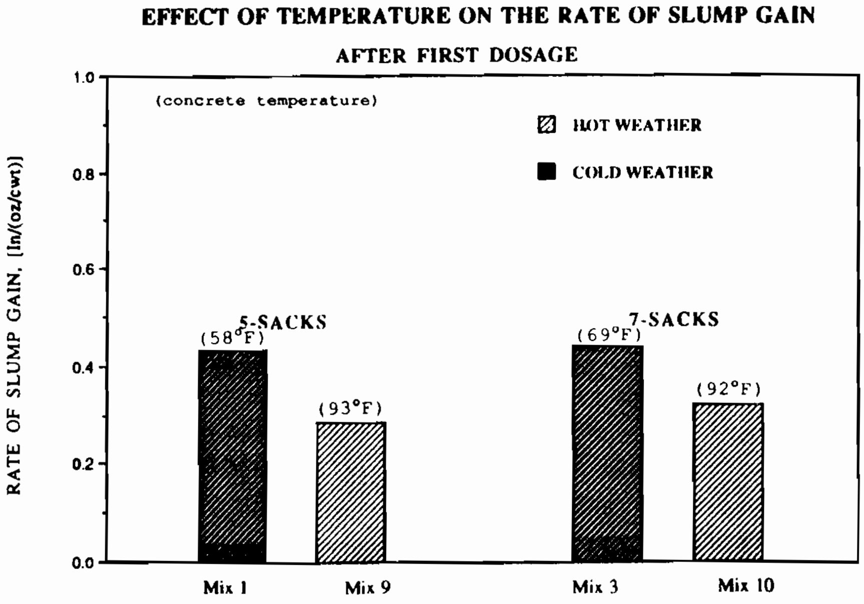


Figure 5.6 Effect of temperature on the rate of slump gain.

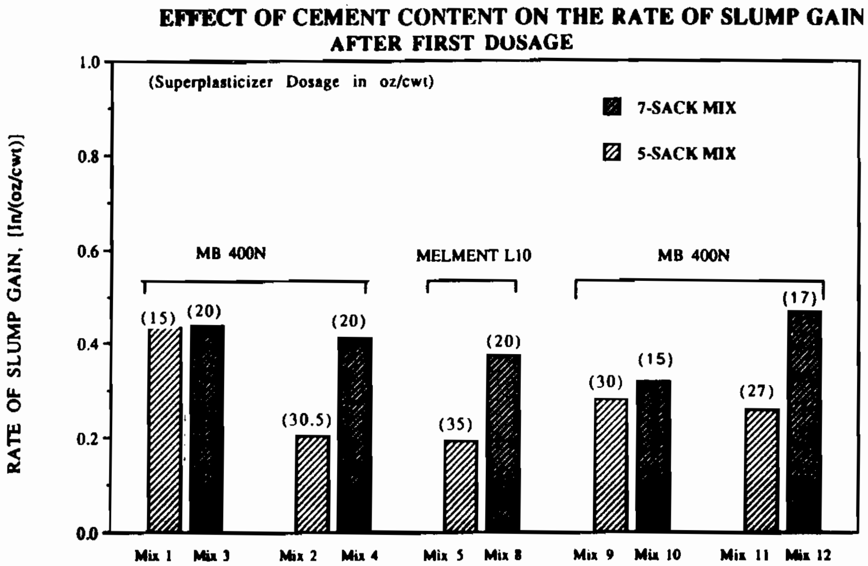


Figure 5.7 Effect of cement content on the rate of slump gain.

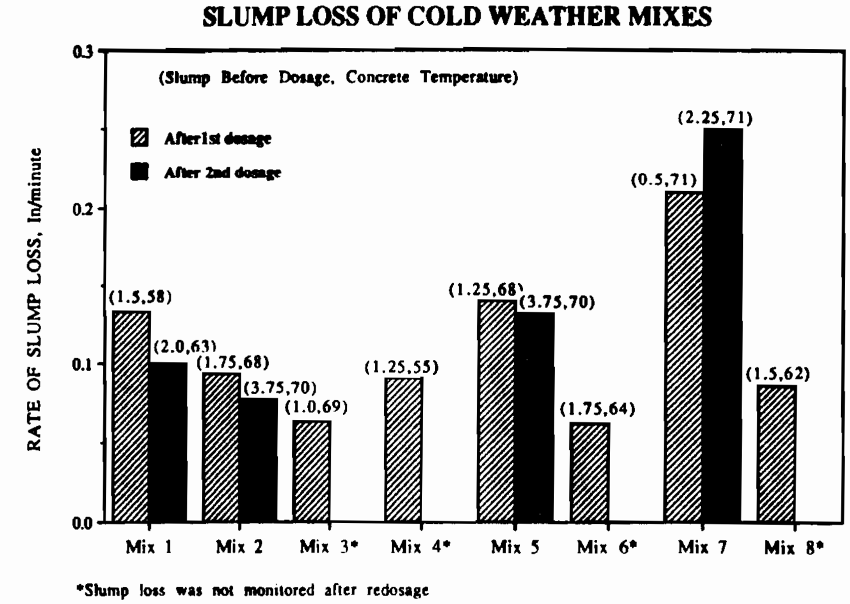


Figure 5.8 Slump loss data for cold weather mixes.

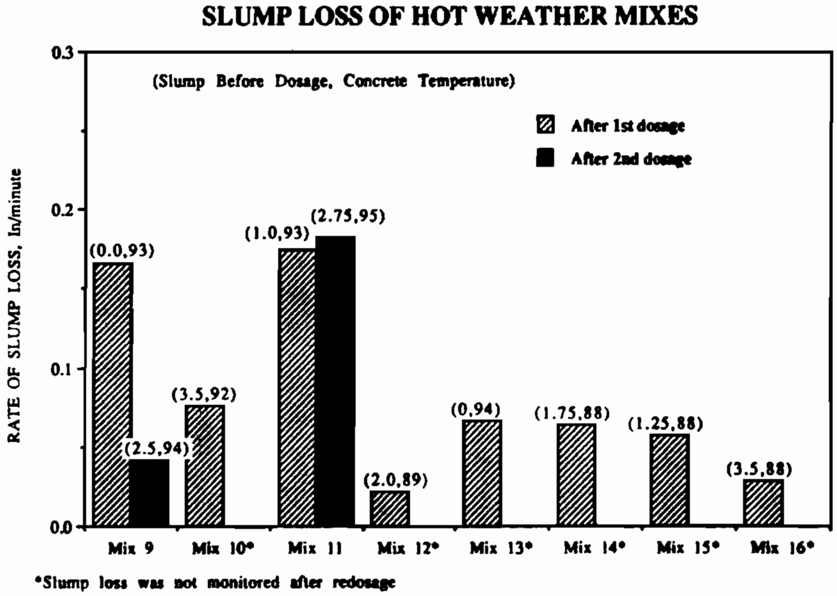


Figure 5.9 Slump loss data for hot weather mixes.

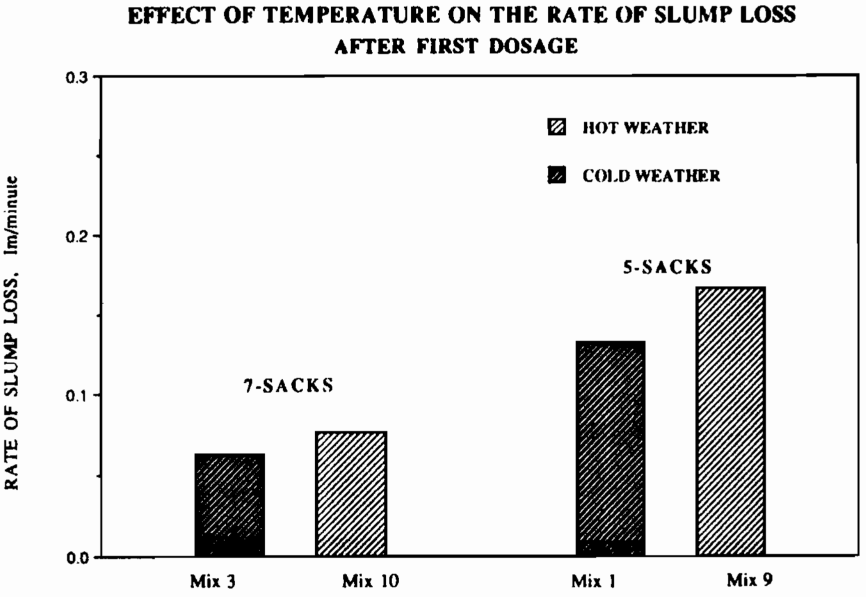


Figure 5.10 Effect of temperature and cement content on the rate of slump loss.

The effect of cement content on slump loss is shown in Figure 5.11, the 7-sack mixes experienced a lower rate of slump loss compared to the 5-sack mixes. Mukherjee and Chojnacki[25] reported similar results. This was even more pronounced in the case of hot weather mixes. However, other researchers found opposite results[27]. Mailvaganam[19] found that the lowest slump losses occur in mixtures with medium cement content (326Kg/m3). High and low cement content mixes have higher slump losses.

The effect of superplasticizer type on slump loss is illustrated in Figure 5.12. The second generation superplasticizers show lower rates of slump loss compared to regular types. Use of Daracem 100 showed the lowest rate of slump loss, followed by Rheobuild 716. Both pozzolith 400N and Melment L10 showed similar slump loss results.

The use of retarding admixtures in cold weather reduced the rate of slump loss prior to the addition of superplasticizer. After the addition of superplasticizer however, the effect of retarders on slump loss was only significant on 7-sack mixes. In fact, as shown in Figure 5.13, the 5-sack mixes with retarders showed higher rate of slump loss.

In general, the mixes that experience a high rate of slump gain show a low rate of slump loss.

5.2.2 Air Content. The average loss of air content during transportation was higher under hot weather than under cold weather conditions. In fact, the average air loss was 1.2 percent during cold weather and 1.8 percent during hot weather. The mixes incorporating a second generation superplasticizer however, had an air content at the batching plant of 5 and 4 percent for Rheobuild 716 and Daracem 100 respectively after the addition of superplasticizer. After transportation to the laboratory, the air content increased to 5.5 and 5 percent respectively. Finally, mix 16, which was tested at the batching plant to eliminate the loss of air due to transportation, had an initial air content of 8.75 percent. After the addition of superplasticizer, the air content dropped to 5.5 percent. Further air loss was observed after the addition of a second dosage, thus decreasing air content from 4 percent to 2.2 percent.

Figure 5.14 shows the change in air content immediately after each addition of superplasticizer. As shown in the figure, the air content increased after the first addition of superplasticizer for mixes 4,7,8,9, and 12, and then decreased. The reason being that the addition of superplasticizer increases the fluidity of the mix, thus making the air-entraining agent more efficient. Ray[32] explains the increase in air content as being a result of slump increase. This is due to the fact that a higher dosage of air-entraining admixture is required for low slump mixes. As the slump increases due to the superplasticizer, the air entraining agent becomes much more effective. The loss of air after the addition of superplasticizer however, is due to the fact that superplasticizers lower the viscosity of the mixture, thus facilitating the escape of air from it. This phenomenon is more important in hot weather since the pressure inside the air bubbles increases at high temperature, and therefore increases the buoyancy of the air bubbles facilitating their ascend to the surface.

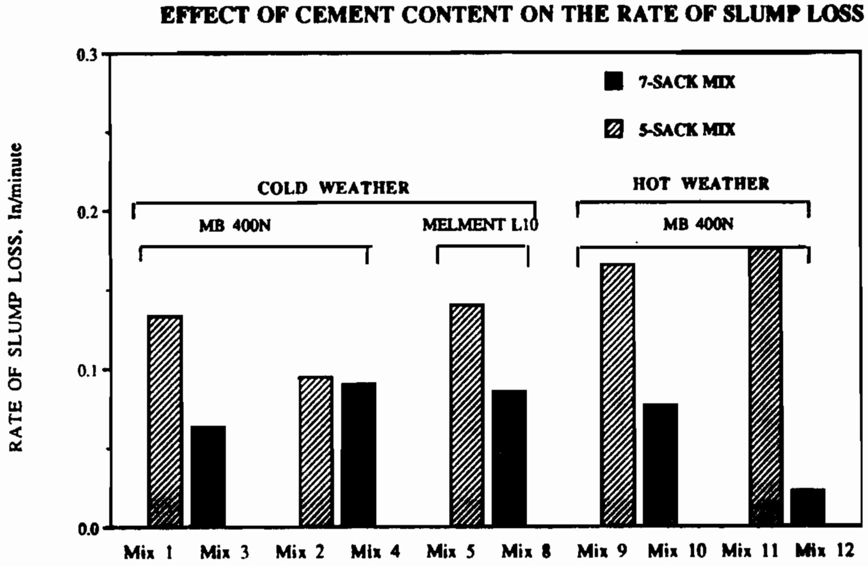


Figure 5.11 Effect of cement content on the rate of slump loss.

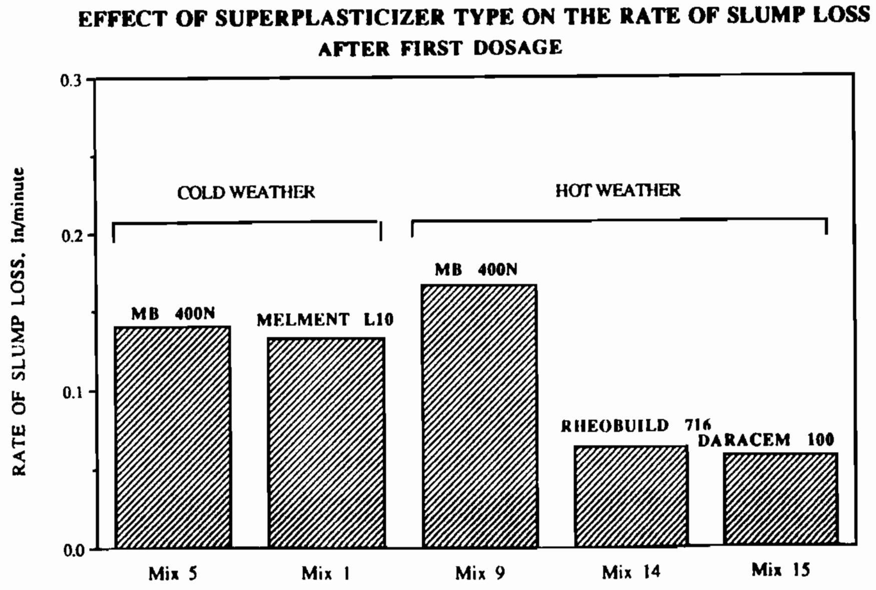


Figure 5.12 Effect of superplasticizer type on the rate of slump loss.

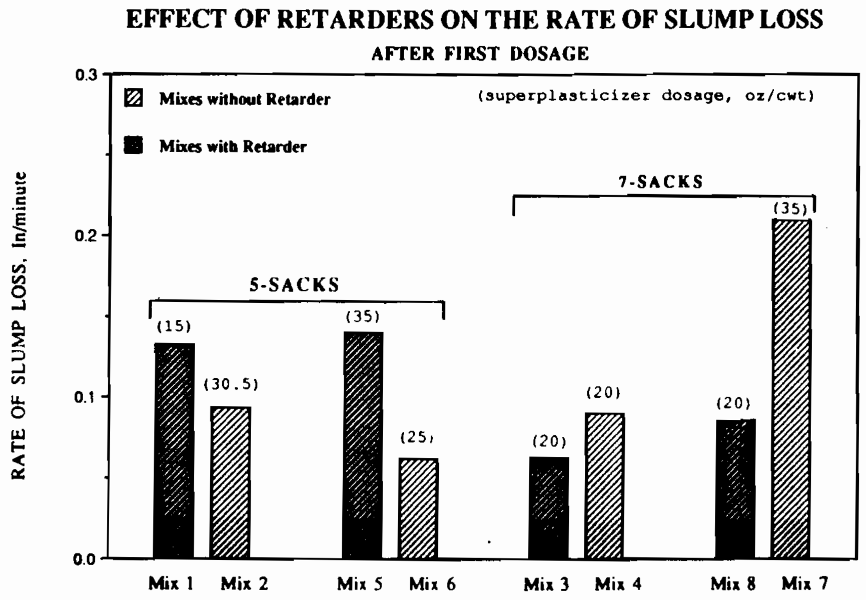


Figure 5.13 Effect of retarder on the rate of slump loss after the first dosage of superplasticizer.

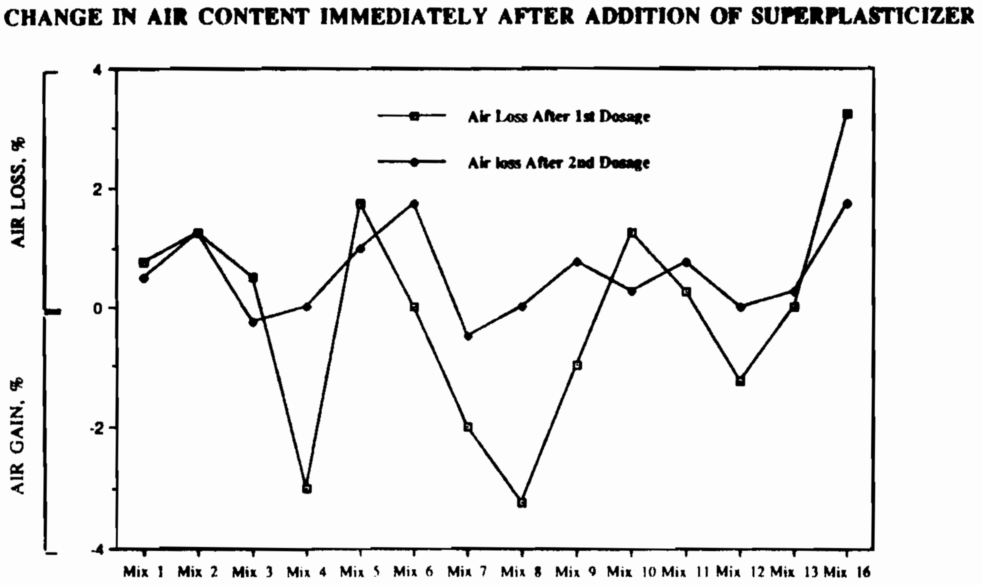


Figure 5.14 Effect of superplasticizer on the air content of fresh concrete.

Air content is further decreased due to the continuing mixing of concrete following each addition of superplasticizer. This is clear since the mixes that required more that one addition of superplasticizer to obtain the required slump experienced higher air loss.

Finally, air loss was affected by the initial air content. Mixes with higher initial air content experienced higher air loss. This was also observed by other researchers[30].

In conclusion, based on the results of mix 16, it was determined that an initial air content of about 8 percent at the batching plant was needed in order to obtain an air content of 4 to 6 percent after the addition of superplasticizer, under hot temperatures. In addition, the superplasticizer should be added not later than an hour after batching. This is a problem since transportation time from the batching plant to the construction site is often longer. A possible advantageous solution is to use second generation superplasticizers which could be added at the batching plant and are capable of retaining an acceptable air content for up to 90 minutes.

5.2.3 Temperature. The average temperature of fresh concrete during the first part of the study was 58°F at the batching plant, and 61°F at the laboratory. During the second part of the study, the average temperature was 86.6 and 90°F at the batching plant and at the laboratory, respectively. The temperature of fresh concrete generally increased right after the addition of superplasticizer. Under cold weather, the average increase was 3°F after the addition of the first dosage and another 2°F after a repeat dosage. The average temperature increase for all mixes cast in hot weather except mixes 14, 15 and 16 was 2°F after the first dosage, and another 4°F after a repeat dosage. In the case of mixes 14 and 15 to which second generation superplasticizers were added at the batching plant, the temperature rise was just 1°F, and remained the same until the concrete arrived at the laboratory. Finally, mix 16 did not experience any temperature rise due to the addition of superplasticizer which occurred 30 minutes after batching. After the second addition which failed to restore fluidity, the temperature increased by 5°F. In some cases however, the increase in temperature after the addition of superplasticizer was followed by a small decrease. The temperature increase was due to the mixing following each dosage. It resulted in increased cement hydration and therefore higher slump loss. On the other hand, it was observed that when the concrete temperature remained constant, slump loss was significantly reduced. In fact, mix 12 which had a constant temperature did not loose its fluidity for more than two hours.

Finally, contrary to the findings of some researchers, both naphthalene and melamine based superplasticizers had a similar effect on the concrete's temperature. However, the use of second generation superplasticizers resulted in a lesser temperature increase and lower slump loss.

5.2.4 Segregation and Bleeding. Specimens with superplasticizer showed increased bleeding compared to the control specimens. Furthermore, a slight segregation was noticed at slump values above 9 inches. These did not have any adverse effect on strength or surface appearance in the hardened state. Similar findings were reported by Gebler[9].

5.2.5 Finishing. The finishing operation depended on the initial slump, temperature and age of the concrete. Mixes with less than one-inch slump were particularly hard to finish since the surface had very little mortar. In fact, in some instances, finishing was not possible without the addition of limited amounts of water to the surface. This resulted in decreased strength and durability of the surface. This was even more pronounced at higher temperature due to faster setting. After the addition of superplasticizer, the surface became sticky and would tear under the action of the trowel. The finishing had to be delayed until the concrete had lost its stickiness. In some mixes, particularly those with high slump loss, the concrete lost its stickiness only minutes before initial set requiring the finishing operation to be done very fast. All finishing operations were done with a hand trowel. Finishing of the specimens cast in hot weather was much harder because of higher slump loss, and faster setting time. Similar findings were reported by Eckert[6].

5.2.6 Setting Time. Initial and final setting times were delayed due to the addition of superplasticizer. This was also found by other researchers[9,22,28,39]. The setting time was delayed even further after the second addition of superplasticizer. The delay in initial and final setting time was generally similar for each addition of superplasticizer. In general, setting time was related to slump loss, the lower the rate of slump loss, the higher was the delay in setting time.

Setting time of the control mixes was reduced at high temperature as shown in Figure 5.15. After the addition of superplasticizer however, mixes 1 and 9 cast in cold and hot weather showed similar setting time values. Furthermore, the time between initial and final setting time is reduced at high temperature.

The effect of retarders in delaying setting time under cold weather is more pronounced on concrete not incorporating superplasticizer. As shown in Figure 5.15, the specimens cast from mix 1 before the addition of superplasticizer had a longer setting time compared to the specimens without superplasticizer from mix 2. They both had similar setting times after the addition of superplasticizer however.

The effect of superplasticizer type on setting time is shown in Figure 5.16. MB 400N resulted in higher retardation compared to Melment L10. Comparing mixes 9, 14 and 15, cast in hot weather, it is clear that Rheobuild 716 results in a slightly higher initial and final setting time than Daracem 100. Nevertheless, both showed slightly shorter setting time compared to MB 400N.

Finally, the type of aggregate was not found to have any effect on setting time.

5.2.7 Unit Weight. The results of the unit weight test are illustrated in Figure 5.17. The unit weight of all mixes cast in cold weather ranged from 143.4 to 147.5 pounds per

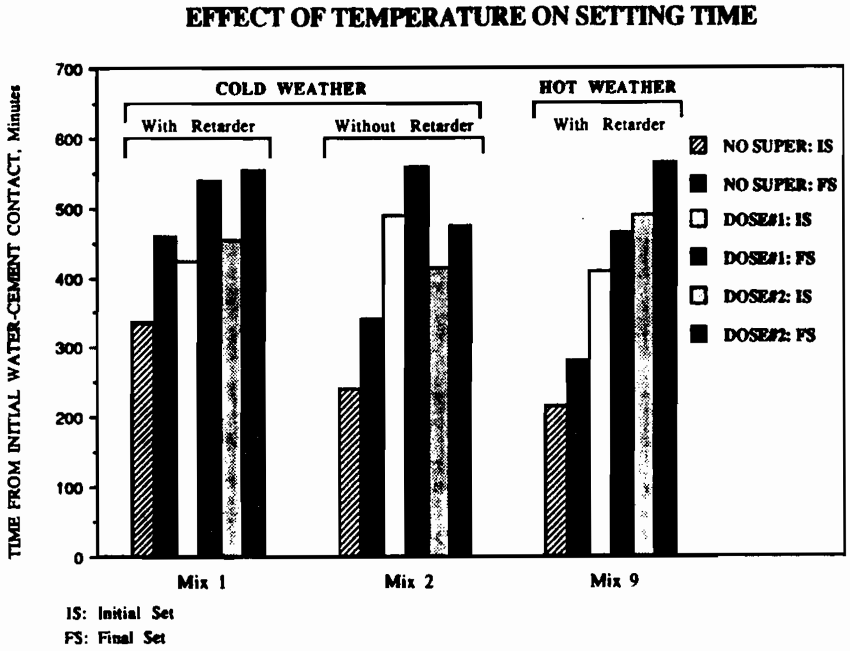


Figure 5.15 Effect of temperature on initial and final setting time.

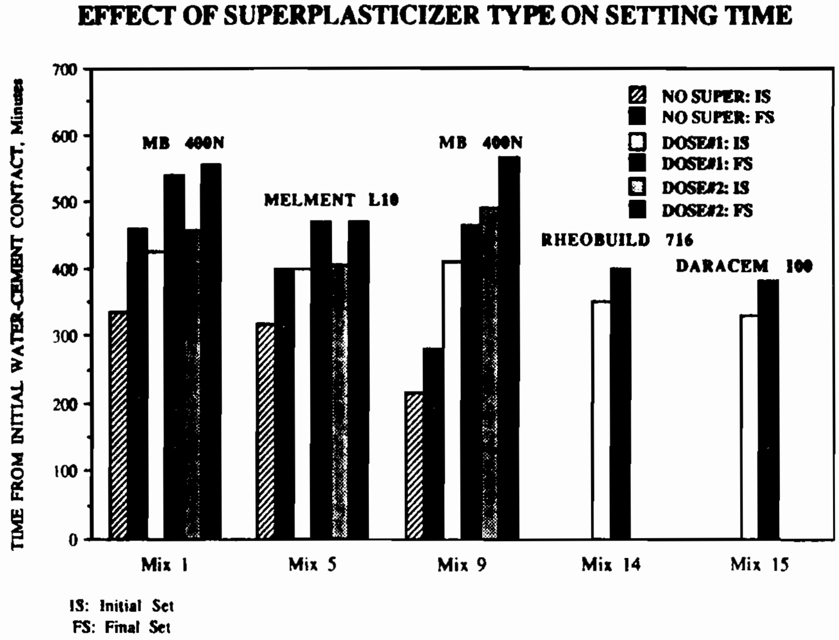


Figure 5.16 Effect of superplasticizer type on initial and final setting time.

cubic feet, with an average value of 145.9. This value increased to 146.3 and 148.3 after the first and second dosage respectively. The unit weight of fresh concrete increased after each addition of superplasticizer in all except mixes 4 and 8. The unit weight of these mixes decreased after the addition of the first dosage of superplasticizer, and then increased after the second addition. The increase in unit weight after each addition of superplasticizer is due to better consolidation and to loss of air from the mixture. Therefore, Ray[32] suggests that unit weight tests be performed on fresh concrete in large projects as a means to detect air loss. This is supported by the fact that the increase in unit weight after the addition of superplasticizer in mixes 4 and 8 was accompanied by an increase in air content as mentioned earlier.

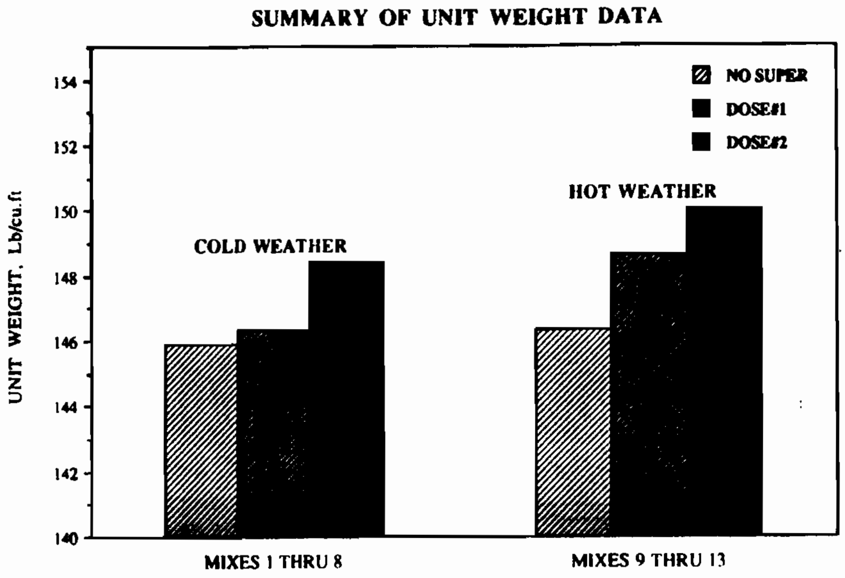


Figure 5.17 Summary of unit weight of fresh concrete.

Mixes 14 and 15 incorporating Daracem 100 and Rheobuild 716 respectively, showed identical unit weight values after the addition of superplasticizer. Figure 5.17 also shows the effect of temperature on unit weight of concrete. While all mixes had identical values before the addition of superplasticizer, hot weather mixes showed much higher values after the first and second dosage. This was due to higher air loss in hot weather.

5.3 Effects Of Superplasticizers On Hardened Concrete

5.3.1 Compressive Strength. The compressive strength of concrete increased after the addition of superplasticizer, except for mixes 4, 9, and 12. Further increase in strength was observed after redosage in all except mix 6. The percent increase after each dosage is shown in Figure 5.18. The increase in strength is, in part, explained by the loss of air occurring after the addition of superplasticizer, as well as by the action of the superplasticizer itself. This is concluded from mix 13 which did not experience any air change during the addition of superplasticizer. Nevertheless, its compressive strength increased by 8.7 percent at 7 days and 11.1 percent at 28 days. On the other hand, the strength decrease experienced by mixes 4, 9, and 12 after the addition of superplasticizer is attributed to the measured increase in air content.

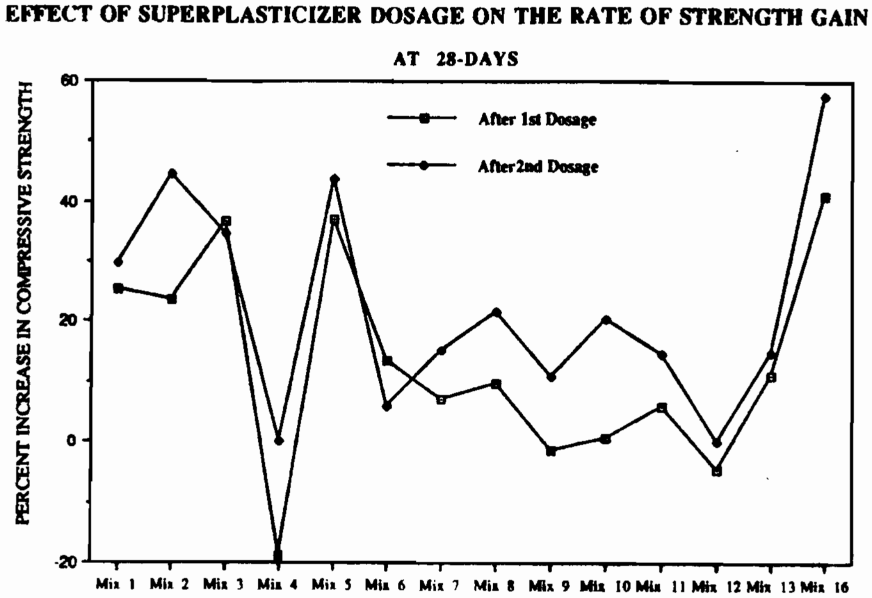


Figure 5.18 Effect of superplasticizer dosage on the rate of strength gain at 28 days.

Superplasticizers increase early strength as well as the strength at 28 days. Previous research indicated that the compressive strength of superplasticized concrete was the same as the control at one year[27]. This was not investigated in this study however. The rate of strength gain after the addition of superplasticizer is affected by the cement content in the mixture. As shown in Figure 5.19, 5-sack mixes showed much higher strength gain after the addition of superplasticizer compared to 7-sack mixes. The rate of strength gain increased even further after the second addition of superplasticizer.

The effect of superplasticizer type on compressive strength is illustrated in Figure 5.19. As shown in the Figure, mixes incorporating Pozzolith 400N showed higher strength gain compared to mixes incorporating Melment L10. Mix 14 and 15, incorporating Rheobuild 716 and Daracem 100 had similar rates of strength gain between 7 and 28 days. The specimens incorporating Daracem 100 showed a higher strength, however. This could be explained by the fact that the mix incorporating Rheobuild 716 had a higher air content.

As shown in Figure 5.20, the increase in strength due to the addition of superplasticizer was much more important for mixes cast in cold weather.

On the other hand, some researchers disagree with the fact that superplasticizers increase the strength of concrete. They reported that the increase in strength was only a result of air loss[9,29]. In fact, Malhotra and Malanka[22] reported that compressive strength was the same before and after the addition of superplasticizer when no air loss occurs. Mix 16 was designed to study the relation between the addition of superplasticizer, air content and compressive strength. As shown in Figure 5.21, the increase in strength is directly related to air loss.

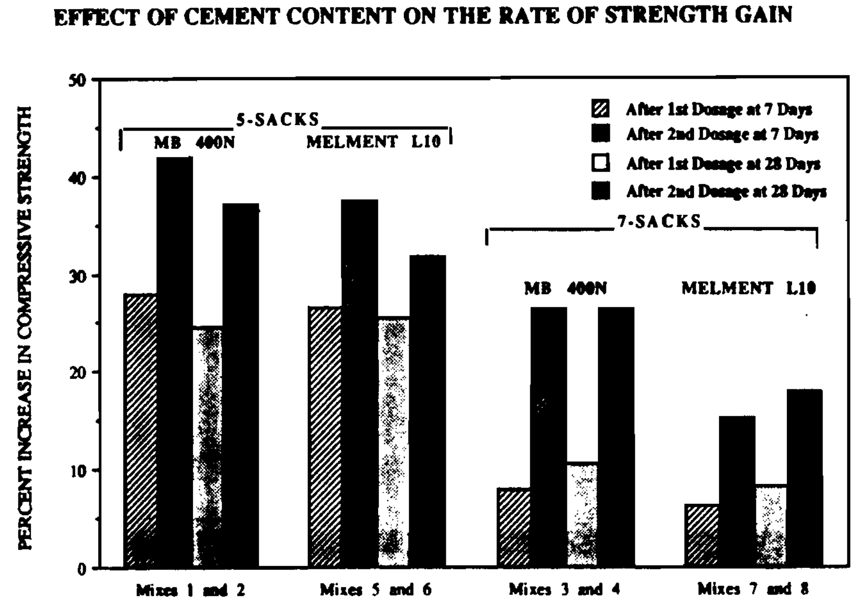


Figure 5.19 Effect of cement content on the rate of strength gain.

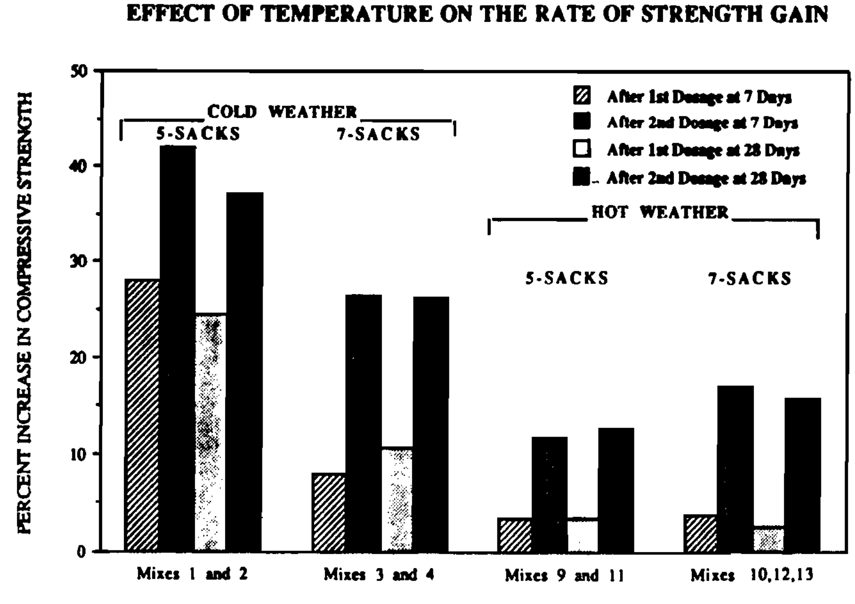


Figure 5.20 Effect of temperature on the rate of strength gain at 7 and 28 days.

Finally, the incorporation of retarding admixtures and type of aggregate used were found not to have any significant effect on compressive strength.

5.3.2 Flexural Strength. Flexural strength followed generally a similar trend as compressive strength. The percent increase and decrease after the addition of superplasticizer is shown in Figure 5.22.

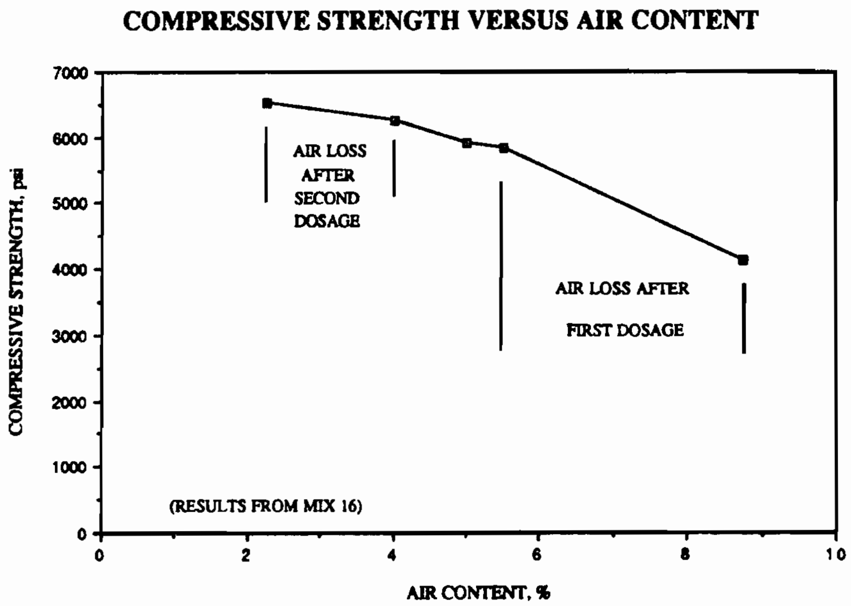


Figure 5.21 Effect of air content on compressive strength from mix 16 cast in the field.

Flexural strength was affected by cement content. As shown in Figure 5.23, mixes with high cement content showed higher flexural strength after the addition of superplasticizer.

Finally, flexural strength was affected by the type of aggregate used, especially for mixes with higher cement content. As shown in Figure 5.23, mix 12, a 7-sack mix containing crushed limestone showed higher flexural strength compared to mix 10, a 7- sack mix containing gravel type coarse aggregate.

5.3.3 Abrasion Resistance. The average abrasion resistance of mixes 1 through 8 cast during the first part of the study, before adding the superplasticizer and after each addition, is shown in Figure 5.24. Generally, abrasion resistance followed a similar trend as compressive strength.

As shown in the figure, the mixes with higher cement content showed a better resistance to abrasion. In all the specimens tested, most of the abrasion occurred during the first two minutes after the beginning of the test. According to the results obtained, the number of dosages of superplasticizer does not appear to have any definite effect on abrasion resistance. Abrasion resistance is affected by the finish applied to the specimens. Properly finished specimens showed greater abrasion resistance.

The test was not performed on the mixes cast during the second part of the study. Nevertheless, it is possible to determine the effects of aggregate type and temperature on abrasion resistance by comparing the results obtained in this study with the ones reported

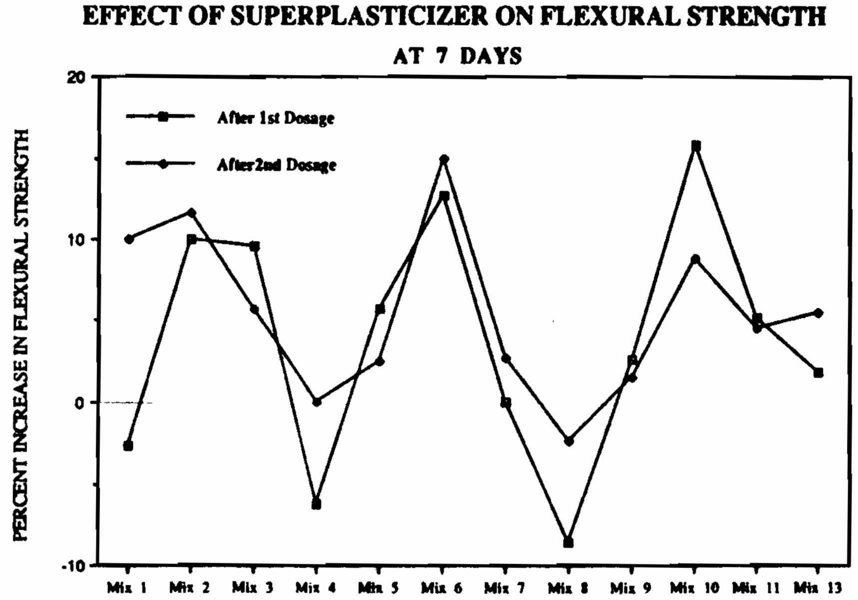


Figure 5.22 Effect of superplasticizer on flexural strength at 7 days.

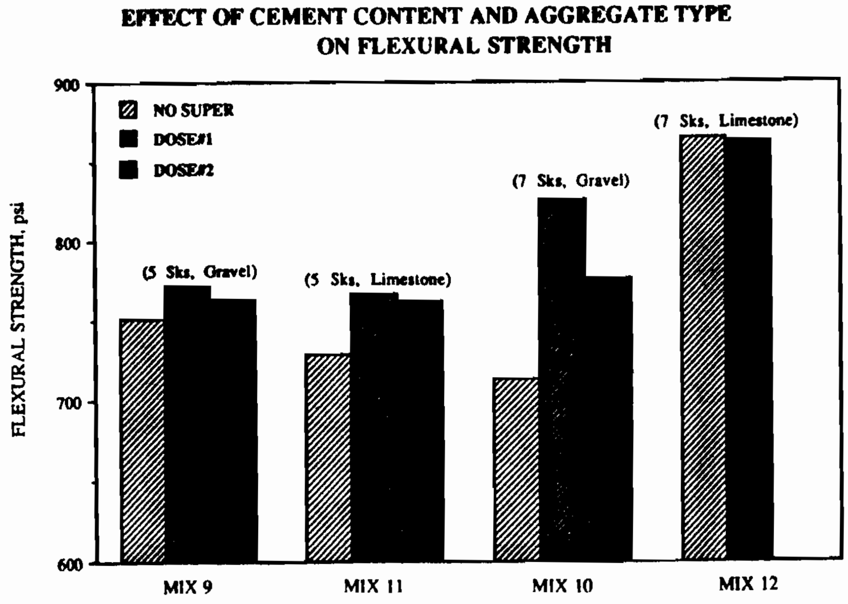


Figure 5.23 Effect of cement content of aggregate type on flexural strength at 7 days.

by Eckert[6] during the course of a related study which specifically addressed the use of superplasticizers in hot weather. Abrasion resistance of mixes with natural gravel was around 73 percent higher than for limestone mixes. Furthermore, mixes cast in cold weather showed higher abrasion resistance.

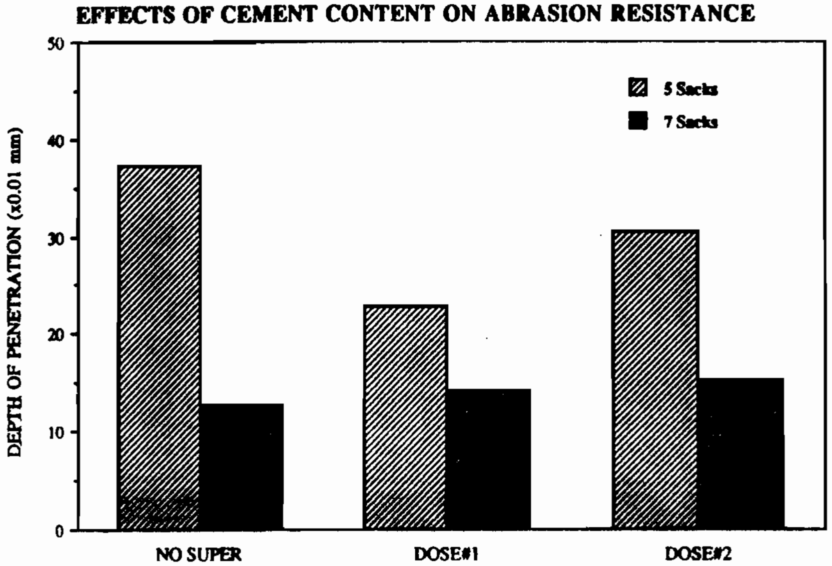


Figure 5.24 Effect of cement content on abrasion resistance.

5.3.4 Freeze-- Thaw Resistance. In general, the resistance of the concrete to freeze--thaw deteriorated after each addition of superplasticizer. This is explained both by the fact that air content usually decreased after each dosage and to the fact that superplasticizers increase the size of the air bubbles thus reducing their usefulness in resisting frost action. This was concluded since even at similar air content values, specimens incorporating superplasticizer showed lower freeze-thaw resistance compared to the control. This is shown in Figure 5.25. In the instances where the air content increased after the addition of superplasticizer, the specimens cast after dosage showed a higher resistance compared to the control. Mix 16 which had an initial air content of 8.75 percent showed excellent resistance to freeze-thaw after the first dosage of superplasticizer. However, the specimens cast after redosage, which had an air content of 2 percent, showed poor resistance.

Freeze-thaw resistance was also found to be affected by the cement content in the mixture; 7-sack mixes show higher frost resistance compared to 5-sack mixes. This is true even when the latter has a higher air content as shown in Figure 5.26.

Freeze-thaw is also affected by the temperature during casting. The results obtained show that hot weather concrete is more vulnerable to freeze-thaw damage compared to cold weather concrete. As shown in Figure 5.27, this is true even when hot weather concrete possess a higher air content.

Initial slump was found to indirectly affect freeze-thaw resistance. Mixes with higher initial slump usually result in lower air loss after the addition of superplasticizers. Therefore, the resistance of the superplasticized concrete is improved with higher initial slump.

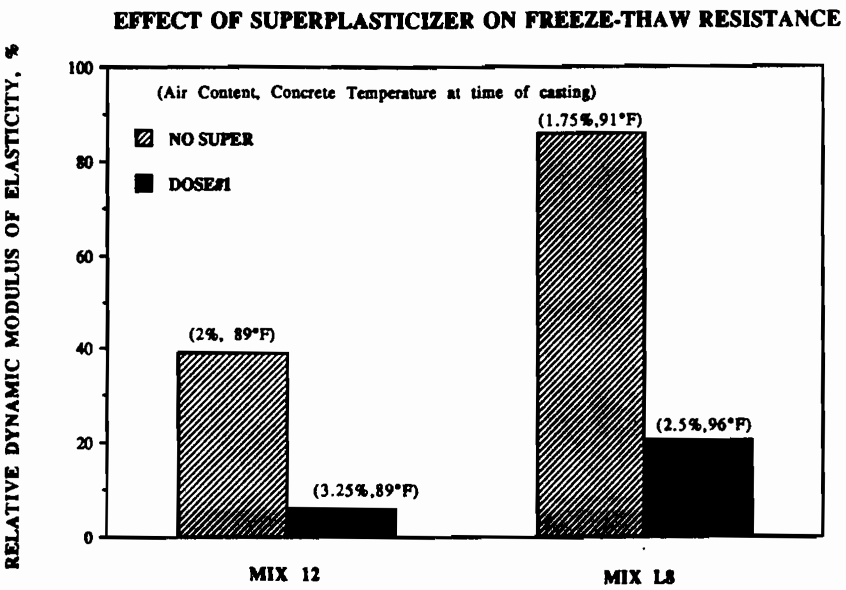


Figure 5.25 Effect of superplasticizer on freeze-thaw resistance.

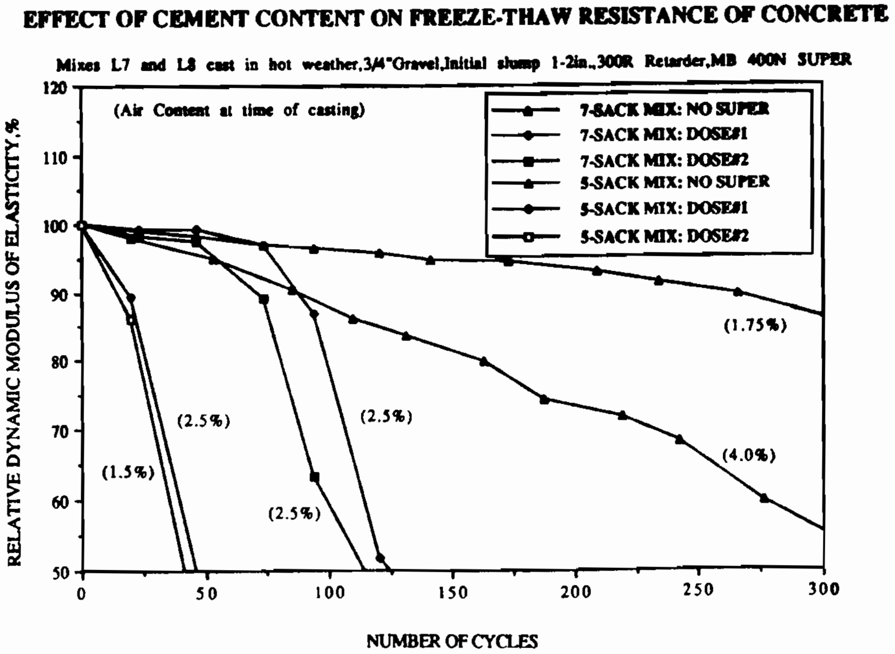


Figure 5.26 Effect of cement content on freeze-thaw resistance.

Finally, mixes 14 and 15 incorporating second generation superplasticizers, showed excellent freeze-thaw resistance. This was expected since these mixes did not loose air after the addition of superplasticizer.

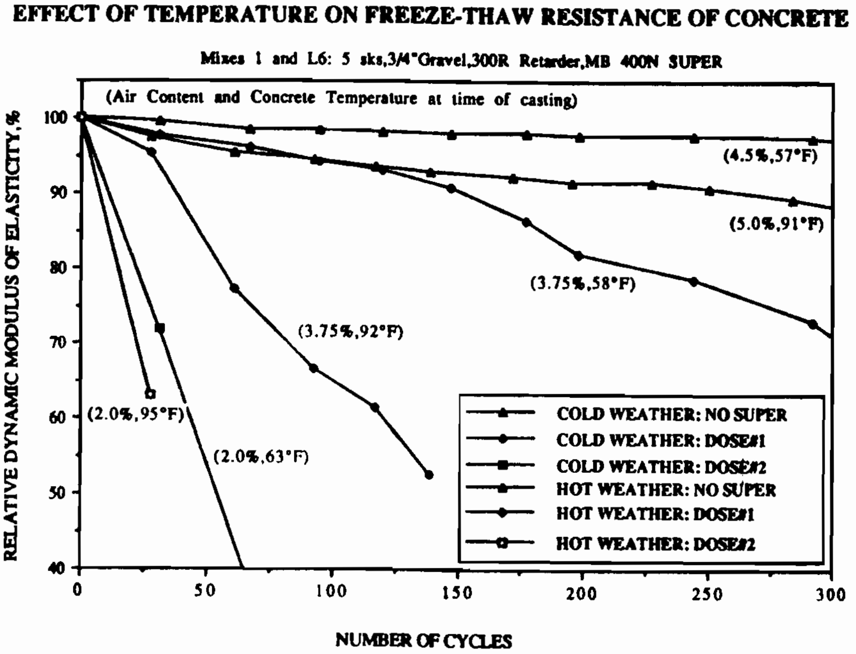


Figure 5.27 Effect of temperature on freeze-thaw resistance.

5.3.5 Deicer--Scaling Resistance. The resistance to deicer--scaling was visually determined. The rating was performed on a scale of 0 to 5, where 0 is the best and 5 the worst. In general, all mixes performed well. The average value for the cold weather mixes was slightly lower than the average value of the hot weather mixes as shown in Figure 5.28. This is due to the fact that the mixes cast in cold weather had a longer setting time. It was therefore possible to finish them slowly ensuring a good finish, while some of the mixes cast in hot weather had a bad finish. The specimens incorporating superplasticizer in general performed worse than the control specimens. Some researchers reported however that for similar slump values, superplasticized concrete has a better deicer-scaling resistance than regular concrete[9].

Finally, mixes 14 and 15 incorporating second generation superplasticizers showed a much higher resistance to deicer-scaling compared to the mixes incorporating conventional superplasticizers.

5.3.6 Chloride Penetration Resistance. In cold weather concreting, the resistance of concrete to chloride penetration was not affected by the addition of superplasticizer. In hot weather, however, the resistance to chloride penetration decreased after the addition of superplasticizer as shown in Figure 5.29. This is explained by the fact that hot weather mixes were particularly hard to finish and consolidate as explained in 5.2.5. In fact, many specimens cast in hot weather developed deep surface cracks due to the action of deicer-scaling and thus allowing the free penetration of chloride ions. The concentration of chloride ions was always higher at shallower depths. The chloride content of both cold and hot weather mixes were lower than the maximum allowable values recommended by ACI-211. These values are 0.06 percent, 0.15 percent and 0.10 percent by weight of cement for prestressed concrete, conventionally reinforced concrete in a moist environment exposed to chloride, and not exposed to chloride, respectively.

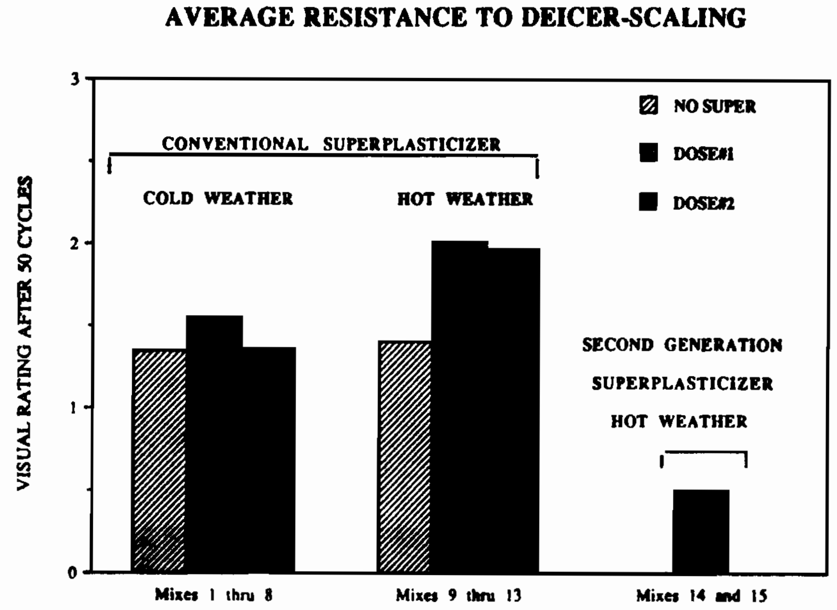
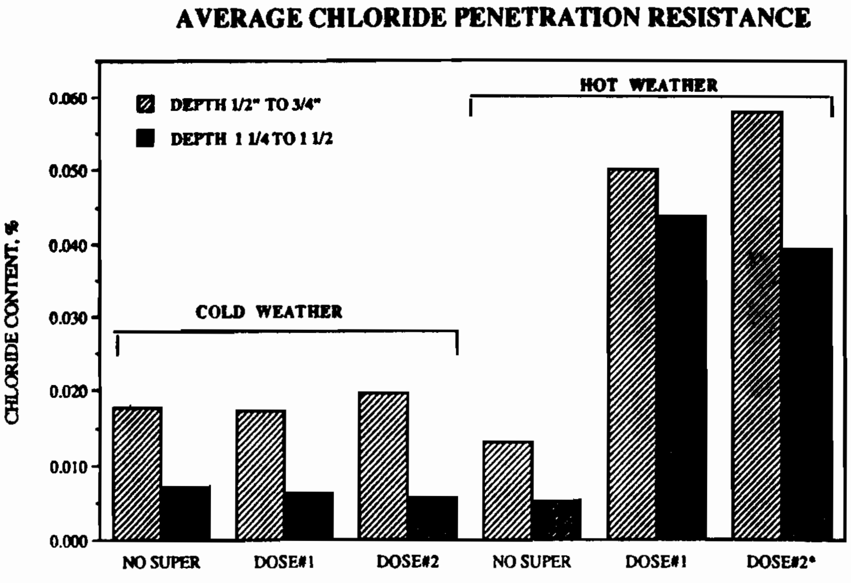


Figure 5.28 Summary of deicer-scaling test data.



*Average of mixes 9 to 13 except mix 10 which had surface cracks.

Figure 5.29 Summary of chloride penetration test data.

CHAPTER VI

SUMMARY AND CONCLUSIONS

6.1 Summary

The use of admixtures in concrete has increased significantly over the past 10 years. Hence, it is urgent to provide the concrete user with guidelines as to the proper use of admixtures for the production of good quality and durable concrete. Some of the more widely used admixtures in concrete are high-range water reducers, commonly referred to as "Superplasticizers", and air-entraining agents, used for protection against damage caused by freeze and thaw cycles. However, the effectivenesses of these admixtures seem to be affected by a wide range of variables, including both environmental and fresh concrete properties.

A comprehensive research program was conducted studying the effect that several variables have on both fresh and hardened properties of concrete. The variables studied included ambient temperature, cement content, coarse aggregate type, slump, retarder dosage, and high-range water reducer type and manufacturer as well as time of addition. The concrete properties investigated included workability, air content, temperature, unit weight, setting time, compressive strength, flexural strength, abrasion resistance, resistance to deicer-scaling, resistance to frost action, and resistance to chloride penetration. The effect of other variables such as retarder dosage, initial slump, and air- entraining agent type were investigated during the first part of this program conducted by William C. Eckert[6].

The concrete used in the study was commercially available ready-mix concrete in order to duplicate existing field conditions as closely as possible. The research program was conducted at Phil Ferguson structural Engineering Laboratory, under the supervision of Dr. Ramon L. Carrasquillo.

6.2 Guidelines for the Use of Superplasticizer

The following guidelines are recommended when using superplasticizers in ready-mix concrete under both cold and hot weather conditions. They are based on the guidelines proposed by William C. Eckert[6] and the ones issued by the Canadian Standard Association (A266.5.M 1981).

1) Choose ready-mix suppliers who can provide concrete with consistent physical and chemical properties.

2) The supplier should be located so that travel time does not exceed 60 minutes.

3) Evaluate in-place strength and durability requirements for the structural concrete, including the proper amount of air-entraining admixture needed when frost resistant is desired. This dosage should be evaluated both in hot and cold weather conditions.

4) Due to loss of air after the addition of superplasticizer, especially in hot weather, it is recommended that the mix be proportioned for 2 to 4 percent higher air than that recommended by the specifications.

5) When the time of addition of the superplasticizer exceeds 30 minutes, a retarding admixture is required under hot weather. In cold weather a retarding admixture is not necessary but its addition increases the rate of slump gain and helps reduce slump loss.

6) The concrete should have an initial slump of one to three inches prior to the addition of superplasticizer. The concrete should have a higher slump at the batching plant when high slump loss due to higher temperature or due to delay time of addition is expected.

7) Conduct at least one full trial batch using the proposed mixture to determine the adequacy of the time of addition of superplasticizer and the proper dosage required to obtain the desired properties. The effect of superplasticizer on air-entraining admixture should be specifically investigated by determining the air content in the fresh mixture before and after the addition of superplasticizer. Slump, air loss, temperature and setting time should be monitored for the time period during which placement is estimated to be completed.

8) In addition to the fresh concrete properties, it is recommended that cylinders be cast to ensure that the compressive strength at 7 and 28 days are within the values in the specifications.

9) When the placing of concrete is delayed, it is possible to add a second dosage of superplasticizer. However, this is not recommended when frost resistance is desired since redosage usually results in significant air loss.

10) The addition of superplasticizer should be conducted in the field immediately before placing the concrete. After the addition of superplasticizer, the concrete should be thoroughly mixed for five minutes.

11) The use of superplasticizer does not require any changes in the standard recommendations for adequate curing.

Recommendations for development of a Work Plan which incorporates these guidelines is included in Appendix E.

6.3 Conclusions

1) The use of second generation superplasticizers is beneficial in improving workability, reducing slump loss, and reducing air loss compared to regular type superplasticizers.

2) Second generation superplasticizers show higher rates of slump gain compared to conventional types of superplasticizers.

3) The use of a retarding admixture is beneficial in cold and hot weather. It increases the efficiency of superplasticizers, thus increasing the rate of slump gain for a given dosage of superplasticizer. The efficiency of a second dosage of superplasticizer is increased even further in the mixes incorporating a retarder.

4) The increase in the superplasticizer's efficiency due to the presence of a retarder is dependent upon the type of admixture used.

5) The efficiency of a superplasticizer decreases at high temperature. A higher dosage is required to achieve a certain slump. Furthermore, the use of a retarder and the time of addition are two major factors controlling the use of superplasticizer under hot weather. In fact, at higher temperature, superplasticizers lose their capacity to improve workability when the concrete does not contain a retarder and the time of addition is significantly delayed.

6) The mixes with 7-sack cement content show higher rate of slump gain compared to 5-sack mixes.

7) Slump loss is increased at higher temperature.

8) Mixes with a 5-sack cement content experience a higher rate of slump loss compared to 7-sack mixes.

9) Conventional type superplasticizers show a much higher rate of slump loss than second generation superplasticizers.

10) The loss of air increases due to high temperature, delay in addition of superplasticizer and especially the number of additions required to achieve the desired slump.

11) In order to obtain a certain air content, a higher dosage of air entraining agent is required for a 7-sack mix compared to a 5-sack mix.

12) For the same dosage of air-entraining agent, air content is increased for higher initial concrete slump.

13) Mixes with crushed limestone need a higher dosage of air-entraining admixture compared to mixes made with gravel to produce the same air content.

14) Air loss results in increased unit weight. Hence, monitoring unit weight is an efficient way to detect air loss in field applications.

15) The use of superplasticizer delays both initial and final setting time. The delay is ggreaterunder cold weather condition.

16) Both compressive and flexural strength are increased due to the addition of superplasticizer. The percent increase is more relevant for the mixes with 5-sack cement content.

17) The rate of strength gain is increased after the second dosage of superplasticizer for 7 and 28-day strength.

18) Higher rate of strength gain occurs at lower temperature than at higher temperature due to the addition of superplasticizers.

19) The increase in strength is due both to loss of air and better dispersion of cement particles due to the addition of superplasticizer.

20) Abrasion resistance is generally better for mixes with higher compressive strength. Mixes with higher cement content show a better resistance to abrasion.

21) Superplasticized concrete show lower resistance to freeze-thaw. This is due to loss of air during the addition of superplasticizer. Nevertheless, superplasticized concrete show good freeze-thaw resistance when its air content after dosage is within 4 to 6 percent.

22) The resistance of superplasticized concrete to freeze-thaw also depends on the cement content in the mix. Mixes with higher cement content show significantly higher freeze-thaw resistance.

23) The resistance of concrete to deicer-scaling is decreased slightly after the addition of superplasticizer. The decrease is larger during hot weather concreting.

24) Mixes incorporating second generation superplasticizers show a much better resistance to deicer-scaling compared to control mixes and mixes incorporating conventional superplasticizers.

25) Finally, the mixes incorporating second generation superplasticizers show improved fresh and hardened concrete properties as compared to similar concrete made using conventional superplasticizers.

26) Differences in performance of concrete made using different formulation of a given generation of superplasticizers are not significant and must be defined on the basis of trial mixes.

APPENDIX A1

Chemical and Physical Properties of Cement

CHEMICAL COMPOSITION, %	
Calcium Oxide (CaO)	64.87
Magnesium Oxide (MgO)	1.31
Silica Dioxide (SiO_2)	20.34
Aluminum Oxide (Al_2O_3)	5.28
Ferric Oxide (Fe_2O_3)	1.91
Sulfur Oxide (SO_3)	3.06
Loss on Ignition (LOI)	1.7
Insoluble Residue (IR)	0.27
Total Alkalies as Na_2O	0.57
Tricalcium Silicate (C_3S)	62.58
Tricalcium Aluminate (C_3A)	10.76

SURFACE AREA (ASTM C204-84)	
Blaine (sq. m/kg)	367
Turbidimeter (sq. m/kg)	- - -

SURFACE AREA (Texas SDHPT 1982)	
Wagner (sq. m/kg)	1911

PERCENT PASSING #325 SIEVES	95.7

SOUNDNESS	
Autoclave Expansion, %	-0.01

TIME OF SETTING (min.)		
Gilmore	Initial	160
	Final	205
Vicat	Initial	115
	Final	210

APPENDIX A2

Concrete Mix Proportions

Mix proportions of mixes 1 through 16 cast in cold and hot weather.

	Design Values of SSD							Actual Values of SSD					
Mix #	Mix Type	Coarse Agg. lb/cu. yd.	Sand lb/cu. yd.	Cement lb/cu. yd.	Water lb/cu. yd.	Air Entr. oz/cwt.	Retarder oz/cwt	Coarse Agg. lb/cu. yd.	Sand lb/cu. yd.	Cement lb/cu. yd.	Water lb/cu. yd.	Air Entr. oz/cwt	Retarder oz/cwt
1	5 sacks 3/4" gravel	1872	1396	470	181.46	0.68	3	1888	1388.5	466.0	181.9	0.68	3.0
2	"	1872	1396	470.68	0	187.6	0	1904	1374.1	480.0	194.9	0.64	0.0
3	7 sacks 3/4" gravel	1712	1285	658	177.8	0.91	3	1752	1239.5	666.0	186.4	0.9	2.9
4	"	1712	1285	658	186.8	0.88	0	1728	1277.5	658.0	190.6	0.88	0. 0
5	5 sacks 3/4" gravel	1872	1396	470	186.9	0.76	3	1888	1358	466.0	186.6	0.77	3.0
6	"	1872	1396	470	186.7	0.89	0	1880	1373	470.0	187.3	0.87	0.0
7	7 sacks 3/4" gravel	1712	1285	658	187.6	0.91	0	1728	1256.3	684.0	191.9	0.88	0.0
8	"	1712	1285	658	194.6	1.39	3	1716	1277	656.0	194.2	1.38	3.9
9	5 sacks 3/4" gravel	1872	1396	470	185.8	0.74	5	1904	1381.8	470.0	186.2	0.72	5.0
10	7 sacks 3/4" gravel	1712	1285	658	194.9	0.76	5	1712	1382	470.0	202.4	0.76	5.0
11	5 sacks 3/4" limestone	1800	1329	470	230.5	0.95	5	1800	1306	456.0	230.3	0.99	5.2
12	7 sacks 3/4" limestone	1712	1285	658	270.6	1.22	3	1712	1270	680.4	267.9	1.18	3.8
13	"	1712	1285	658	235.5	1.37	5	1712	1267.8	651.6	241.8	1.38	5 .1
14	5 sacks 3/4" gravel	1872	1396	470	135.8	1.13	0	1880	1394	470.0	195	1.13	0.0
15	"	1872	1396	470	145.8	1.13	0	1880	1394	516.6	143.7	1.03	0.0
16	"	1872	1396	470	168.5	1.77	5	1880	1410	470.0	195.6	1.77	5.0

APPENDIX A3

Properties of Fresh Concrete

Mix proportions of mixes L1 through L9 cast by William C. Eckert [6] under hot weather

		Design Values at SSD					Actual Values at SSD				
Mix#	Mix Type	Coarse Agg. lb/cu.yd	Sand lb/cu.yd	Cement lb/cu.yd	Water lb/cu.yd	Retarder oz/cwt	Coarse Agg. lb/cu.yd	Sand lb/cu.yd	Cement lb/cu.yd	Water lb/cu.yd	Retarder oz/cwt
L1	5 Sacks 3/4"Gravel	1872	1396	470	221.5	3.0	1888	1439.7	467.5	233.3	2.9
L2	"	1872	1396	470	237.5	3.0	1890	1406.5	497.5	239.3	2.8
L3	5 Sacks,3/4" Limestone	1800	1329	470	225.2	3.0	1836	1315	468.0	233.8	3.0
L4	"	1800	1329	470	224.4	3.0	1800	1317.6	463.2	225.9	3.0
L5	"	1800	1329	470	205.6	3.0	1788	1315.8	468.0	204.4	3.0
L6	5 Sacks 3/4'Gravel	1872	1396	470	216.6	5.0	1928	1401.6	470.0	220.6	5.0
L7	"	1872	1396	470	214	5.0	1872	1378.4	476.0	214.4	4.9
L8	7 Sacks 3/4"Gravel	1712	1285	658	225.6	3.0	1712	1335.8	660.0	229.6	3.0
L9	5 Sacks 3/4"Gravel	1872	1396	470	205.4	3.0	1872	1370.4	466.0	205.5	3.0

Properties of fresh concrete before the addition of superplasticizer for mixes 1 through 8

		Req 'd		At The PLant						At The Lab						
Mix#	Description	Slump in.	Air %	Retarder (oz/cwt)	A/E Dose oz/cwt	Slump in.	Air %	Concrete Temp. °F	Time Of Batch	Time of Arrival	Air Temp. (°F)	Rel.Hum %	Slump in.	Air %	Concrete Temp. °F	Unit Wt. lb/cu.ft
1	5 Sks Gravel 300R, 400N	1 - 2	4 - 6	3.0	0.68	2.25	4.5	N/A	11:05 am	11:55 am	63	41	1.5	4.5	57	145.2
2	5 Sks Gravel No Ret.,400N	1 - 2	4 - 6	0.0	0.64	1.75	4	56	10:18 am	11:12 am	62	32	0.75	3.25	62	147
3	7 Sks Gravel 300R, 400N	1 - 2	4 - 6	2.9	0.9	2.25	4	N/A	2:28 pm	3:25 pm	54	52	1	3	68	147.5
4	7 Sks Gravel No Ret.,400N	1 - 2	4 - 6	0.0	0.88	2.25	4	N/A	12:37 pm	1:35 pm	42	44	1.25	3	54	145.6
5	5 Sks Gravel 300R,Mel. L10	1 - 2	4 - 6	3.0	0.77	1	5.5	54	8:59 am	9:45 am	65	40	1.25	5	57	143.5
6	5 Sks Gravel No Ret.,Mel.L10	1 - 2	4 - 6	0.0	0.87	2.5	6	60	1:25 pm	2:09 pm	61	43	1.75	5	62	145
7	7 Sks Gravel No Ret.,Mel.L10	1 - 2	4 - 6	0.0	0.88	1.75	3.25	N/A	11:03 am	11:52 am	58	43	0.5	3	67	146.6
8	7 Sks Gravel 300R,Mel.L10	1 - 2	4 - 6	3.9	1.38	1.75	5.25	62	11:01 am	12:10 pm	52	37	1.5	3.75	63	147

N/A: Not Available

Properties of fresh concrete after the first and second addition of superplasticizer for mixes 1 through 8

	1st Dosage of Superplasticizer										2nd Dosage of Superplasticizer									
Mix #	Dosage oz/cwt	No. of Additions	Time	Elapsed Time(min)	Slump (in		Air %		Concrete Temp.°F	Unit Wt. lb/cu.ft	Dosage oz/cwt	No. of Additions	Time	Elapsed Time(min)	Slump (in		Air %		Concrete Temp.°F	Unit Wt. lb/cu.ft
					From	To	From	To							From	To	From	To		
1	15	1	12:05 pm	60	1.5	8	4.5	3.75	58	149.6	10	1	1:05 pm	120	2	8.25	2.5	2	63	150.8
2	30.5	2	11:18 am	77	1.75	8	3.25	2	68	150.9	10	1	12:35 pm	137	3.75	8.75	2.25	1	70	151
3	20	1	3:33 pm	65	1	9.75	3	2.5	69	146.4	5	1	5:03 pm	155	5	9.5	2.25	2.5	69	150
4	20	1	1:42 pm	65	1.25	9.5	3	6	55	142	0	NONE	3:07 pm	150	2.75	N/A	2	N/A	57	147
5	35	5	9:59 am	100	1.25	8	5	3.25	68	146.2	15	1	11:20 am	140	3.75	8.75	3	2	70	151.1
6	25	1	2:29 pm	64	1.75	8.5	5	4.75	64	145.4	20	1	4:25 pm	180	2	8.25	4	2.25	67	145.4
7	35	2	12:03 pm	72	0.5	9	3	3	71	149	20	1	1:03 pm	120	2.25	8.25	1.5	2	71	148.6
8	20	1	12:15 pm	74	1.5	9	3.75	7	62	141.1	20	1	2:15 pm	194	2.5	9.5	6.75	N/A	62	143.2

N/A: Not Available

Properties of fresh concrete before the addition of superplasticizers for mixes 9 through 16

		Req 'd		At The PLant						At The Lab						
Mix#	Description	Slump in	Air %	Retarder oz/cwt	A/E Dose oz/cwt	Slump in.	Air %	Concrete Temp.°F	Time Of Batch	Time of Arrival	Air Temp (°F)	Rel.Hum %	Slump in.	Air %	Concrete Temp.°F	Unit Wt. lb/cu.ft
9	5 Sks Gravel 300R, 400N	1-2	4-6	5.0	0.72	1	4	86	9:45 am	10:37 am	86	64	0	1.5	91	147.1
10	7 Sks Gravel 300R,400N	1-2	4-6	5.0	0.76	1.5	3.75	88	9:23 am	10:14 am	85	68	3.5	3.75	89	148.1
11	5 Sks Limestone 300R,400N	1-2	4-6	5.2	0.99	1.25	3.75	85	10:04 am	11:15 am	86	62	1	1.75	90	145.3
12	7 Sks Limestone 300R,400N	1-2	4-6	3.8	1.18	3	4.5	86	9:41 am	10:44 am	86	59	2	2	89	144.5
13	7 Sks Limestone 300R,400N	1-2	4-6	5.1	1.38	1.25	3.5	86	11:18 am	12:20 pm	92	56	0	2.25	91	146.8
14	5 Sks Gravel Rheobuild716	1-2	4-6	0.0	1.13	1.75	5	87	10:01 am	10:48 am	88	64	N/A	N/A	N/A	N/A
15	5 Sks Gravel Daracem 100	1-2	4-6	0.0	1.03	1.25	4	87	10:19 am	11:09 am	88	64	N/A	N/A	N/A	N/A
16	5 Sks Gravel 300R,400N	2-3	6-8	5.0	1.77	3.5	8.75	88	8:46 am	9:00 am	78	N/A	N/A	N/A	N/A	N/A

N/A: Not Available

Properties of fresh concrete after the first and second addition of superplasticizer for mixes 9 through 16

	1st Dosage of Superplasticizer												2nd Dosage of Superplasticizer											
Mix#	Dosage oz/cwt	No. of Additions	Time	Elapsed Time(min)	Slump (in)		Air %		Concrete Temp.°F	Unit Wt. lb/cu.ft	Dosage oz/cwt	No. of Additions	Time	Elapsed Time(min)	Slump (in)		Air %		Concrete Temp.°F	Unit Wt. lb/cu.ft
					From	To	From	To							From	To	From	To		
9	30	2	11:00 am	85	0	8.5	1.5	2.5	93	149.06	15	1	12:00 pm	135	3.5	9.25	2	1.25	94	150.8
10	15	1	10:38 am	75	3.5	8.25	3.75	2.5	92	149.79	15	1	12:07 pm	164	2.5	9.25	1.5	1.25	97	152.3
11	27	2	11:35 am	102	1	8	1.75	1.5	93	148.22	15	1	12:30 pm	146	2.75	9.5	1.75	1	95	148
12	17	1	10:51 am	70	2	10	2	3.25	89	148.76	0	NONE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
13	20	1	12:24 pm	66	0	8.5	2.25	2.25	94	147.3	15	1	2:15 pm	177	2.5	8.5	1.75	1.5	97.5	148.8
14	15.8	1	10:16 am	15	1.8	9.25	5	5.5	88	143.26	0	NONE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
15	12.7	1	10:34 am	15	1.3	9	4	5	88	143.18	0	NONE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
16	18	1	9:16 am	30	3.5	9.5	8.75	5.5	88	N/A	10.1	2	11:36 am	185	6.5	7.5	4	2.25	96	N/A

N/A: Not Available

Properties of fresh concrete before the addition of superplasticizers for mixes L1 through L9

		Req 'd		At The PLant					At The Lab						
Mix#	Description	Slump in.	Air %	Retarder (oz/cwt)	Slump in.	Air %	Concrete Temp. °F	Time Of Batch	Time of Arrival	Air Temp (°F)	Rel.Hum %	Slump in.	Air %	Concrete Temp. °F	Unit Wt. lb/cu.ft
L1	5 Sks Gravel 300R, 400N	1-2	4-6	3.0	N/A	N/A	N/A	1:00 pm	1:30 pm	90	53	2	4	88	146.1
L2	•	4-6	4-6	3.0	5	•	•	12:55 pm	1:37 pm	87	62	3	4.75	90	144
L3	5 Sks Limestone 300R, 400N	1-2	4-6	3.0	2.5	•	•	2:48 pm	3:32 pm	90	62	1.5	4.25	93	143.7
L4	•	6-7	4-6	3.0	7	•	•	1:22 pm	2:11 pm	90	58	4	4.5	90	141.7
L5	•	4-5	4-6	3.0	4	•	•	1:16 pm	2:12 pm	90	57	1.75	4	91	145.4
L6	5 Sks Gravel 3/4"Gravel	4-5	4-6	5.0	4	•	•	12:35 pm	1:16 pm	91	54	2.5	5	91	143.3
L7	•	1-2	4-6	5.0	1	•	•	12:23 pm	1:00 pm	93	53	0.75	4	94	147.2
L8	7 Sks Gravel 300R, 400N	1-2	4-6	3.0	1.5	•	•	1:30 pm	2:14 pm	90	40	0	1.75	91	143.5
L9	5 Scks,Gravel Micro Air	1-2		3.0	1.5	•	•	12:48 pm	1:46 pm	90	54	3	6	89	142.1

N/A: Not Available

Properties of fresh concrete after the first and second addition of superplasticizers for mixes L1 through L9

	1st Dosage of Superplasticizer										2nd Dosage of Superplasticizer									
Mix #	Dosage oz/cwt	No. of Additions	Time	Elapsed Time(min)	Slump (in		Air %		Concrete Temp.°F	Unit Wt. lb/cu.ft	Dosage oz/cwt	No. of Additions	Time	Elapsed Time(min)	Slump (in		Air %		Concrete Temp.°F	Unit Wt. lb/cu.ft
					From	To	From	To							From	To	From	To		
L1	18	2	1:50 pm	50	2	8	4	1.75	92	150.7	10	1	2:50 pm	99	5.75	8.5	1.75	1.25	94	151.6
L2	10	1	1:50 pm	55	3	9	4.75	2	91	149	10	1	2:56 pm	121	6	8.75	2.75	1	92	150.6
L3	17	1	3:44 pm	56	1.5	8	4.25	2.75	94	147.5	12.3	1	4:34 pm	106	4	8.75	1.5	0.75	95	149.3
L4	10	1	2:20 pm	58	4	9	4.5	3	90	144.1	10	1	3:17 pm	115	4	9.5	2.75	1.5	93	146.4
L5	14	1	2:19 pm	63	1.75	8.75	4	1.25	92	148.5	14	1	3:16 pm	120	2	9	1.75	1	94.5	149.6
L6	12	1	1:28 pm	67	2.5	8.5	5	3.75	92	146.8	8	1	2:28 pm	127	5.75	8	3.25	2	95	149.5
L7	20	2	1:16 pm	53	0.75	8.5	4	2.5	97	150	15.4	1	2:17 pm	95	3.75	8.75	2.5	1.5	99.5	150.9
L8	24.2	3	2:28 pm	57	0	8	1.75	2.5	96	149.1	14	1	3:21 pm	90	3	9.75	2.5	2.5	96	149.5
L9	15	1	1:53 pm	65	3	9	6	5	89	144.9	9	1	3:06 pm	138	4.25	8	5	2.25	92	148.8

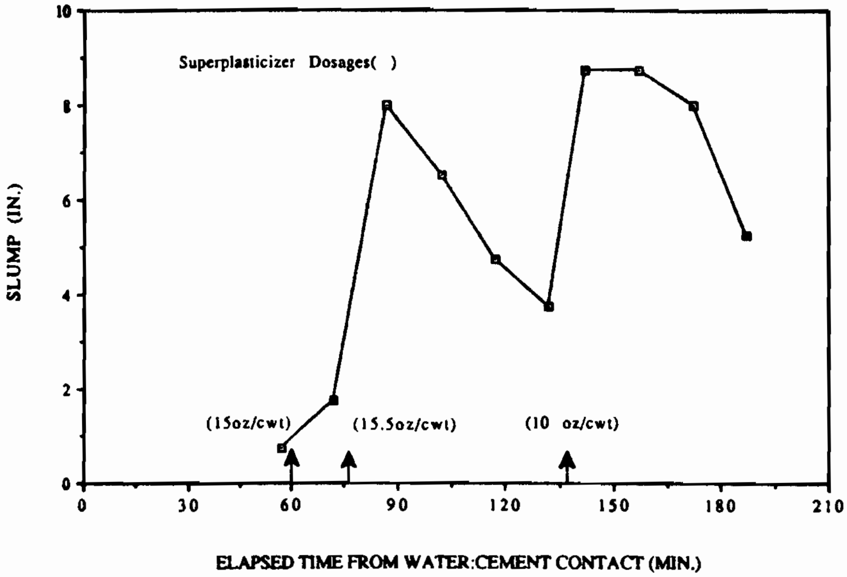
N/A: Not Available

APPENDIX B1

Change in Slump with Time for All Mixes

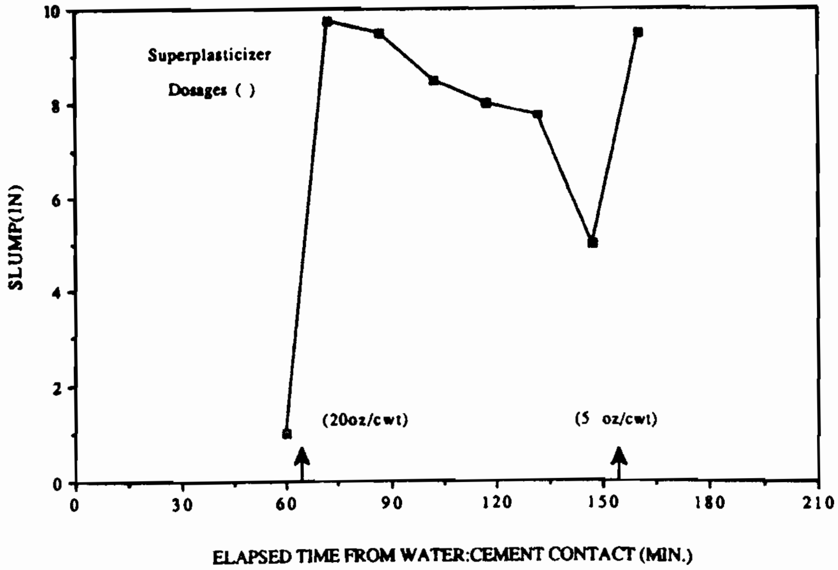
CHANGE IN SLUMP VS. TIME

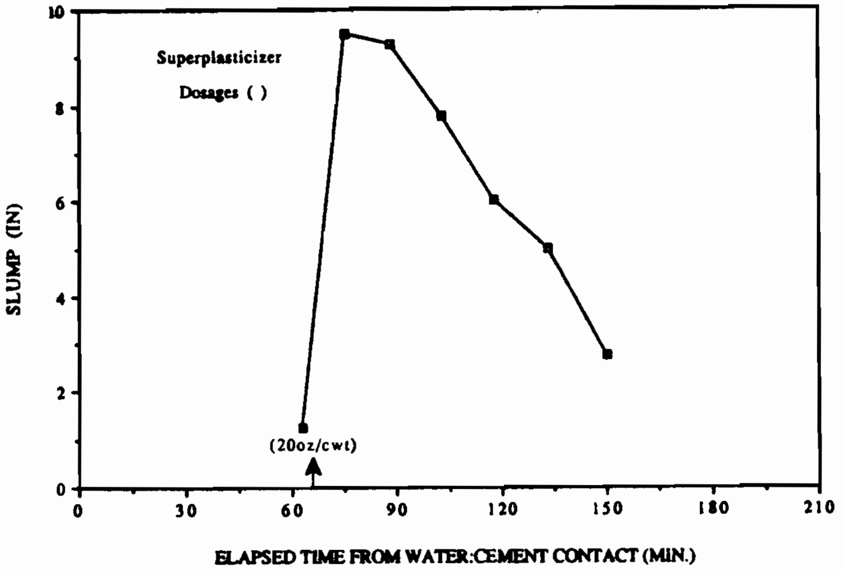
Mix 2: 5 Sks,3/4"Gravel,No Retarder,MB 400N SUPER



CHANGE IN SLUMP VS. TIME

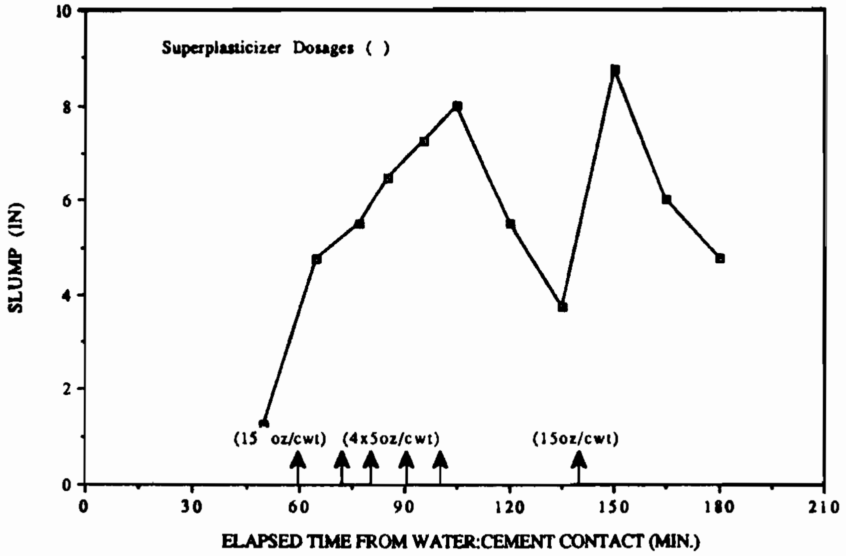
Mix 3: 7 Sks,3/4"Gravel,300R Retarder,MB 400N SUPER





CHANGE IN SLUMP VS. TIME

Mix 4: 7 Sks,3/4"Gravel,No Retarder,MB 400N SUPER

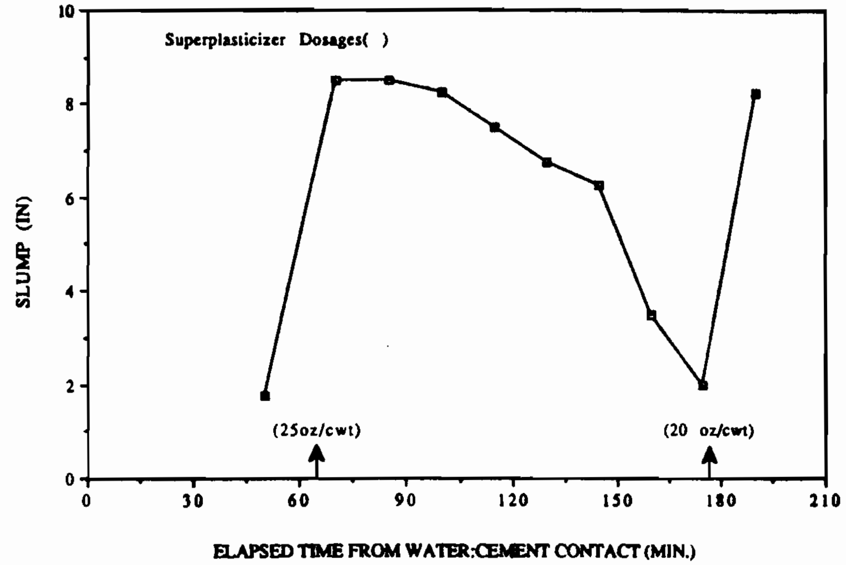


CHANGE IN SLUMP VS. TIME

Mix 5: 5 Sks,3/4"Gravel,300R Retarder,MELMENT L10 SUPER

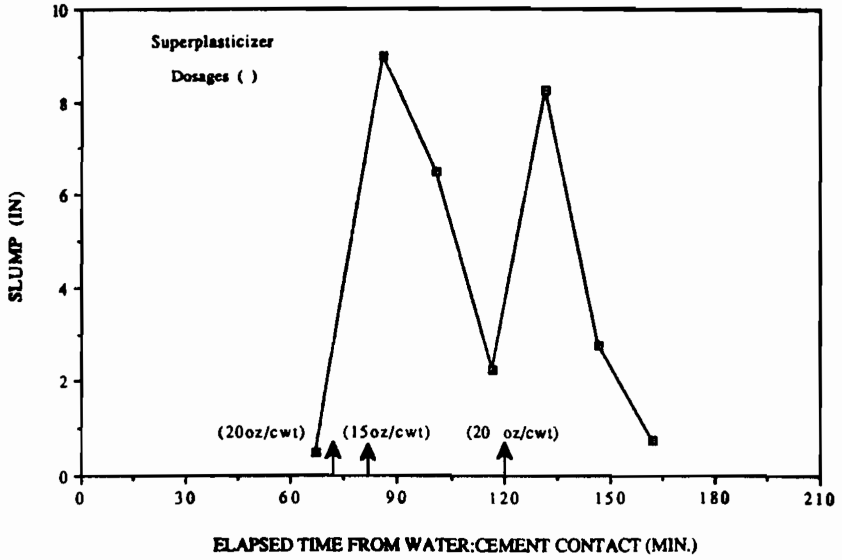
CHANGE IN SLUMP VS. TIME

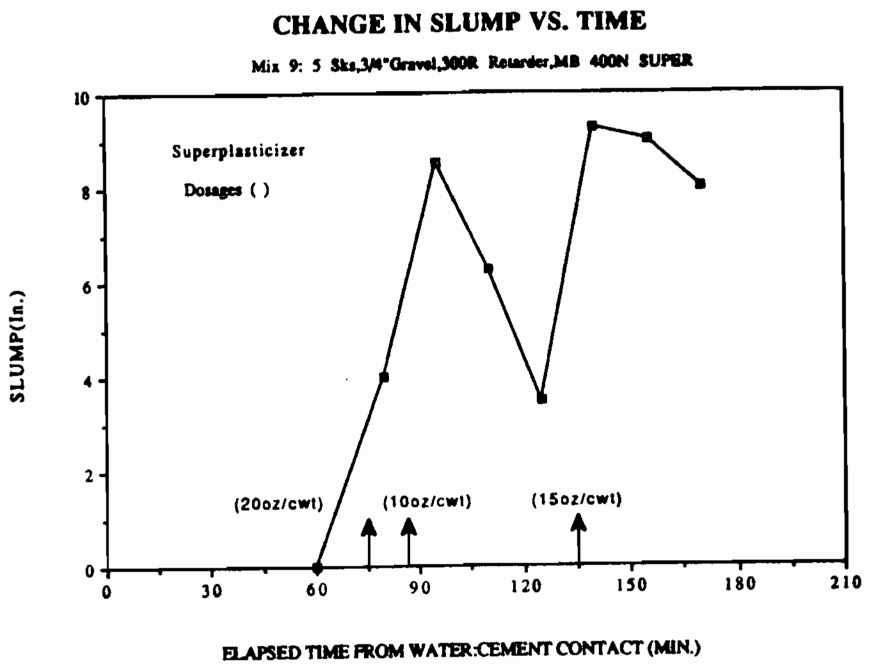
Mix 6: 5 Sks,3/4"Gravel,No Retarder,MELMENT L10 SUPER



CHANGE IN SLUMP VS. TIME

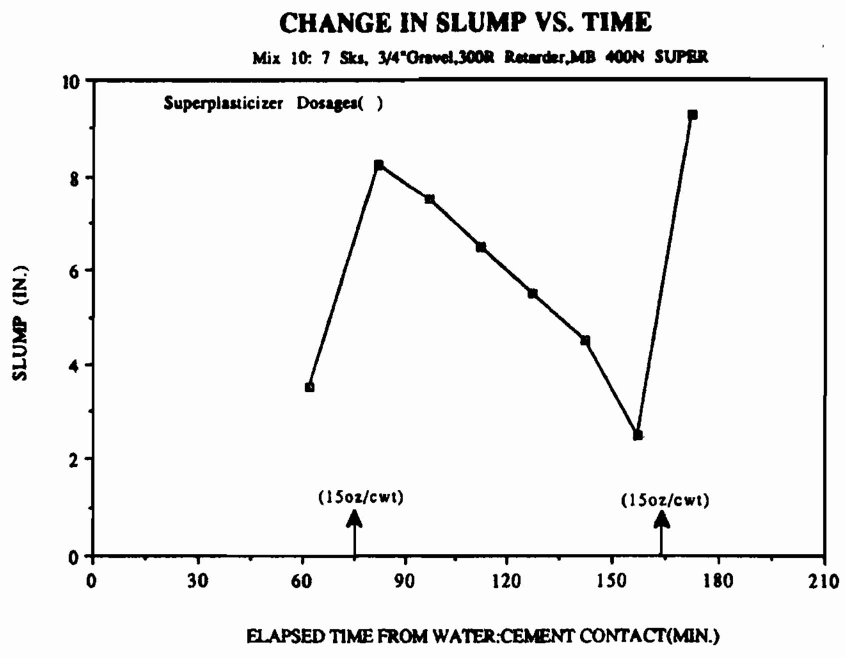
Mix 7: 7 Sks,3/4"Gravel,No Retarder,MELMENT L10 SUPER





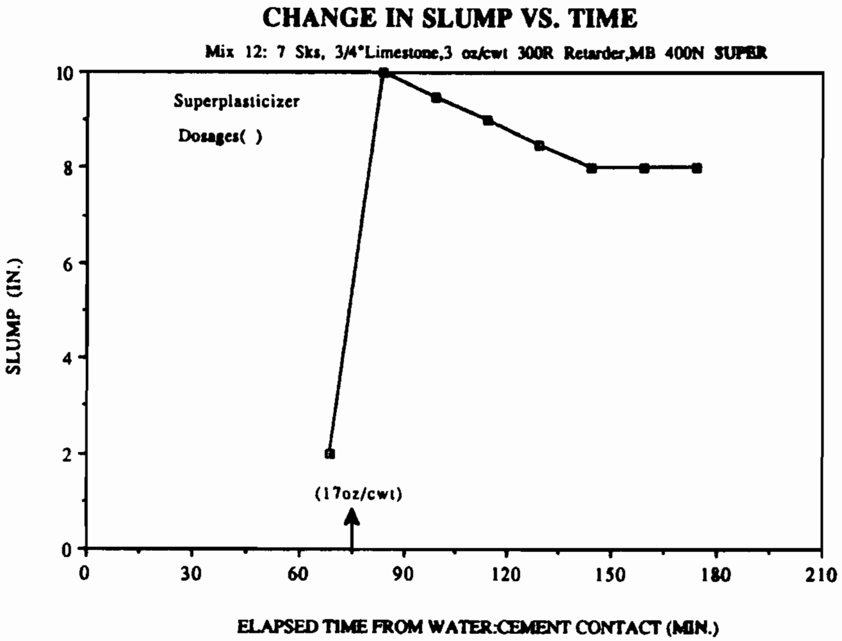
CHANGE IN SLUMP VS. TIME

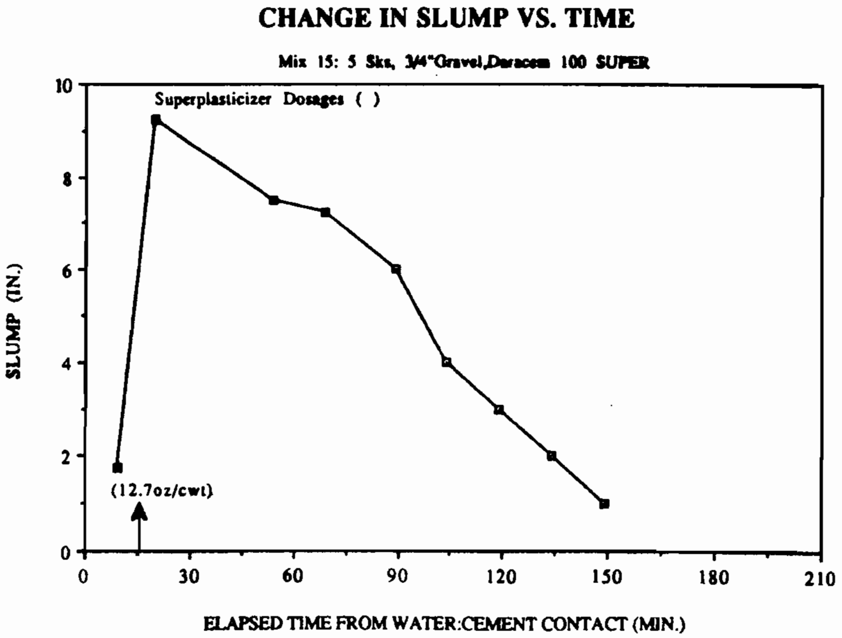
Mix 9: 5 Sks,3/4"Gravel,300R Retarder,MB 400N SUPER



CHANGE IN SLUMP VS. TIME

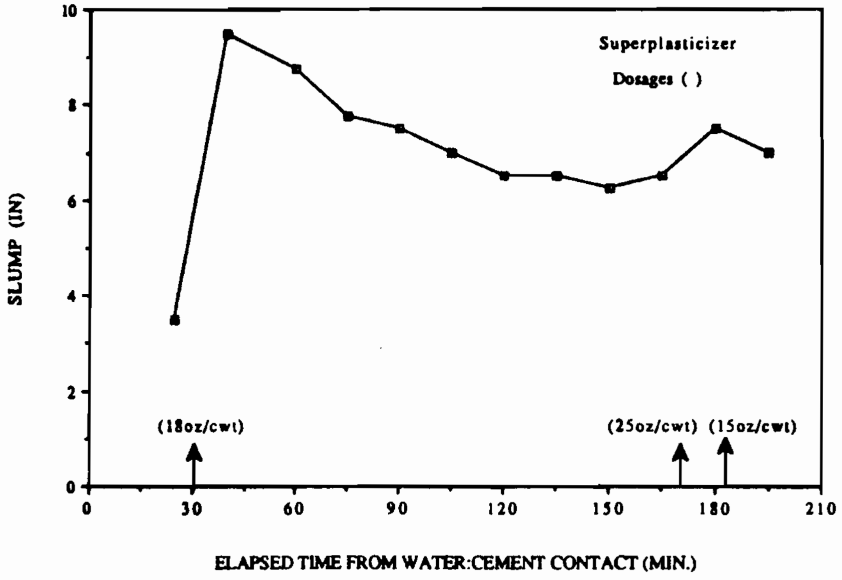
Mix 10: 7 Sks, 3/4"Gravel,300R Retarder,MB 400N SUPER


CHANGE IN SLUMP VS. TIME
Mix 12: 7 Sks, 3/4"Limestone,3 oz/cwt 300R Retarder,MB 400N SUPER
Superplasticizer
Dosages( )
(17oz/cwt)
SLUMP (IN.)
0
2
4
6
8
10
0
30
60
90
120
150
180
210
ELAPSED TIME FROM WATER:CEMENT CONTACT (MIN.)


CHANGE IN SLUMP VS. TIME
Mix 15: 5 Sks, 3/4"Gravel,Daracem 100 SUPER
Superplasticizer Dosages ( )
(12.7oz/cwt)
SLUMP (IN.)
0
2
4
6
8
10
0
30
60
90
120
150
180
210
ELAPSED TIME FROM WATER:CEMENT CONTACT (MIN.)

CHANGE IN SLUMP VS. TIME

Mix 16: 5 Sks,3/4"Gravel,300R Retarder,MB 400N SUPER

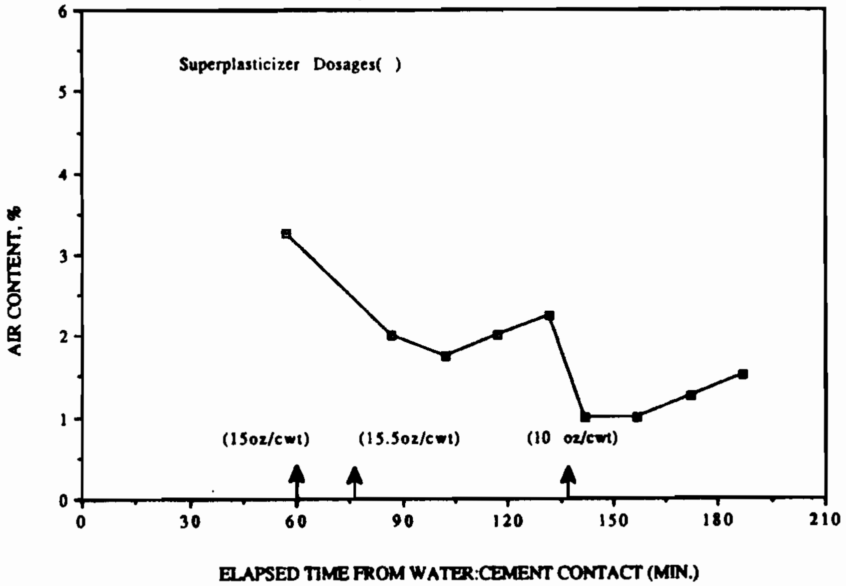


APPENDIX B2

Change in Air Content with Time for All Mixes

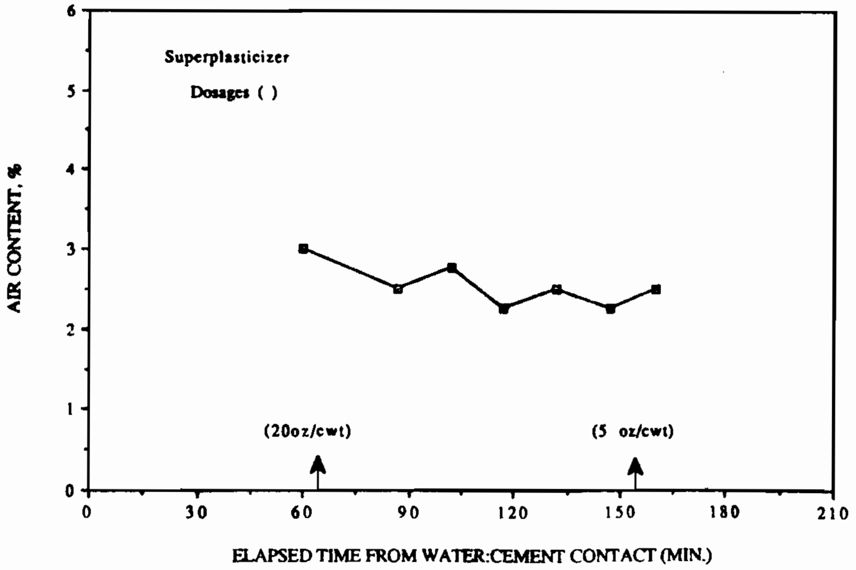
CHANGE IN AIR CONTENT VS. TIME

Mix 2: 5 Sks,3/4"Gravel,No Retarder,MB 400N SUPER



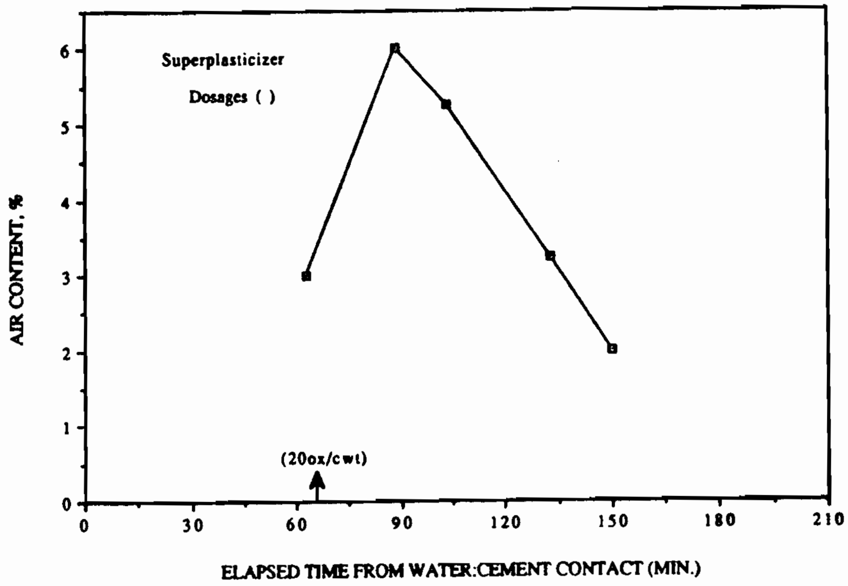
CHANGE IN AIR CONTENT VS. TIME

Mix 3: 7 Sks,3/4"Gravel,300R Retarder,MB 400N SUPER



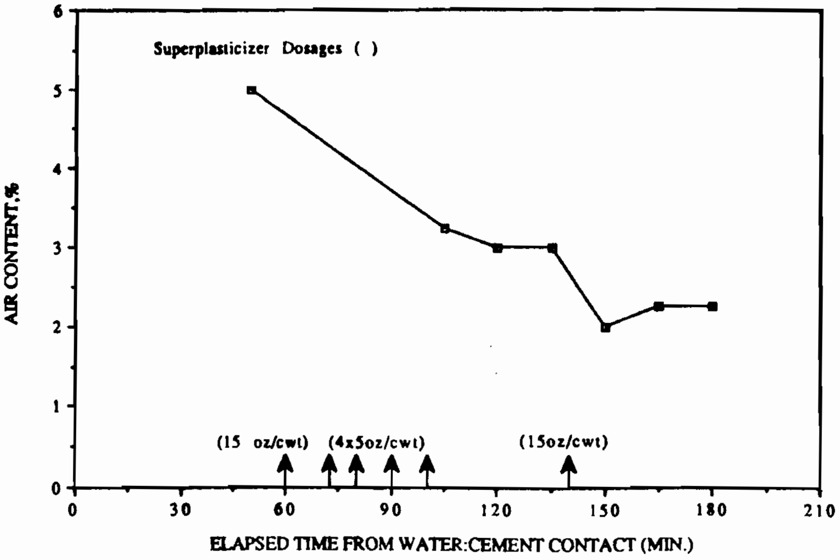
CHANGE IN AIR CONTENT VS. TIME

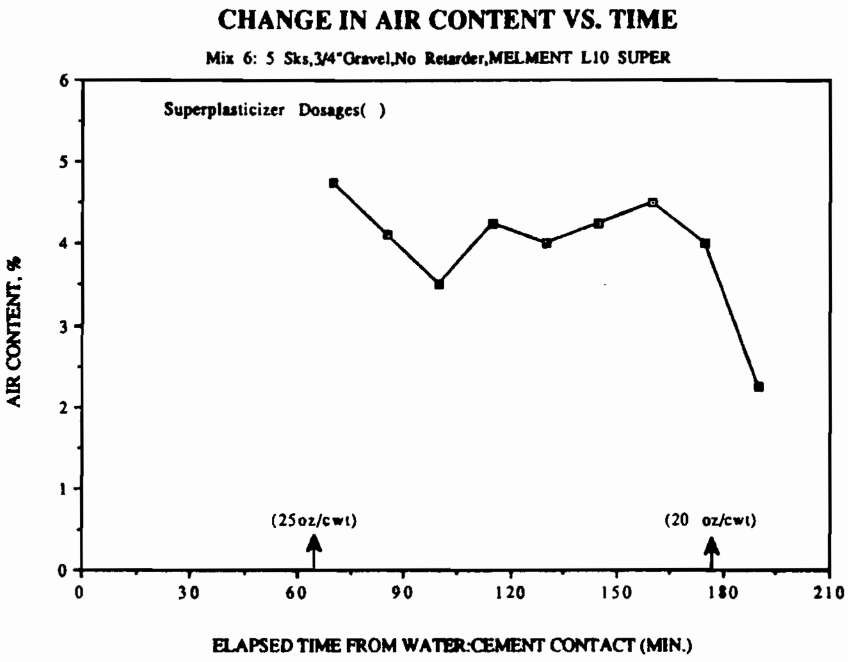
Mix 4: 7 Sks,3/4"Gravel,No Retarder,MB 400N SUPER

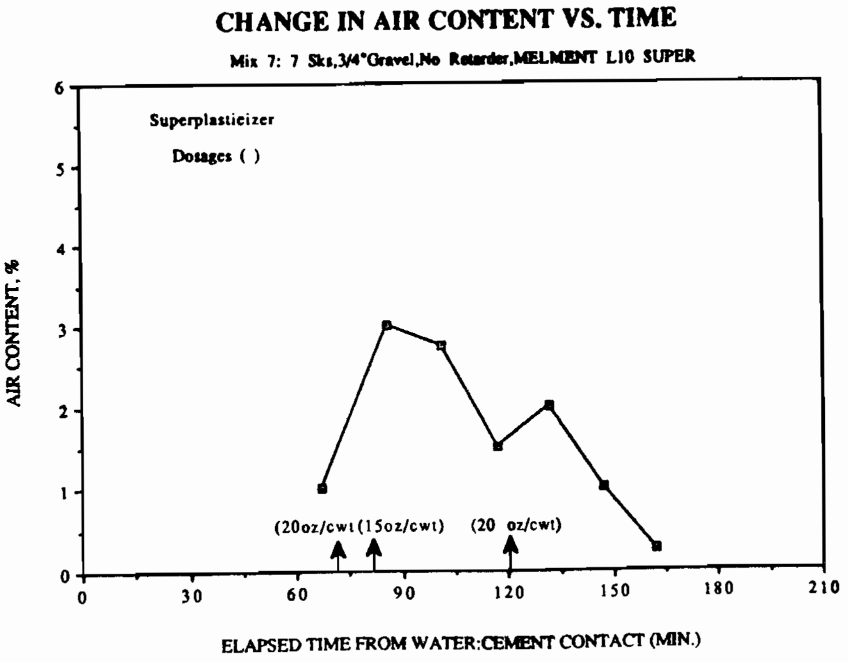


CHANGE IN AIR CONTENT VS. TIME

Mix 5: 5 Sks,3/4"Gravel,300R Retarder,MELMENT L10 SUPER

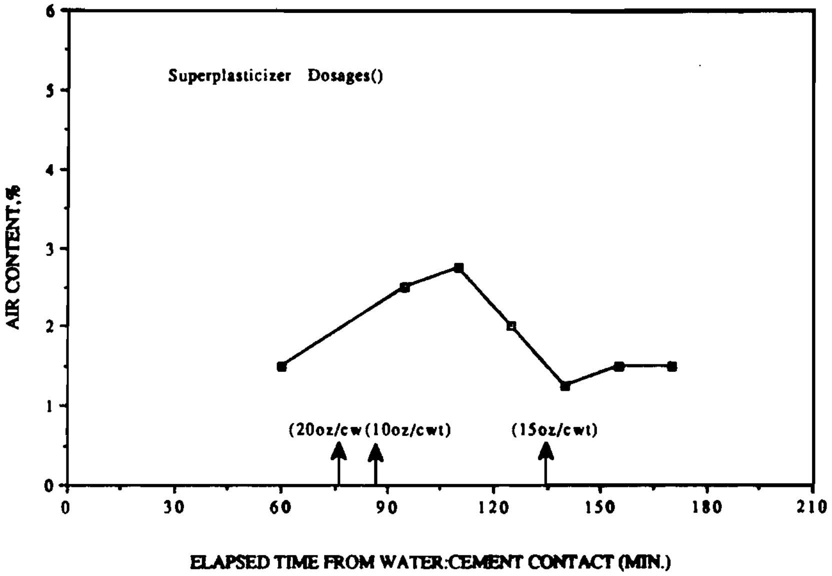



CHANGE IN AIR CONTENT VS. TIME
Mix 6: 5 Sks,3/4"Gravel,No Retarder,MELMENT L10 SUPER
Superplasticizer Dosages( )
(25oz/cwt)
(20 oz/cwt)
AIR CONTENT, %
0
1
2
3
4
5
6
0
30
60
90
120
150
180
210
ELAPSED TIME FROM WATER:CEMENT CONTACT (MIN.)


CHANGE IN AIR CONTENT VS. TIME
Mix 7: 7 Sks,3/4"Gravel,No Retarder,MELMENT L10 SUPER
Superplasticizer
Dosages ( )
(20oz/cwt
(15oz/cwt)
(20 oz/cwt)
AIR CONTENT, %
0
1
2
3
4
5
6
0
30
60
90
120
150
180
210
ELAPSED TIME FROM WATER:CEMENT CONTACT (MIN.)

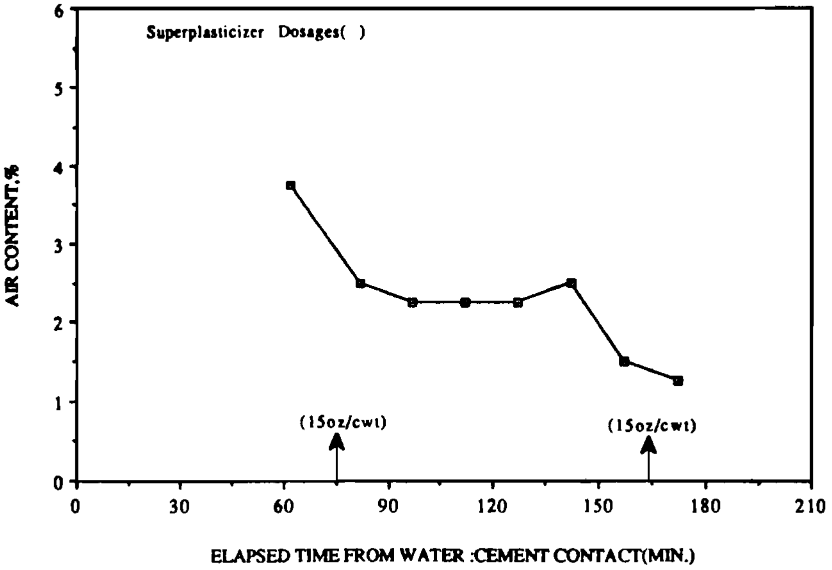
CHANGE IN AIR CONTENT VS. TIME

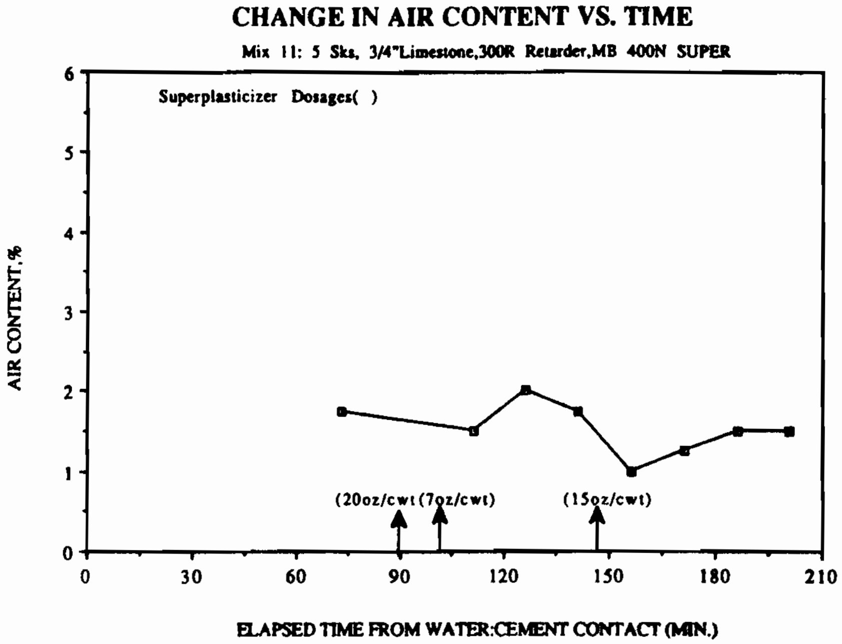
Mix 9: 5 Sks,3/4"Gravel,300R Retarder,MB 400N SUPER



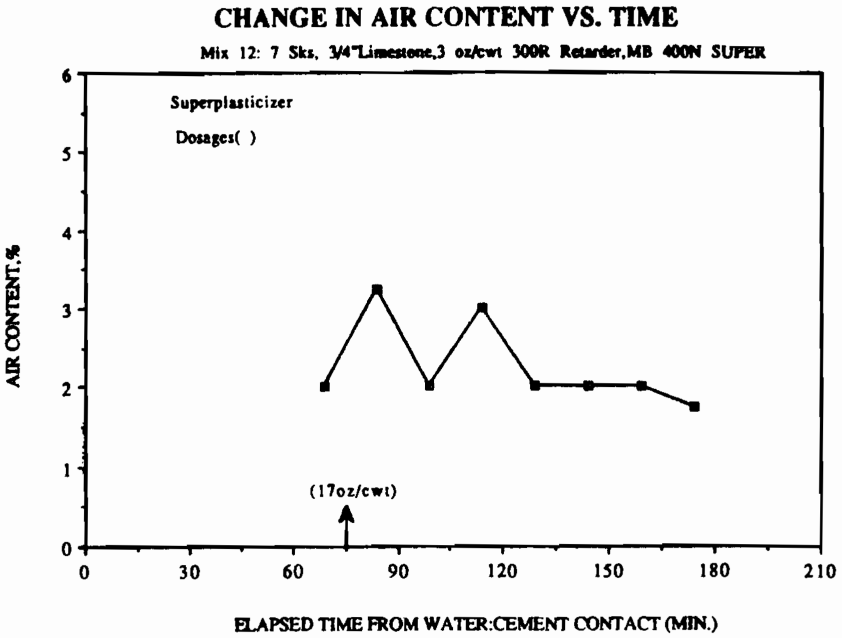
CHANGE IN AIR CONTENT VS. TIME

Mix 10: 7 Sks, 3/4"Gravel,300R Retarder,MB 400N SUPER

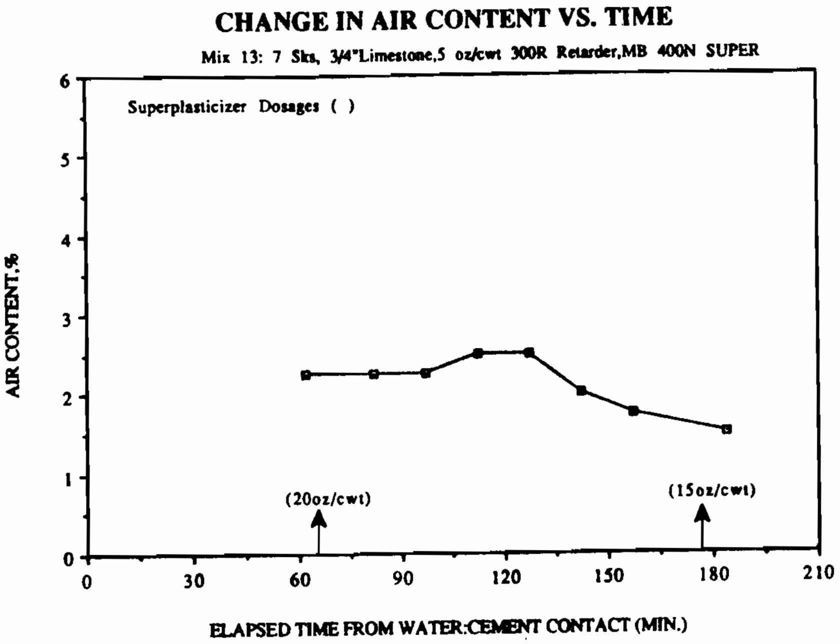


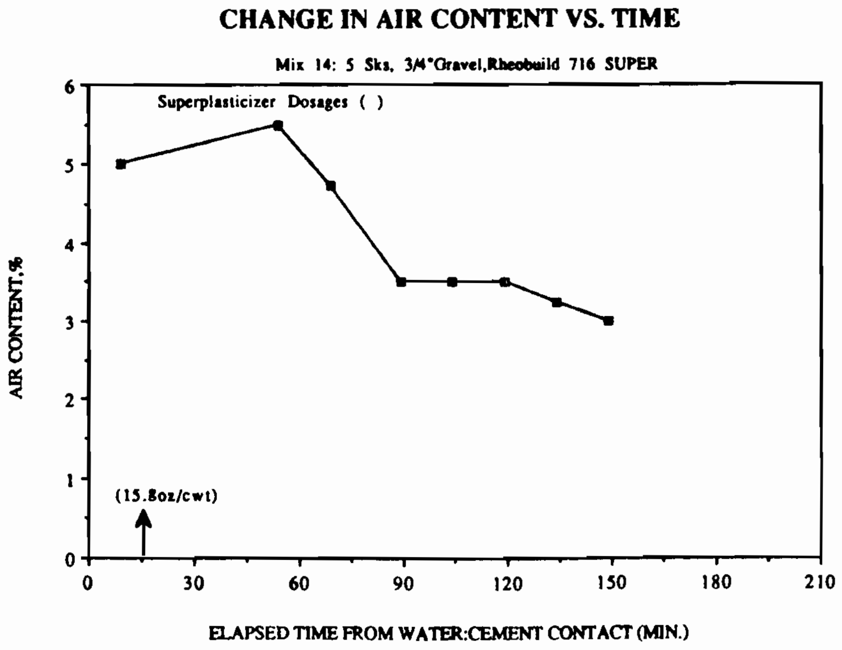

CHANGE IN AIR CONTENT VS. TIME

Mix 11: 5 Sks. 3/4"Limestone,300R Retarder,MB 400N SUPER


CHANGE IN AIR CONTENT VS. TIME

Mix 12: 7 Sks. 3/4"Limestone,3 oz/cwt 300R Retarder,MB 400N SUPER


CHANGE IN AIR CONTENT VS. TIME
Mix 13: 7 Sks, 3/4"Limestone,5 oz/cwt 300R Retarder,MB 400N SUPER
Superplasticizer Dosages ( )
(20oz/cwt)
(15oz/cwt)
AIR CONTENT,%
0
1
2
3
4
5
6
0
30
60
90
120
150
180
210
ELAPSED TIME FROM WATER:CEMENT CONTACT (MIN.)

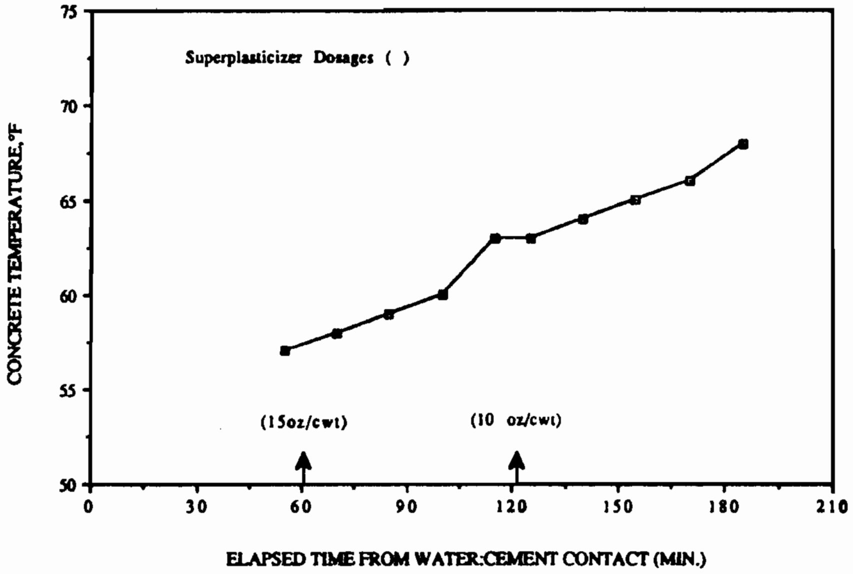

CHANGE IN AIR CONTENT VS. TIME
Mix 14: 5 Sks, 3/4"Gravel,Rheobuild 716 SUPER
Superplasticizer Dosages ( )
(15.8oz/cwt)
AIR CONTENT,%
0
1
2
3
4
5
6
0
30
60
90
120
150
180
210
ELAPSED TIME FROM WATER:CEMENT CONTACT (MIN.)

APPENDIX B3

Change in Concrete Temperature with Time for All Mixes

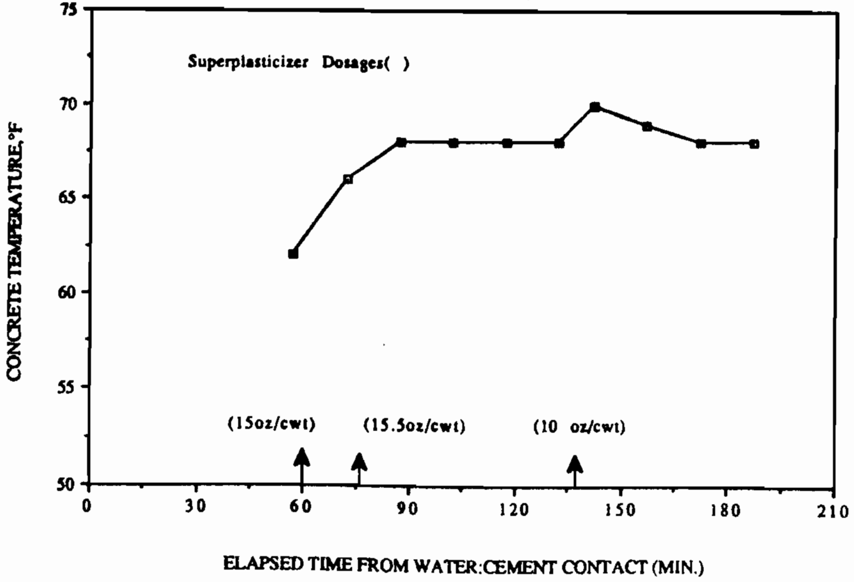
CHANGE IN CONCRETE TEMPERATURE VS. TIME

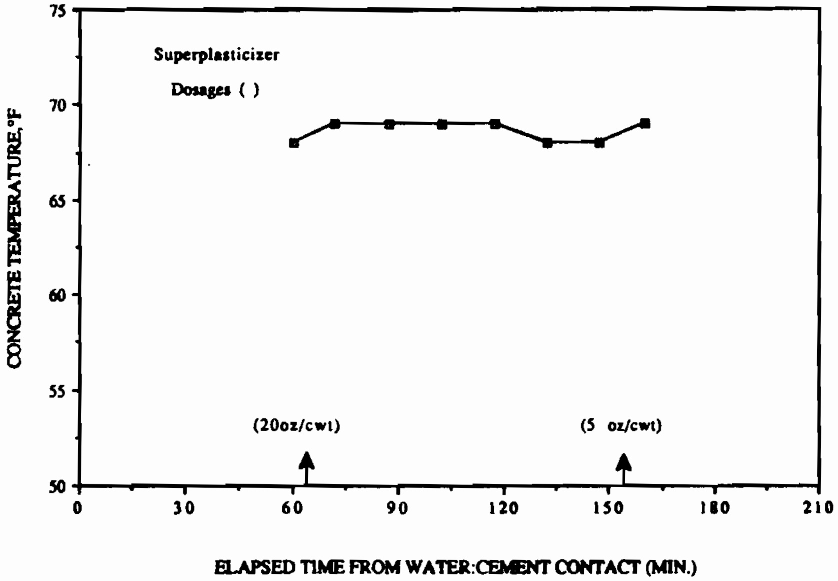
Mix 1: 5 Sks,3/4"Gravel,300R Retarder,MB 400N SUPER



CHANGE IN CONCRETE TEMPERATURE VS. TIME

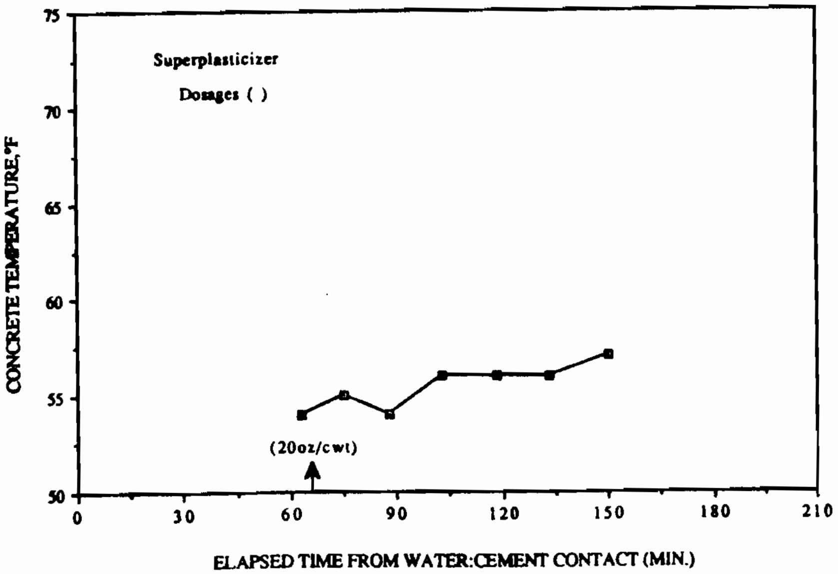
Mix 2: 5 Sks,3/4"Gravel,No Retarder,MB 400N SUPER





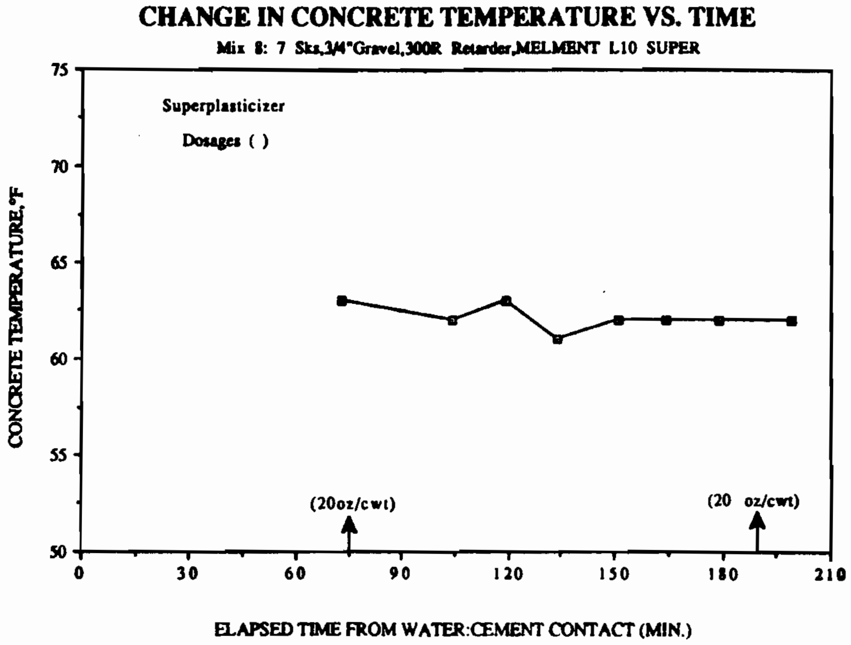
CHANGE IN CONCRETE TEMPERATURE VS. TIME

Mix 3: 7 Sks,3/4"Gravel,300R Retarder,MB 400N SUPER



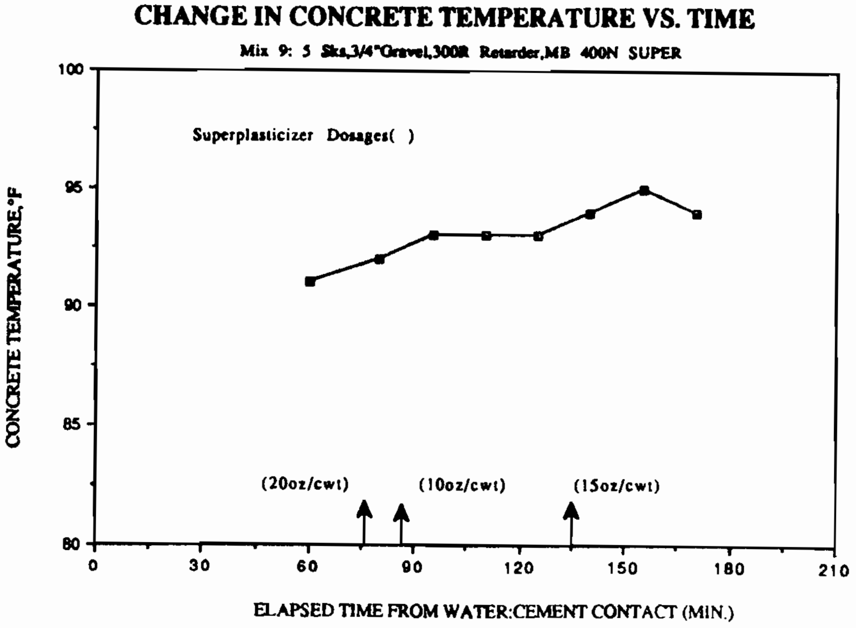
CHANGE IN CONCRETE TEMPERATURE VS. TIME

Mix 4: 7 Sks,3/4"Gravel,No Retarder,MB 400N SUPER



CHANGE IN CONCRETE TEMPERATURE VS. TIME

Mix 8: 7 Sks,3/4"Gravel,300R Retarder,MELMENT L10 SUPER

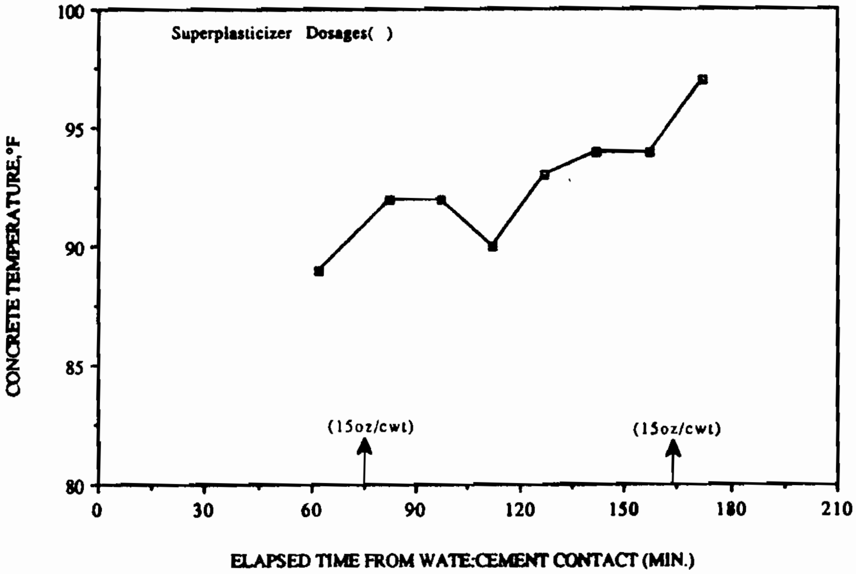


CHANGE IN CONCRETE TEMPERATURE VS. TIME

Mix 9: 5 Sks,3/4"Gravel,300R Retarder,MB 400N SUPER

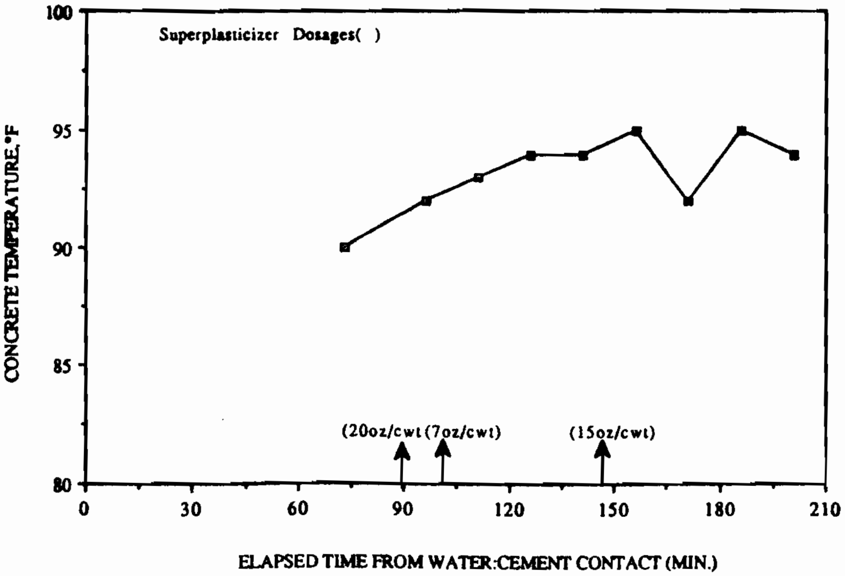
CHANGE IN CONCRETE TEMPERATURE VS. TIME

Mix 10: 7 Sks, 3/4"Gravel,300R Retarder,MB 400N SUPER



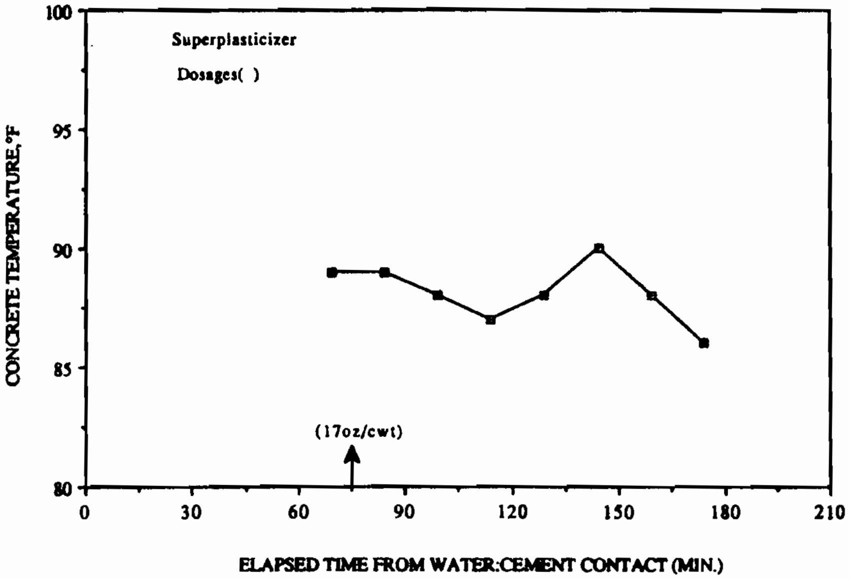
CHANGE IN CONCRETE TEMPERATURE VS. TIME

Mix 11: 5 Sks, 3/4"Limestone,300R Retarder,MB 400N SUPER



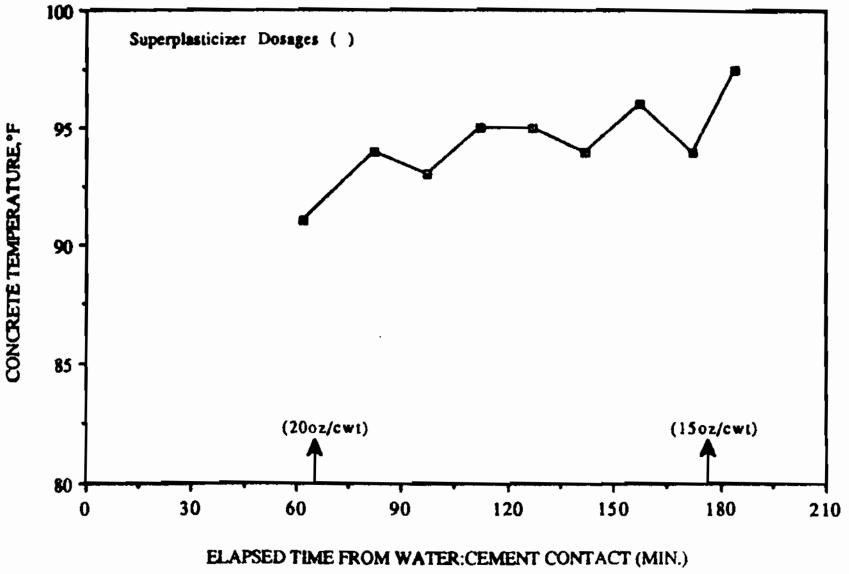
CHANGE IN CONCRETE TEMPERATURE VS. TIME

Mix 12: 7 Sks, 3/4"Limestone,3 oz/cwt 300R Retarder,MB 400N SUPER

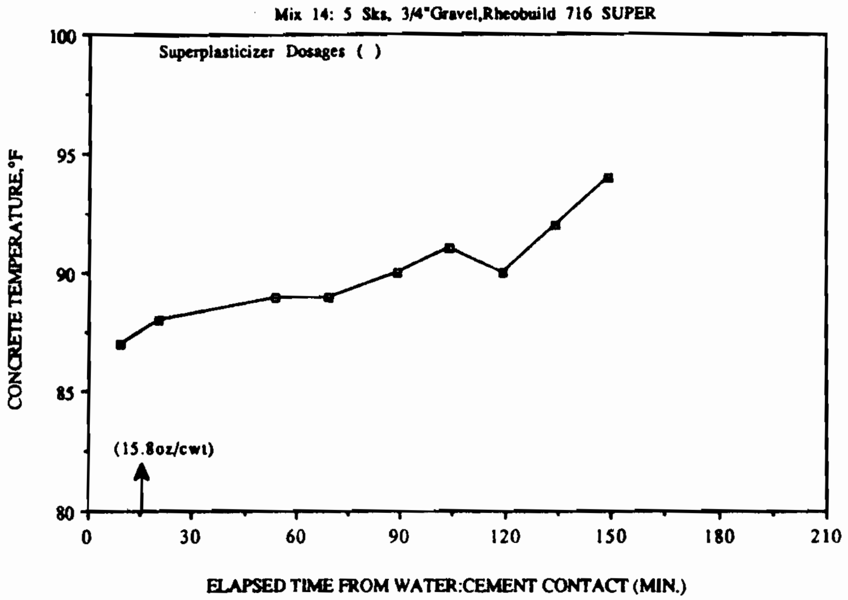


CHANGE IN CONCRETE TEMPERATURE VS. TIME

Mix 13: 7 Sks, 3/4"Limestone,5 oz/cwt 300R Retarder,MB 400N SUPER



CHANGE IN CONCRETE TEMPERATURE VS. TIME

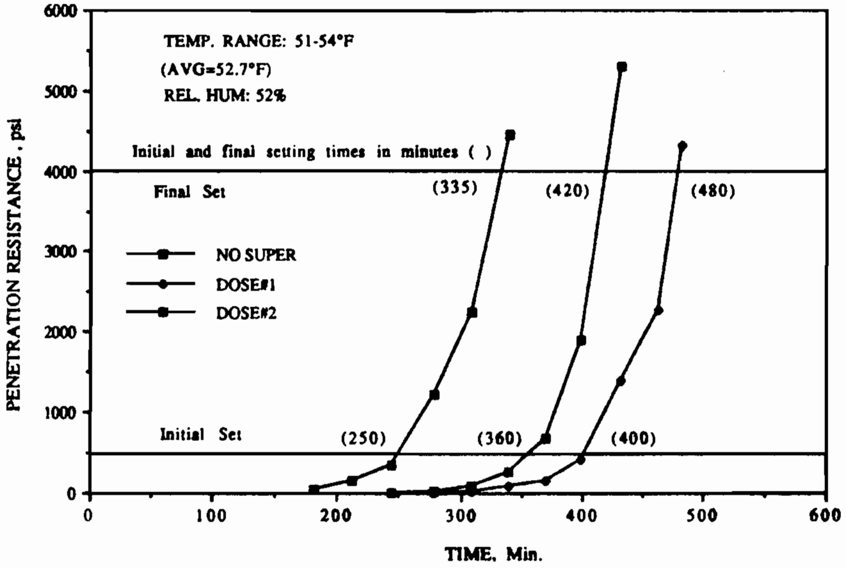


APPENDIX B4

Setting Time Test Data for All Mixes

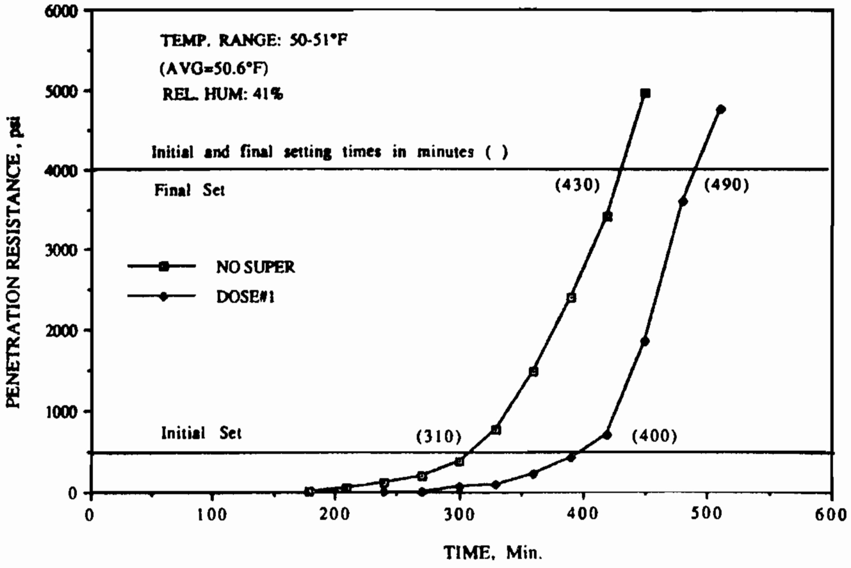
SETTING TIME OF FRESH CONCRETE

MIX 3: 7 Sks,3/4"Gravel,300R Retarder,MB 400N SUPER



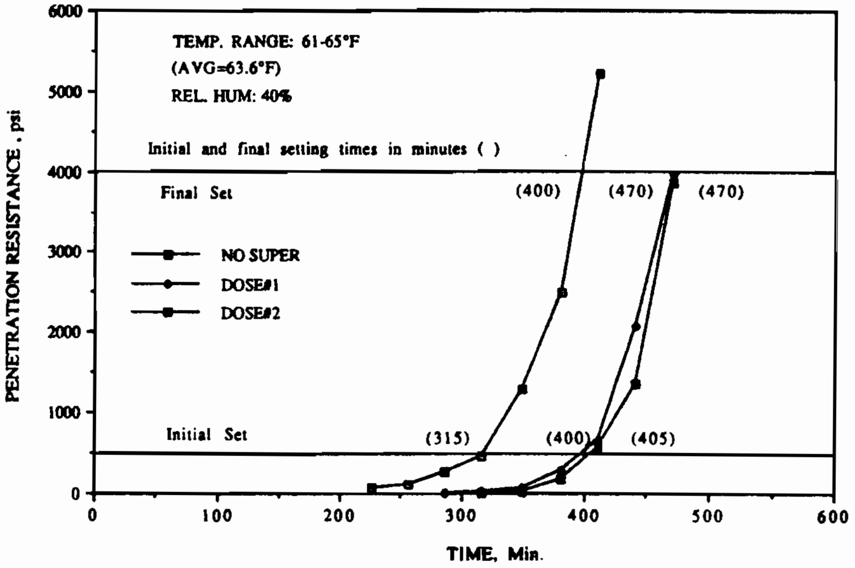
SETTING TIME OF FRESH CONCRETE

MIX 4: 7 Sks,3/4"Gravel,No Retarder,MB 400N SUPER



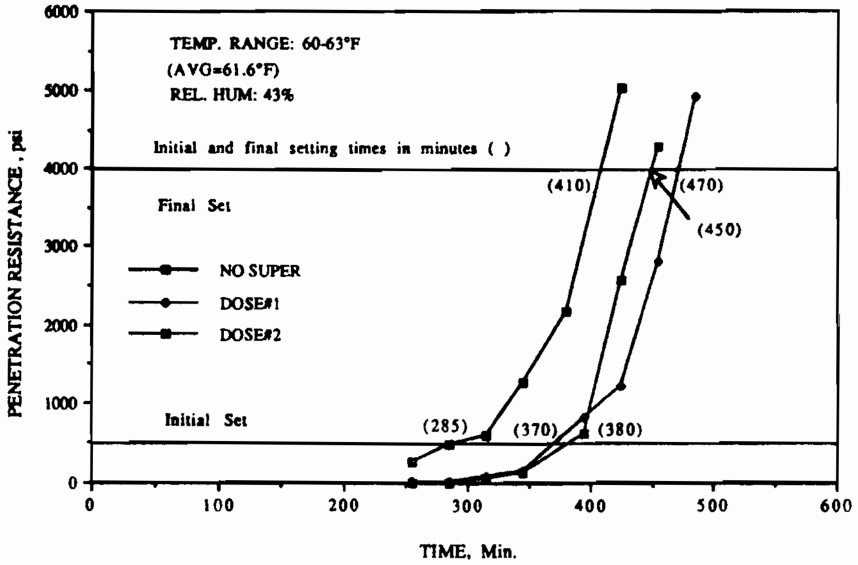
SETTING TIME OF FRESH CONCRETE

MIX 5: 5 Sks,3/4"Gravel,300R Retarder,MELMENT L10 SUPER



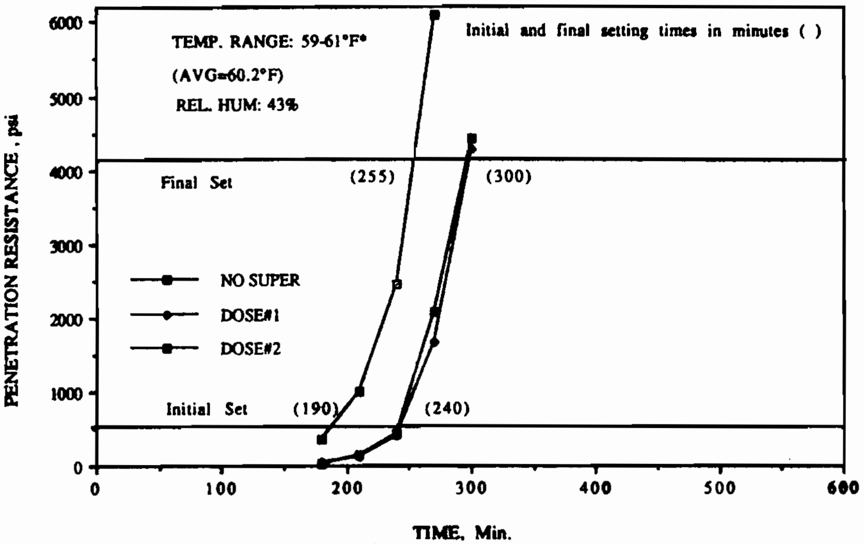
SETTING TIME OF FRESH CONCRETE

MIX 6: 5 Sks,3/4"Gravel,No Retarder,MELMENT L10 SUPER



SETTING TIME OF FRESH CONCRETE

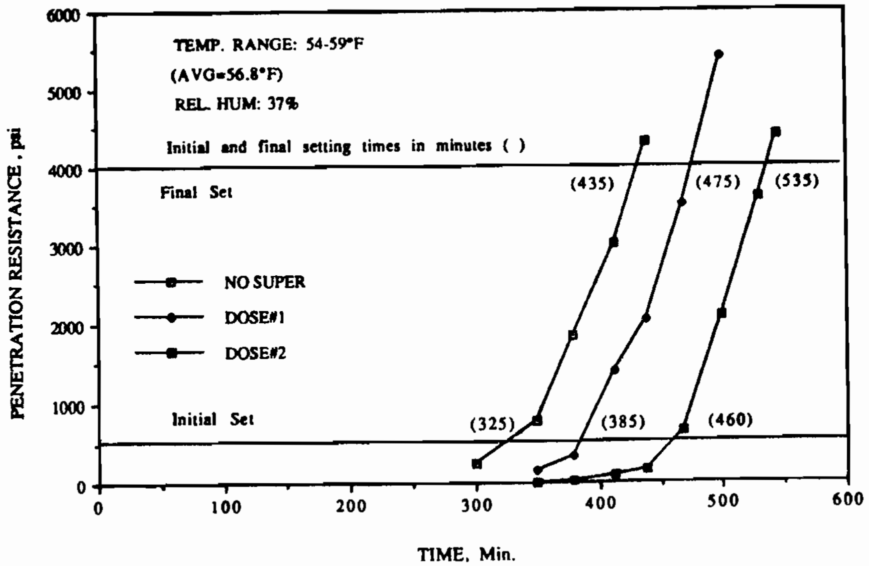
MIX 7: 7 Sks,3/4"Gravel,No Retarder,MELMENT L10 SUPER



* Concrete temperature was about 70°F

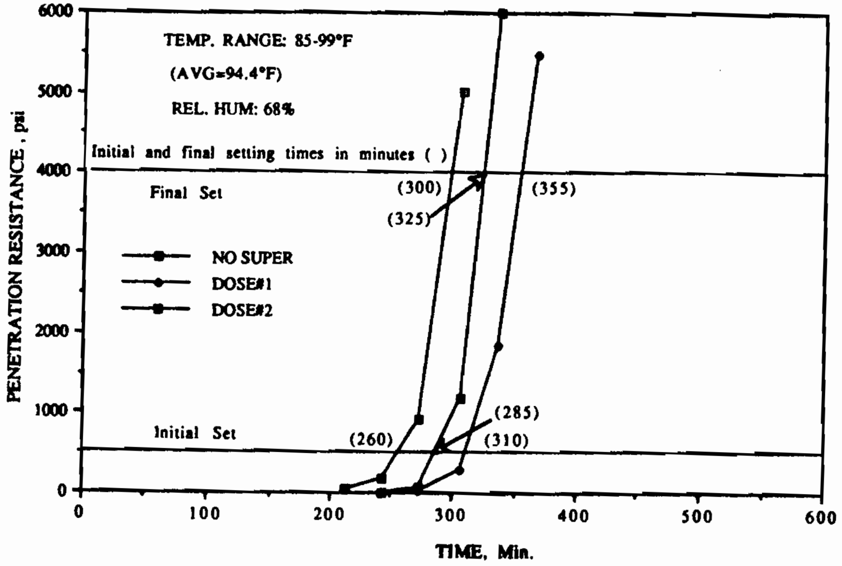
SETTING TIME OF FRESH CONCRETE

MIX 8: 7 Sks,3/4"Gravel,300R Retarder,MELMENT L10 SUPER



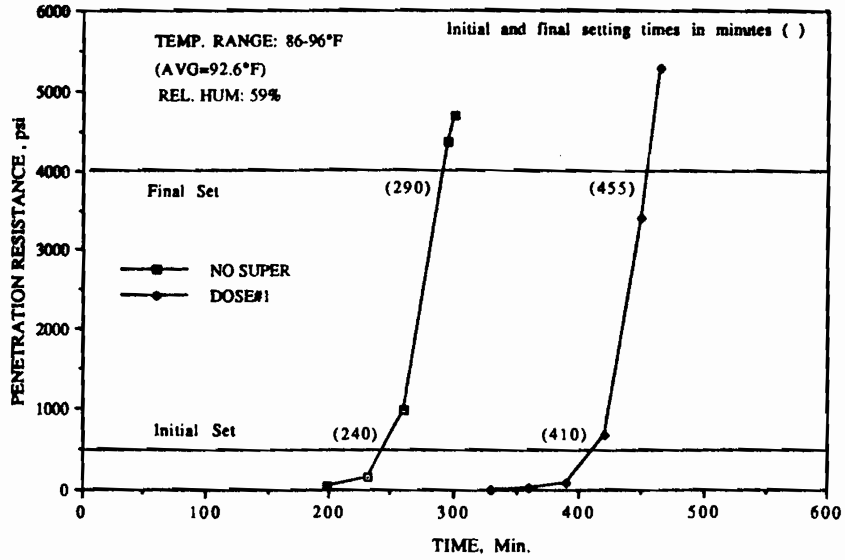
SETTING TIME OF FRESH CONCRETE

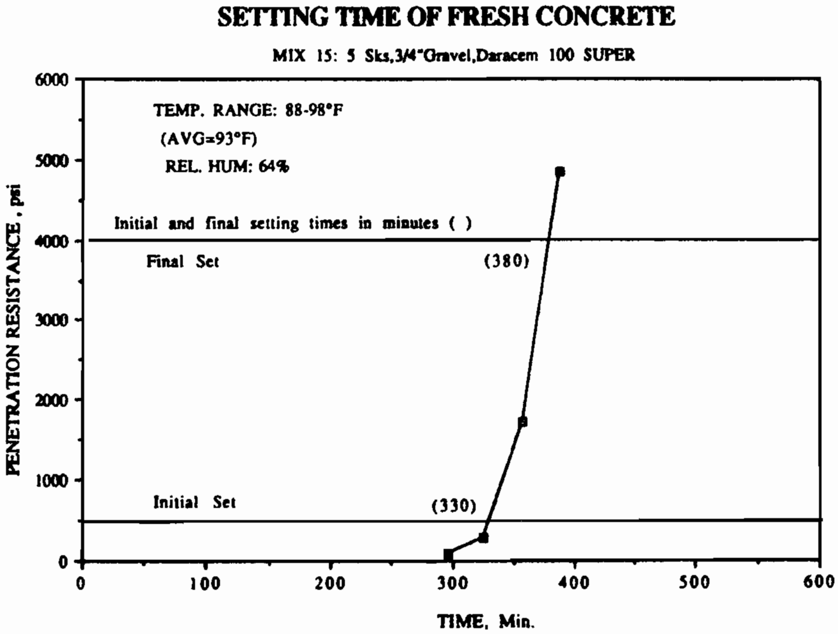
MIX 10: 7 Sks,3/4"Gravel,300R Retarder,MB 400N SUPER



SETTING TIME OF FRESH CONCRETE

MIX 12: 7 Sks,3/4"Limestone,3oz/cwt 300R Retarder,MB 400N SUPER



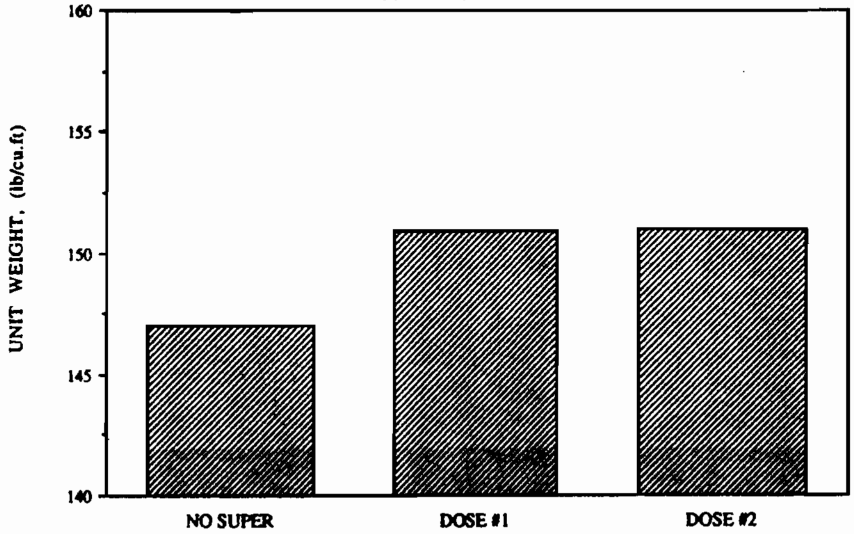

SETTING TIME OF FRESH CONCRETE
MIX 15: 5 Sks,3/4"Gravel,Daracem 100 SUPER
TEMP. RANGE: 88-98°F
(AVG=93°F)
REL. HUM: 64%
Initial and final setting times in minutes ( )
Final Set
(380)
Initial Set
(330)
PENETRATION RESISTANCE, psi
0
1000
2000
3000
4000
5000
6000
0
100
200
300
400
500
600
TIME, Min.

APPENDIX B5

Unit Weight Test Data for All Mixes

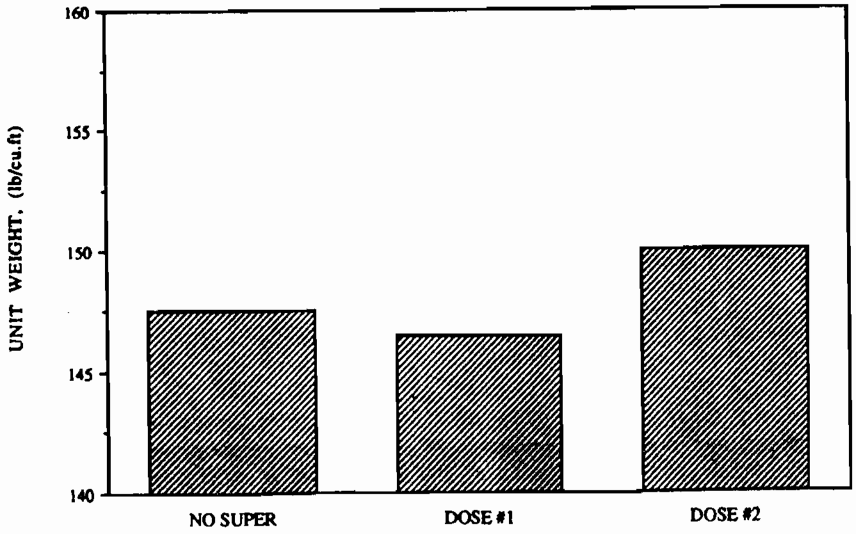
CONCRETE UNIT WEIGHT VS. SUPERPLASTICIZER DOSAGE

MIX 2: 5 Sks,3/4"Gravel,No Retarder,MB 400N SUPER



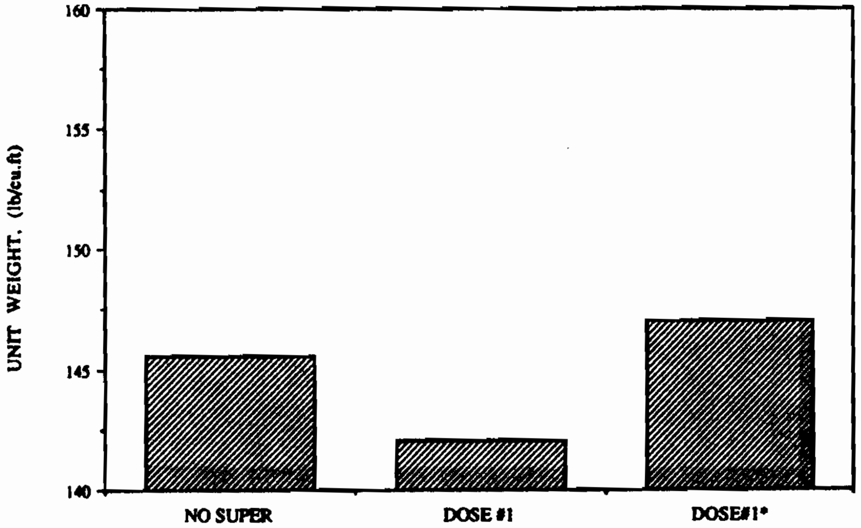
CONCRETE UNIT WEIGHT VS. SUPERPLASTICIZER DOSAGE

MIX 3: 7 Sks,3/4"Gravel,300R Retarder,MB 400N SUPER



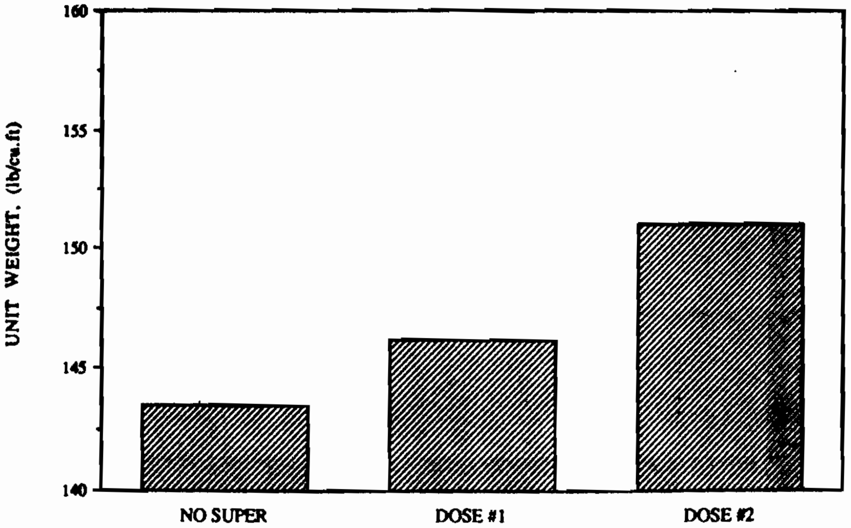
CONCRETE UNIT WEIGHT VS. SUPERPLASTICIZER DOSAGE

MIX 4: 7 Sks,3/4"Gravel,No Retarder,MB 400N SUPER



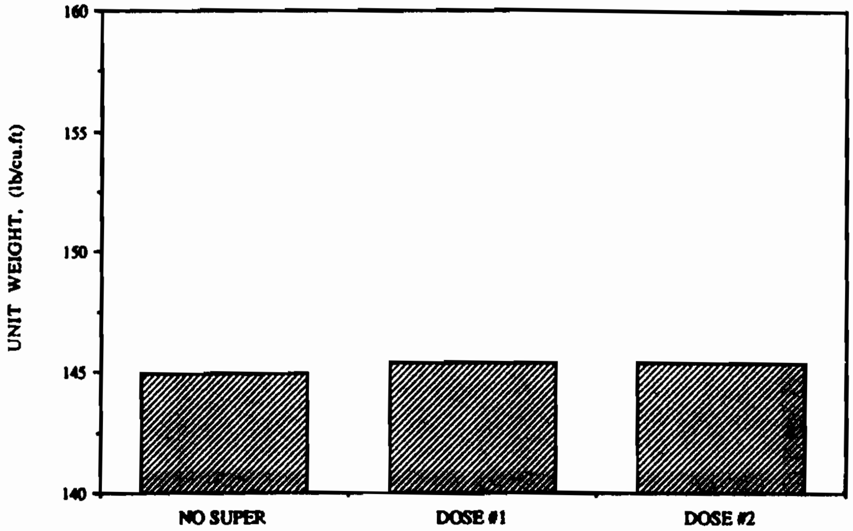
CONCRETE UNIT WEIGHT VS. SUPERPLASTICIZER DOSAGE

MIX 5: 5 Sks,3/4"Gravel,300R Retarder,MELMENT L10 SUPER



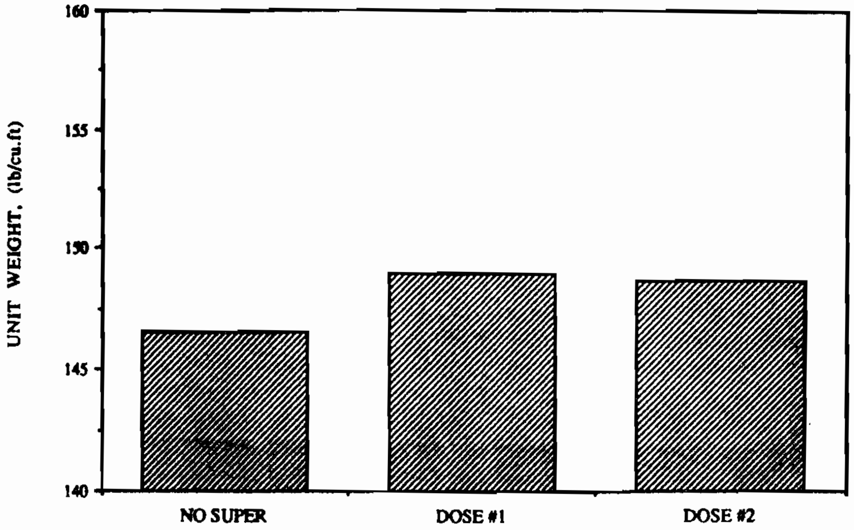
CONCRETE UNIT WEIGHT VS. SUPERPLASTICIZER DOSAGE

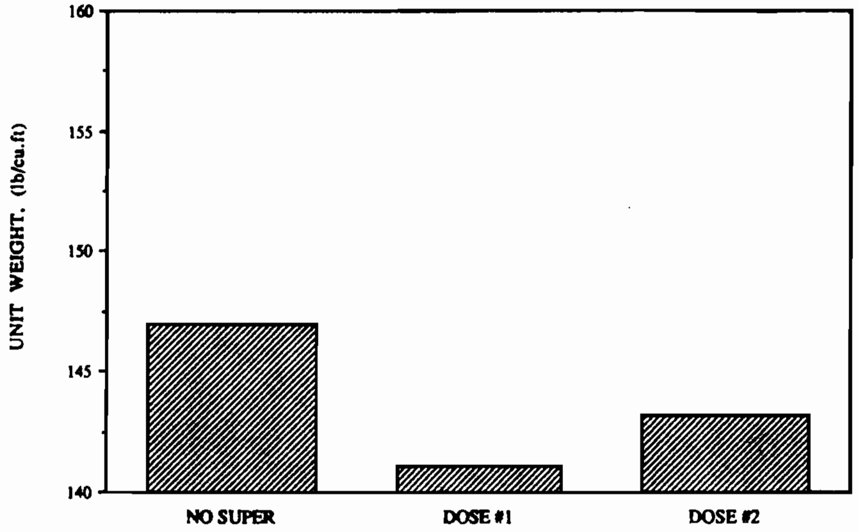
MIX 6: 5 Sks,3/4"Gravel,No Retarder,MELMENT L10 SUPER



CONCRETE UNIT WEIGHT VS. SUPERPLASTICIZER DOSAGE

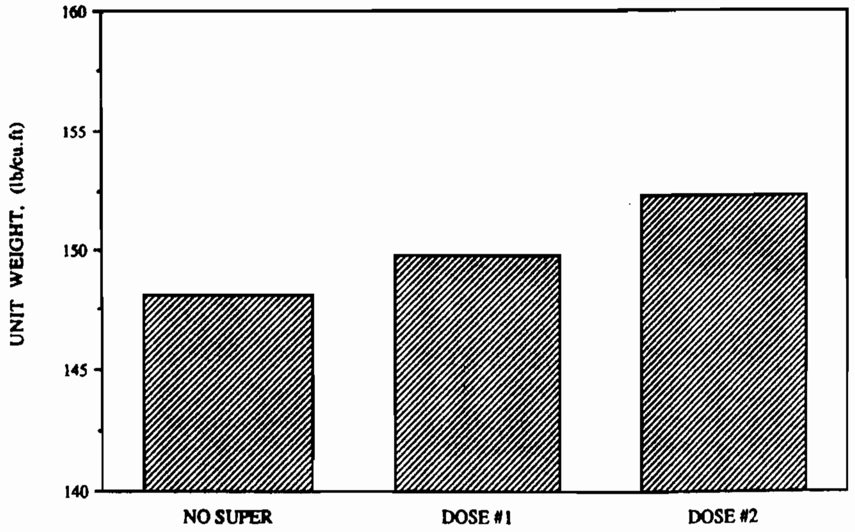
MIX 7: 7 Sks,3/4"Gravel,No Retarder,MELMENT L10 SUPER





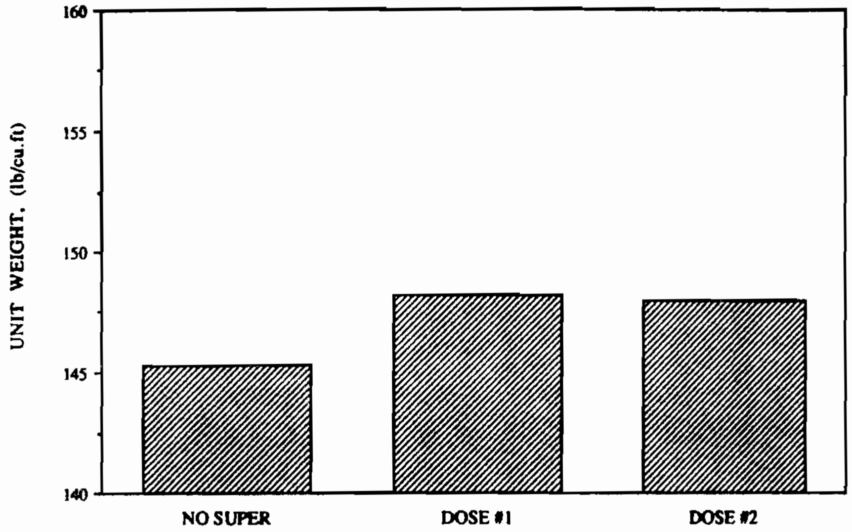
CONCRETE UNIT WEIGHT VS. SUPERPLASTICIZER DOSAGE

MIX 8: 7 Sks,3/4"Gravel,300R Retarder,MELMENT L10 SUPER



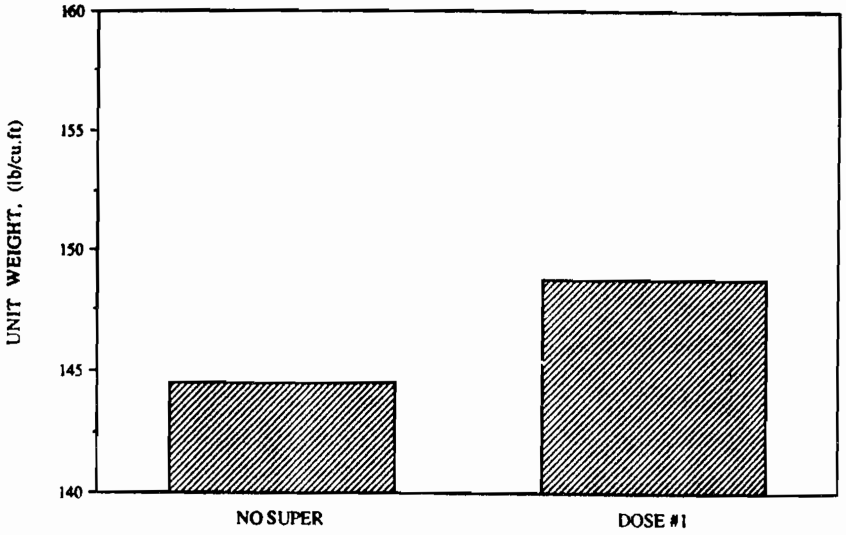
CONCRETE UNIT WEIGHT VS. SUPERPLASTICIZER DOSAGE

MIX 10: 7 Sks,3/4"Gravel,300R Retarder,MB 400N SUPER



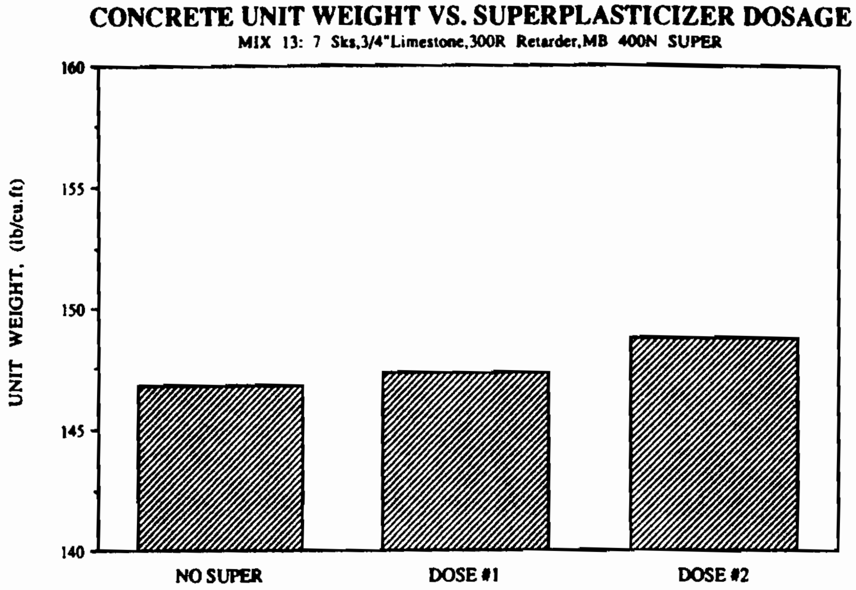
CONCRETE UNIT WEIGHT VS. SUPERPLASTICIZER DOSAGE

MIX 11: 5 Sks,3/4"Limestone,300R Retarder,MB 400N SUPER



CONCRETE UNIT WEIGHT VS. SUPERPLASTICIZER DOSAGE

MIX 12: 7 Sks,3/4"Limestone,300R Retarder,MB 400N SUPER

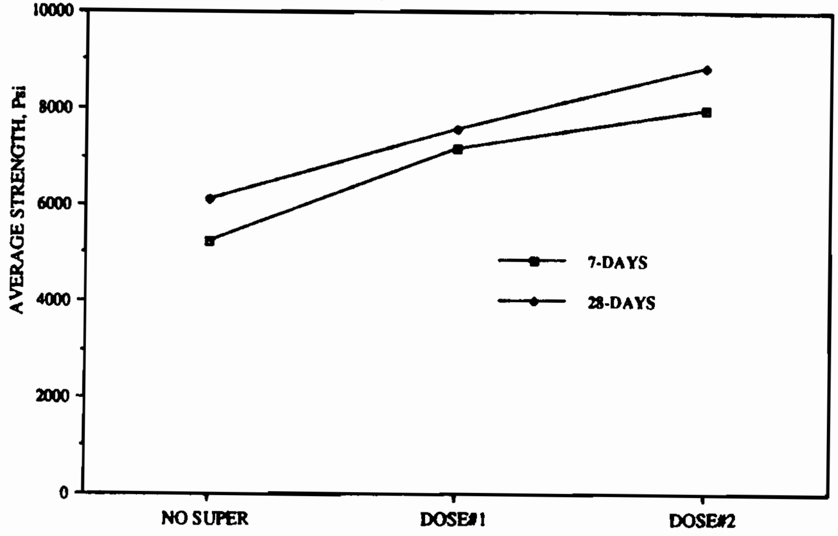

CONCRETE UNIT WEIGHT VS. SUPERPLASTICIZER DOSAGE
MIX 13: 7 Sks,3/4"Limestone,300R Retarder,MB 400N SUPER
UNIT WEIGHT, (lb/cu.ft)
160
155
150
145
140
NO SUPER
DOSE #1
DOSE #2

APPENDIX B6

Compressive Strength Test Data for All Mixes

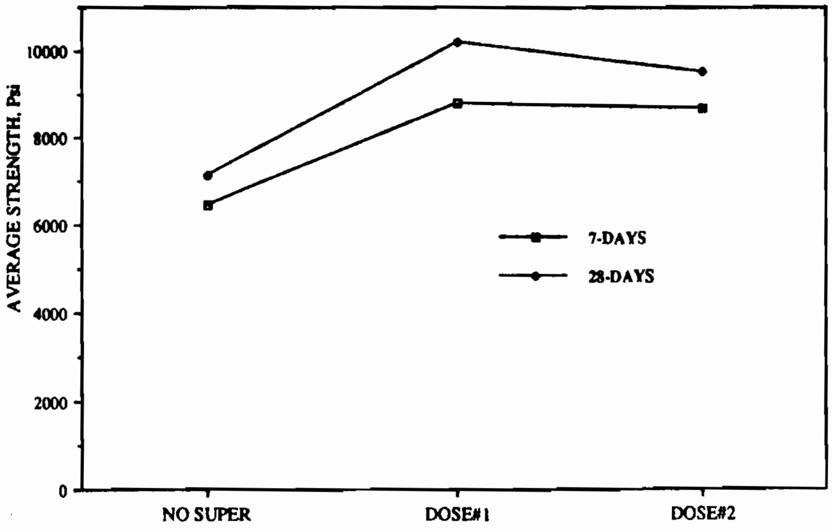
COMPRESSIVE STRENGTH OF MIX 1

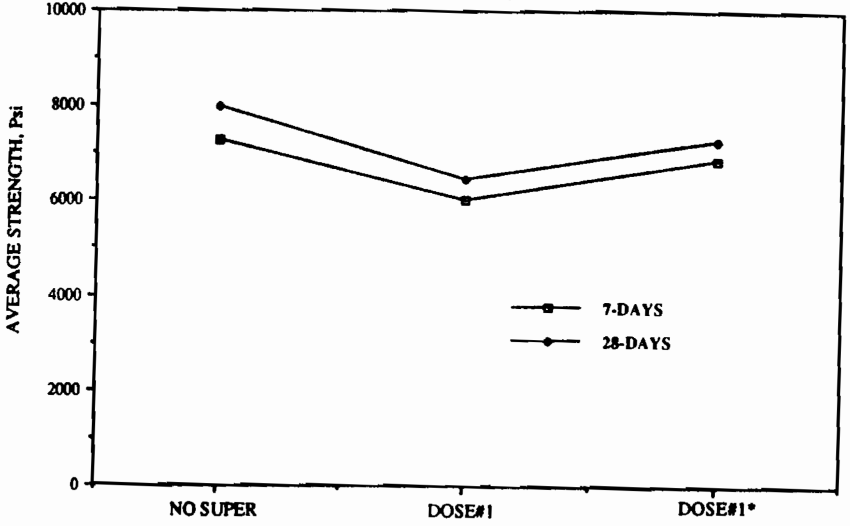
5 Sks, 3/4"Gravel, MB 300 R, MB 400N SUPER



COMPRESSIVE STRENGTH OF MIX 2

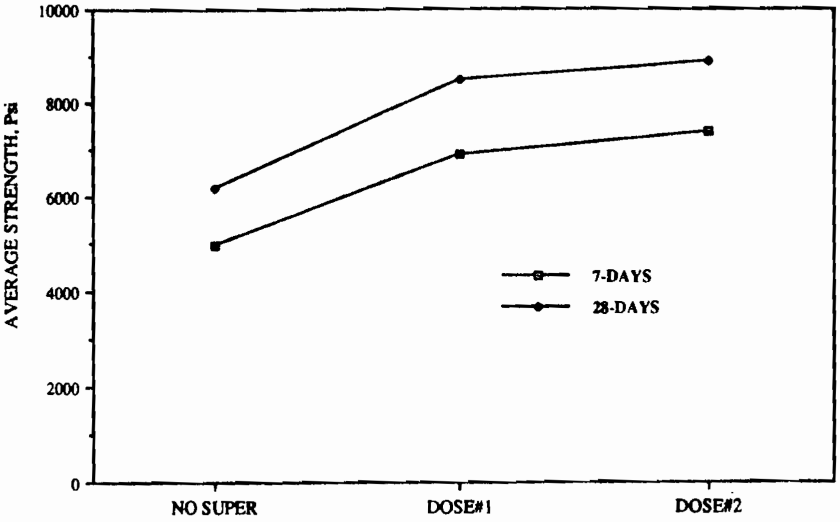
5 Sks, 3/4"Gravel, No Retarder, MB 400N SUPER





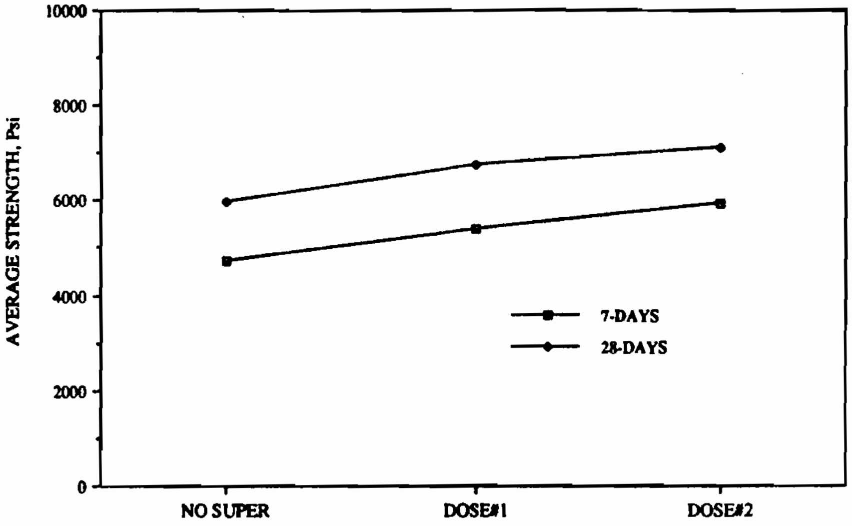
COMPRESSIVE STRENGTH OF MIX 4

7 Sks, 3/4"Gravel,No Retarder, MB 400N SUPER



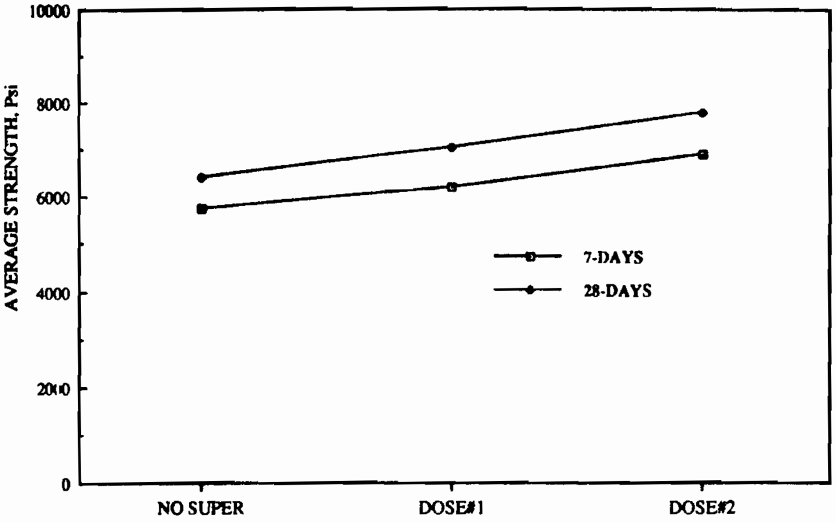
COMPRESSIVE STRENGTH OF MIX 5

5 Sks, 3/4"Gravel,300R Retarder, Melment L10 SUPER



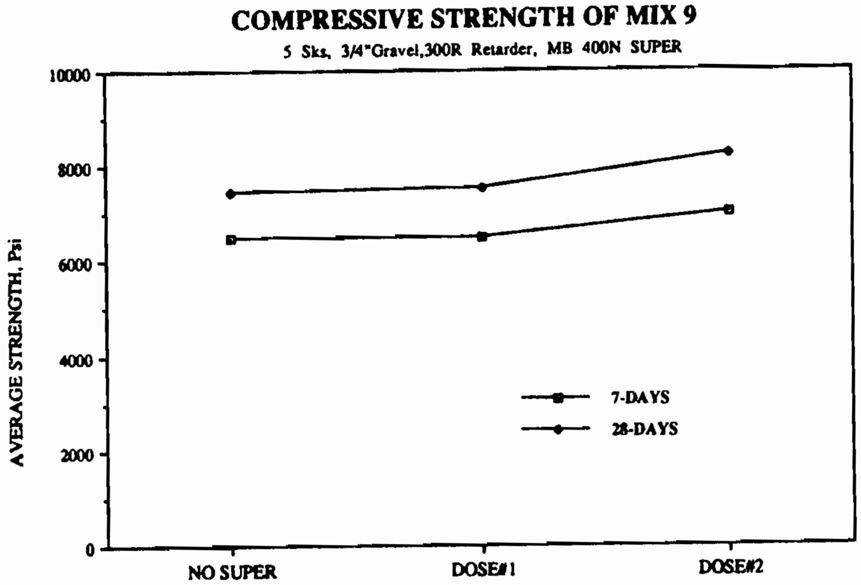
COMPRESSIVE STRENGTH OF MIX 6

5 Sks, 3/4"Gravel, No Retarder, Melment L10 SUPER



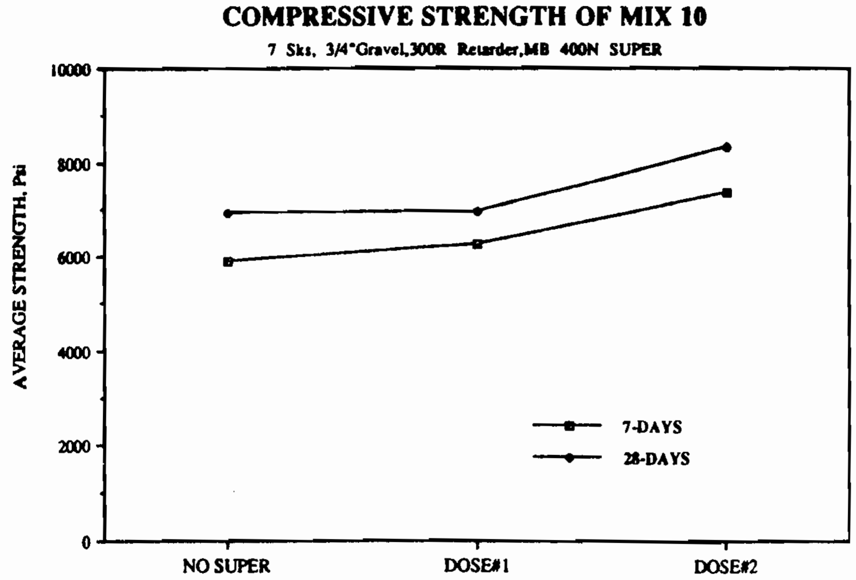
COMPRESSIVE STRENGTH OF MIX 8

7 Sks, 3/4"Gravel, MB 300 R, Melment L-10



COMPRESSIVE STRENGTH OF MIX 9

5 Sks, 3/4"Gravel,300R Retarder, MB 400N SUPER

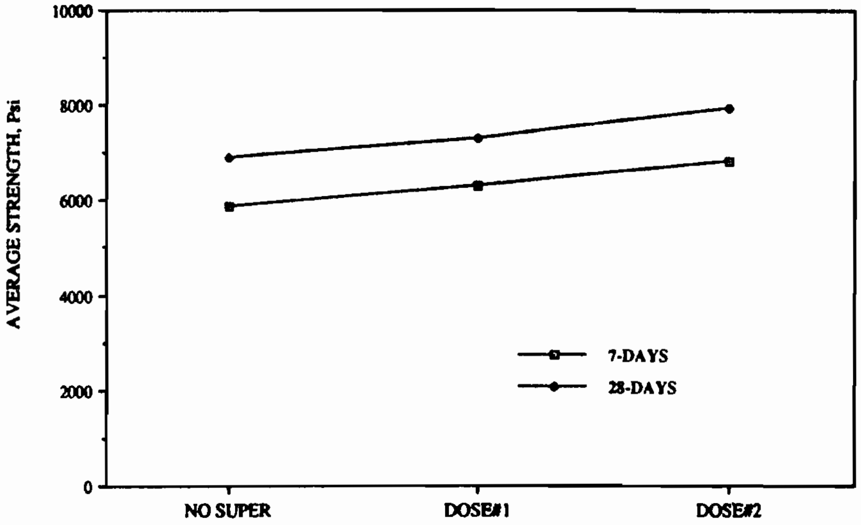


COMPRESSIVE STRENGTH OF MIX 10

7 Sks, 3/4"Gravel,300R Retarder,MB 400N SUPER

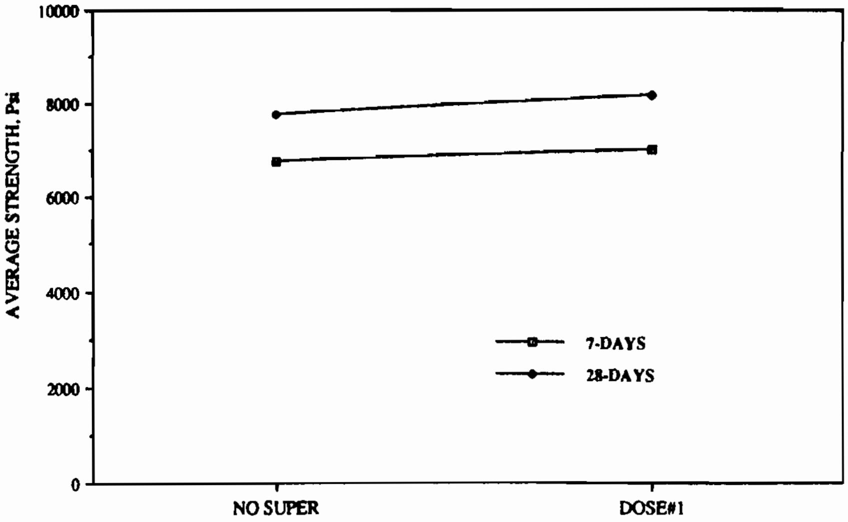
COMPRESSIVE STRENGTH OF MIX 11

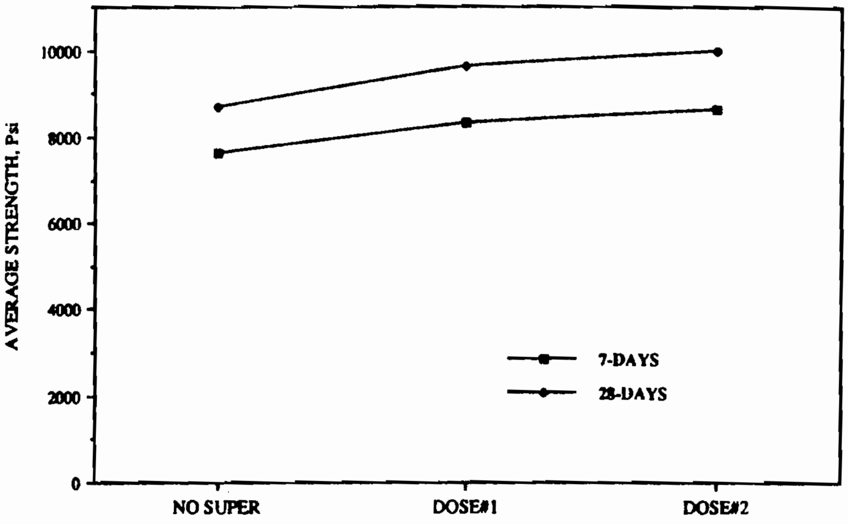
5 Sks, 3/4"Limestone,300R Retarder,MB 400N SUPER



COMPRESSIVE STRENGTH OF MIX 12

7 Sks, 3/4"Limestone,300R Retarder, MB 400N SUPER





COMPRESSIVE STRENGTH OF MIX 13

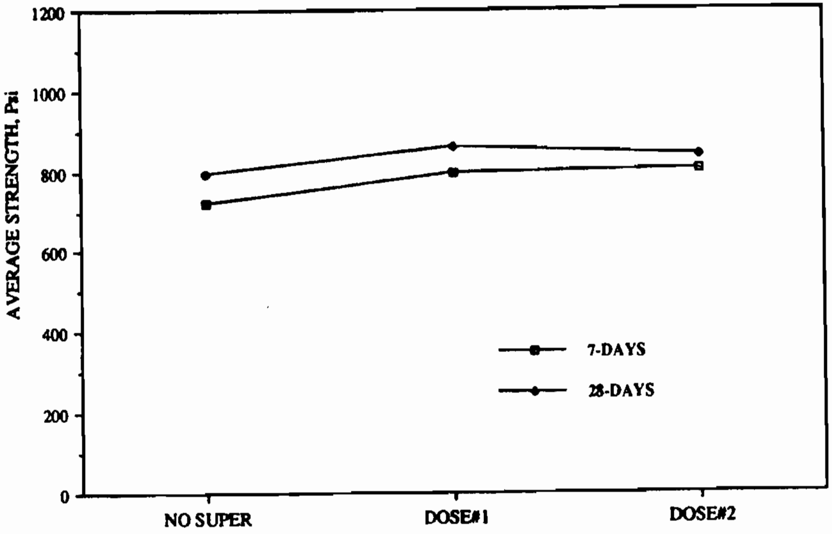
7 Sks, 3/4"Limestone,300R Retarder, MB 400N SUPER

APPENDIX B7

FLEXURAL STRENGTH TEST DATA FOR ALL MIXES

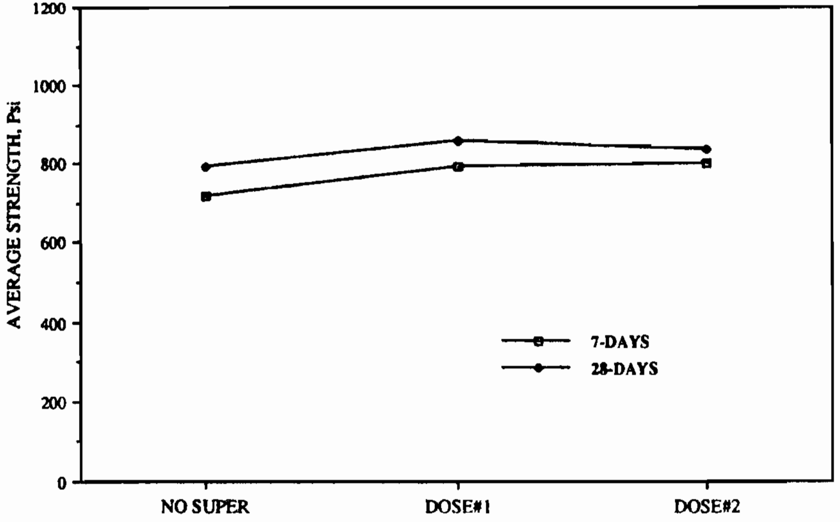
FLEXURE STRENGTH OF MIX 1

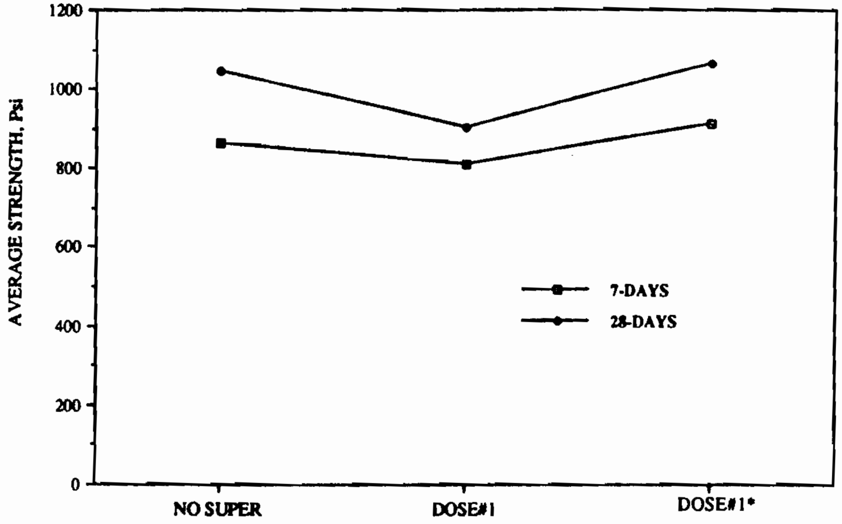
5 Sks, 3/4"Gravel, MB 300 R, MB 400N SUPER



FLEXURE STRENGTH OF MIX 2

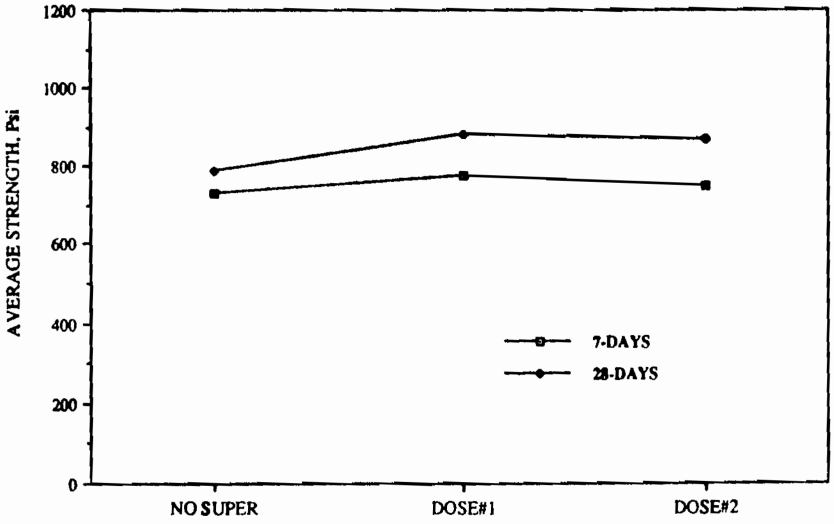
5 Sks, 3/4"Gravel,No Retarder,MB 400N SUPER





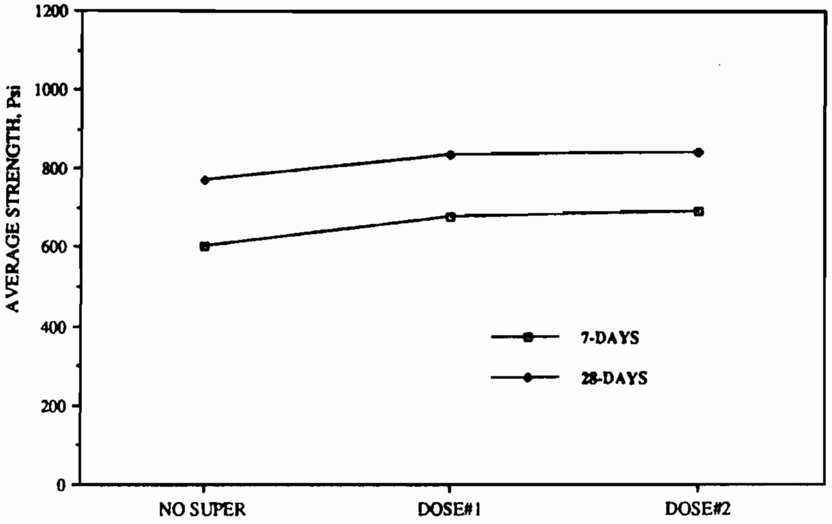
FLEXURE STRENGTH OF MIX 4

7 Sks, 3/4"Gravel,No Retarder, MB 400N SUPER



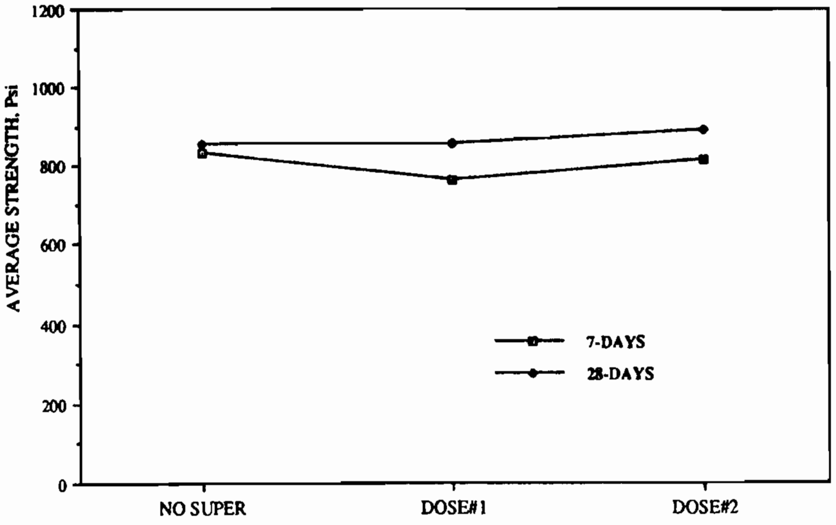
FLEXURE STRENGTH OF MIX 5

5 Sks, 3/4"Gravel,300R Retarder, Melment L10 SUPER



FLEXURE STRENGTH OF MIX 6

5 Sks, 3/4"Gravel, No Retarder, Melment L-10

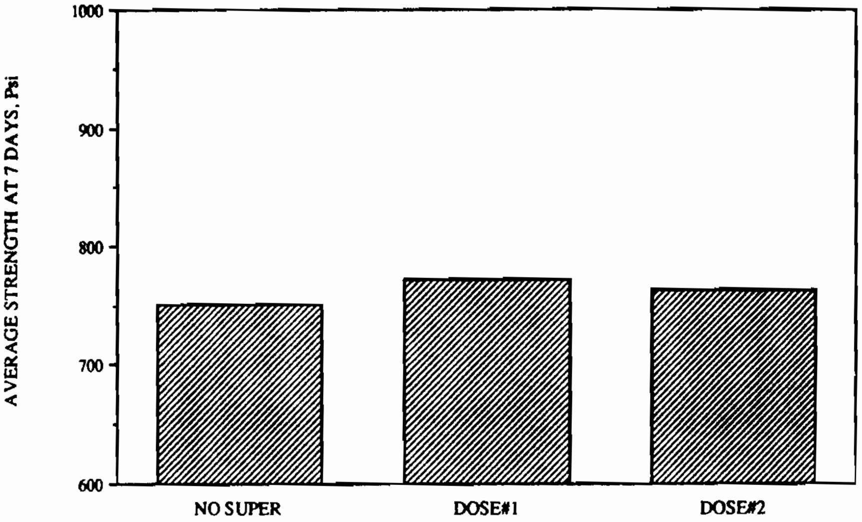


FLEXURE STRENGTH OF MIX 8

7 Sks, 3/4"Gravel, MB 300 R, Melment L-10

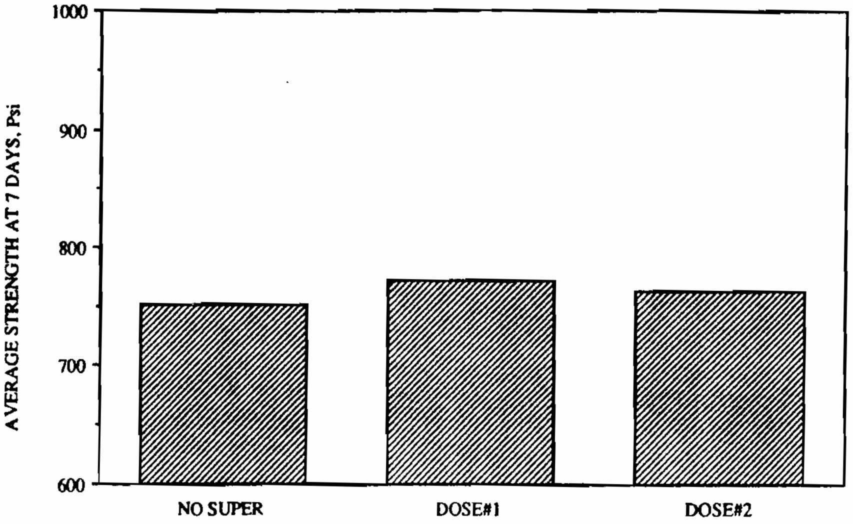
FLEXURE STRENGTH OF MIX 9

5 Sks, 3/4"Gravel,300R Retarder, MB 400N SUPER



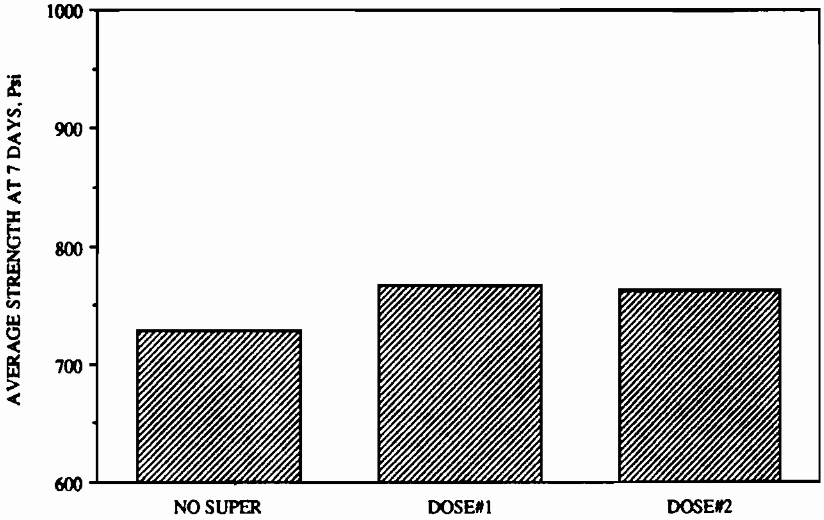
FLEXURE STRENGTH OF MIX 10

7 Sks, 3/4"Gravel,300R Retarder, MB 400N SUPER



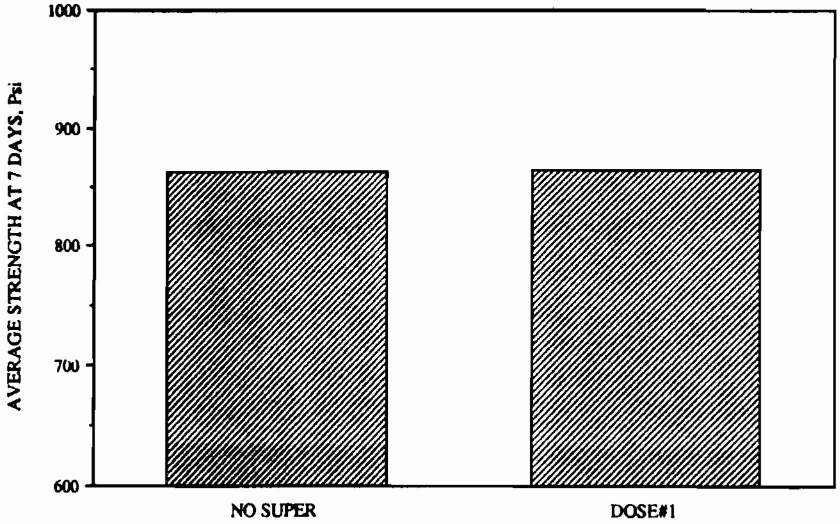
FLEXURE STRENGTH OF MIX 11

5 Sks, 3/4"Limestone,300R Retarder, MB 400N SUPER



FLEXURE STRENGTH OF MIX 12

7 Sks, 3/4"Limestone,300R Retarder, MB 400N SUPER

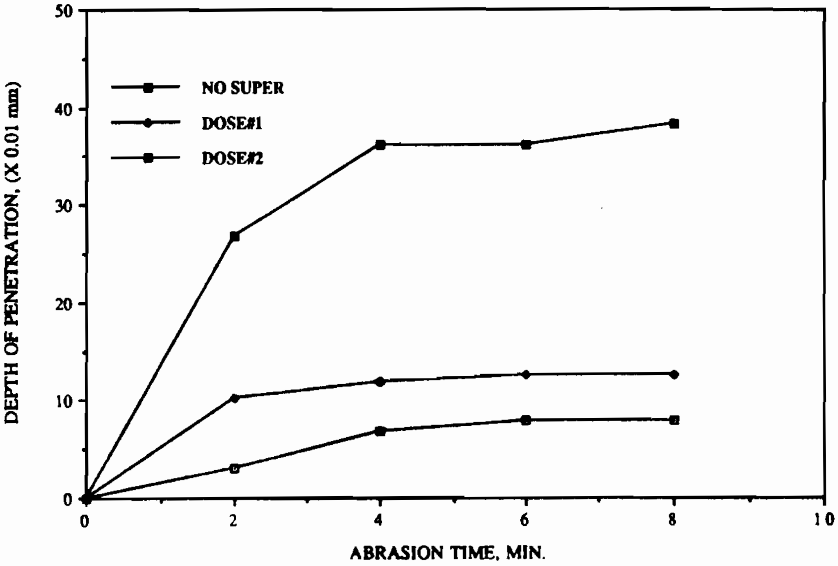


APPENDIX B8

ABRASION RESISTANCE TEST DATA FOR ALL MIXES

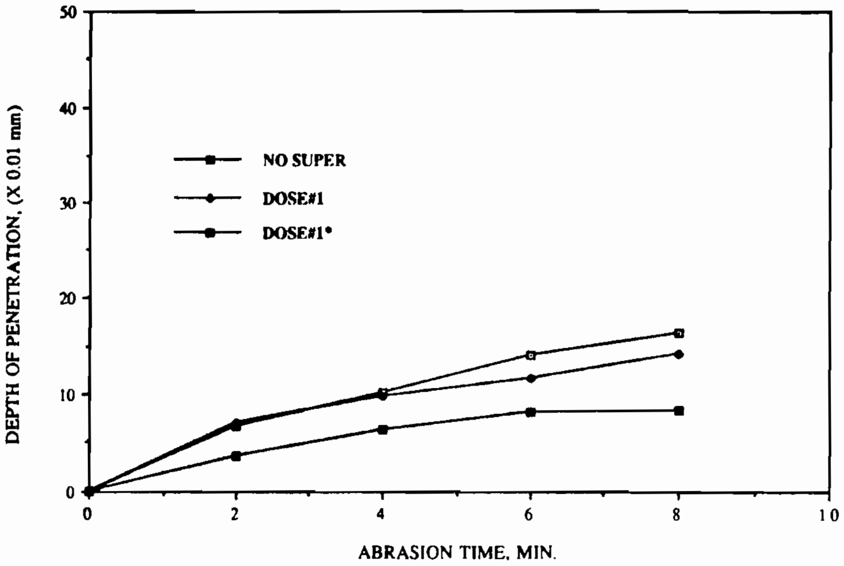
ABRASION RESISTANCE OF MIX 2

5 Sks, 3/4"Gravel,No Retarder,MB 400N SUPER



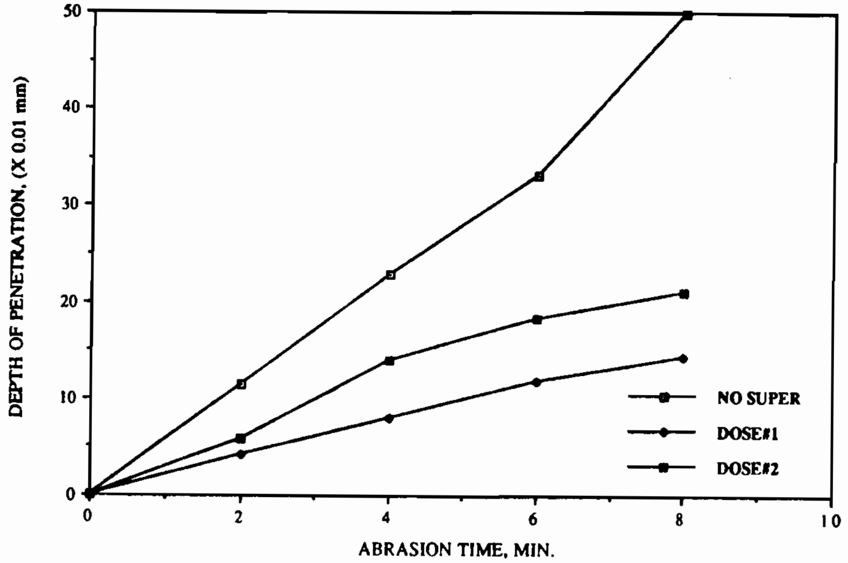
ABRASION RESISTANCE OF MIX 4

7 Sks, 3/4"Gravel,No Retarder,MB 400N SUPER



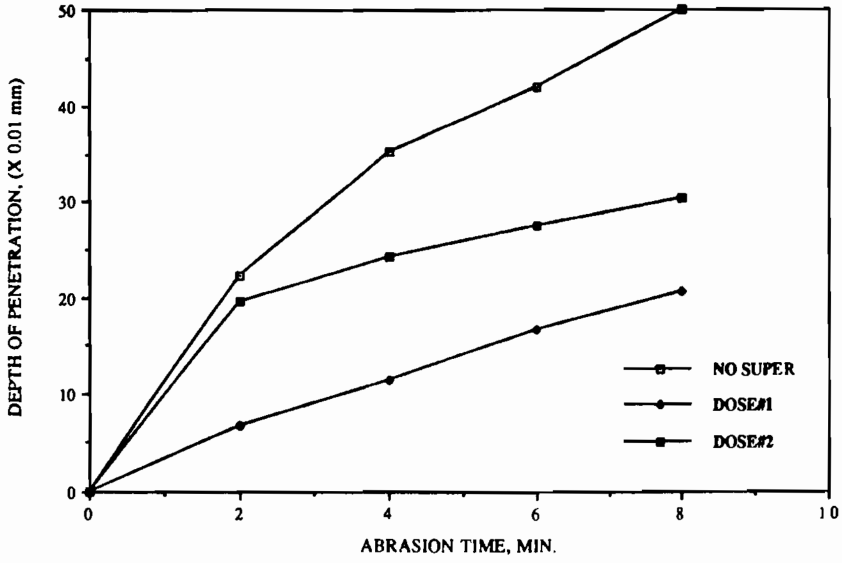
ABRASION RESISTANCE OF MIX 5

5 Sks, 3/4"Gravel,300R Retarder, Melment L10 SUPER



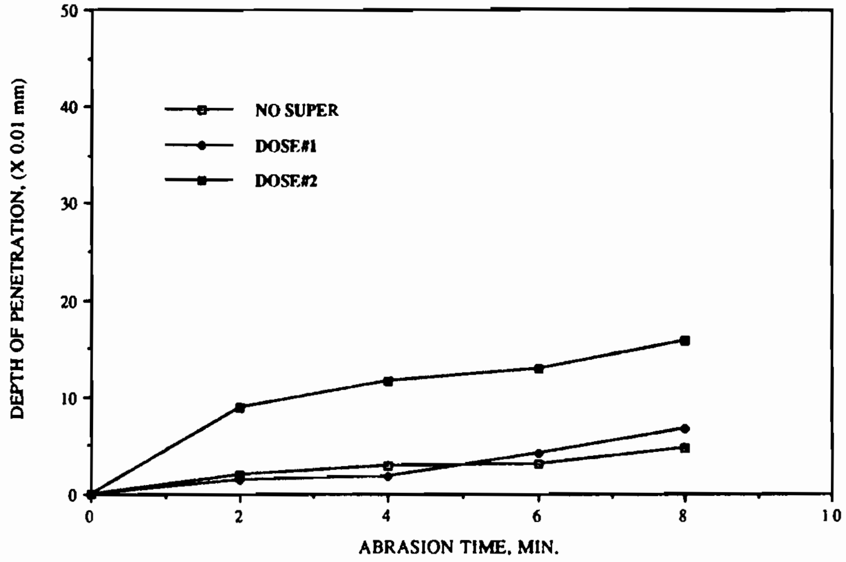
ABRASION RESISTANCE OF MIX 6

5 Sks, 3/4"Gravel, No Retarder, Melment L10 SUPER



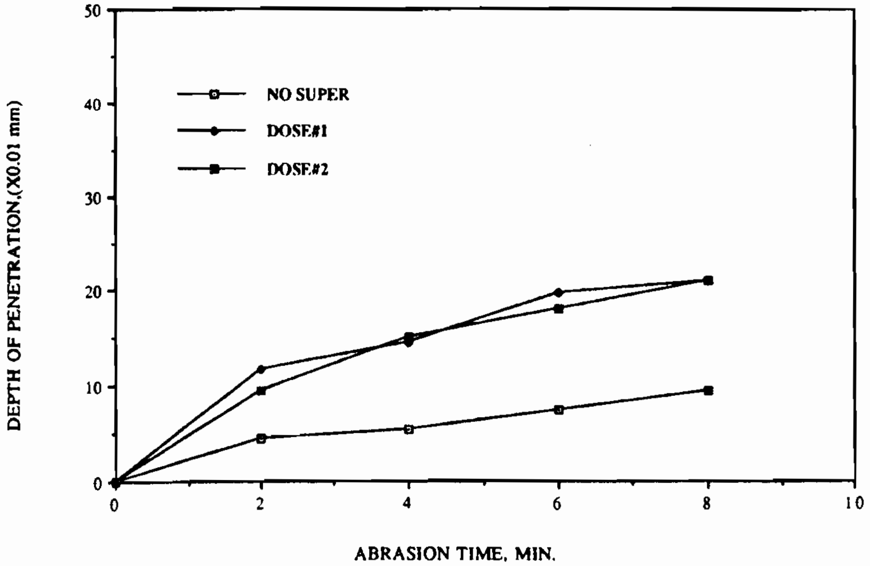
ABRASION RESISTANCE OF MIX 7

7 Sks, 3/4"Gravel, No Retarder, Melment L10 SUPER



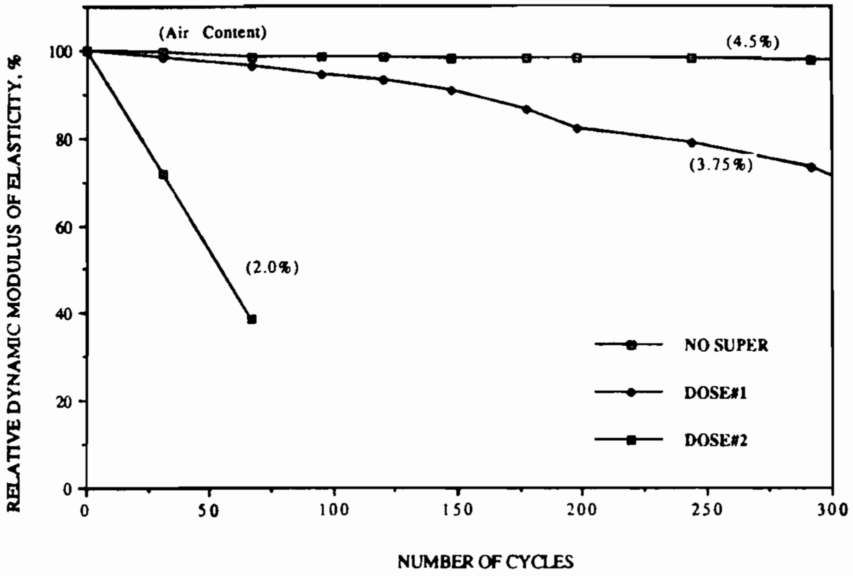
ABRASION RESISTANCE OF MIX 8

7 Sks, 3/4"Gravel,300R Retarder, Melment L10 SUPER



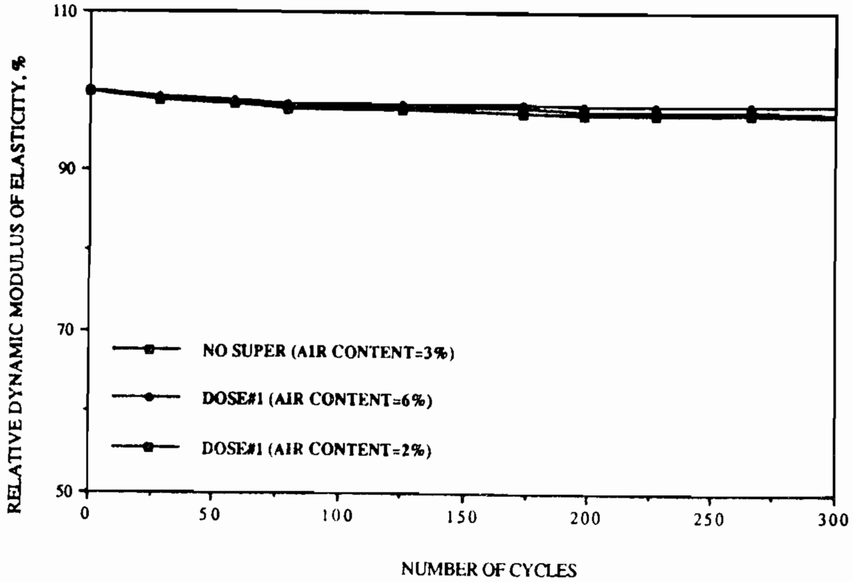
APPENDIX B9

FREEZE-THAW RESISTANCE OF ALL MIXES



FREEZE-THAW RESISTANCE OF MIX 1

5 Sks,3/4"Gravel,300R Retarder,MB 400N SUPER

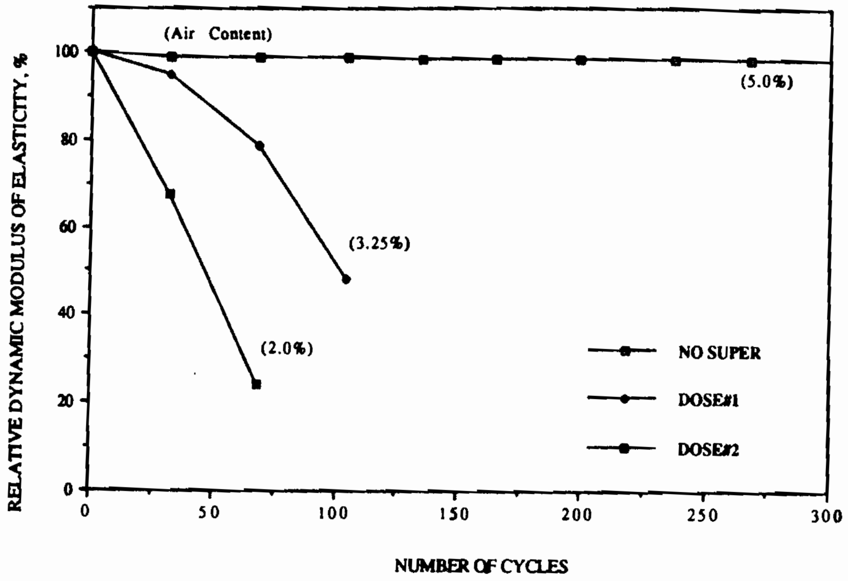


FREEZE-THAW RESISTANCE OF MIX 4

7 Sks,3/4"Gravel,No Retarder,MB 400N SUPER

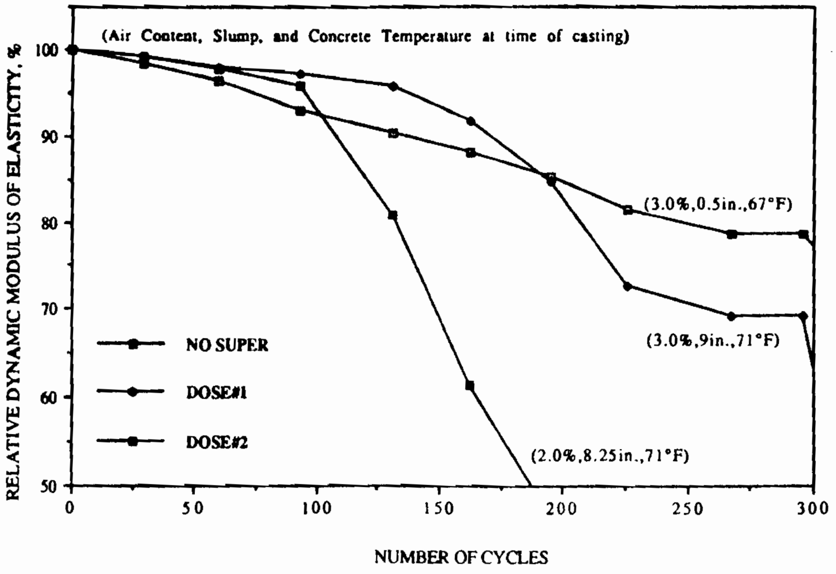
FREEZE-THAW RESISTANCE OF MIX 5

5 Sks,3/4"Gravel,300R Retarder,MELMENT L10 SUPER



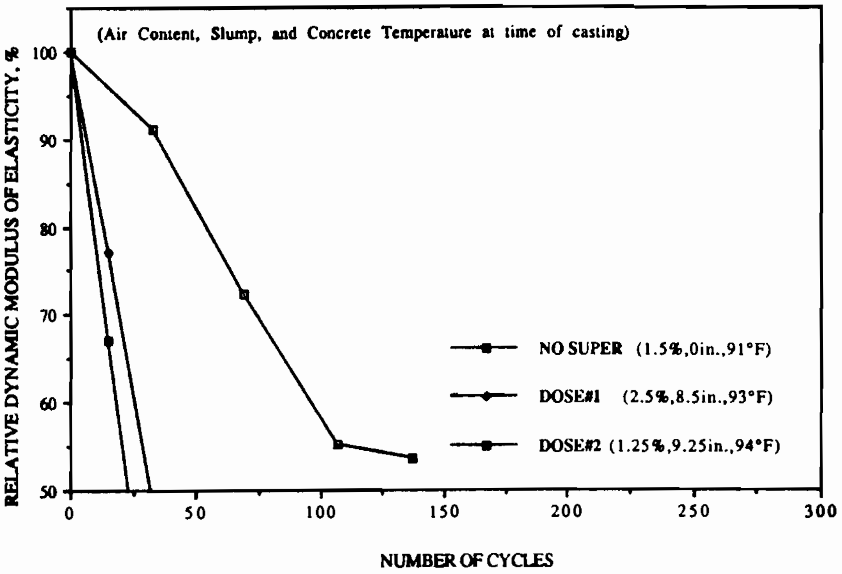
FREEZE-THAW RESISTANCE OF MIX 7

7 Sks,3/4"Gravel,Initial slump 1-2in.,No Retarder,MELMENT L10 SUPER



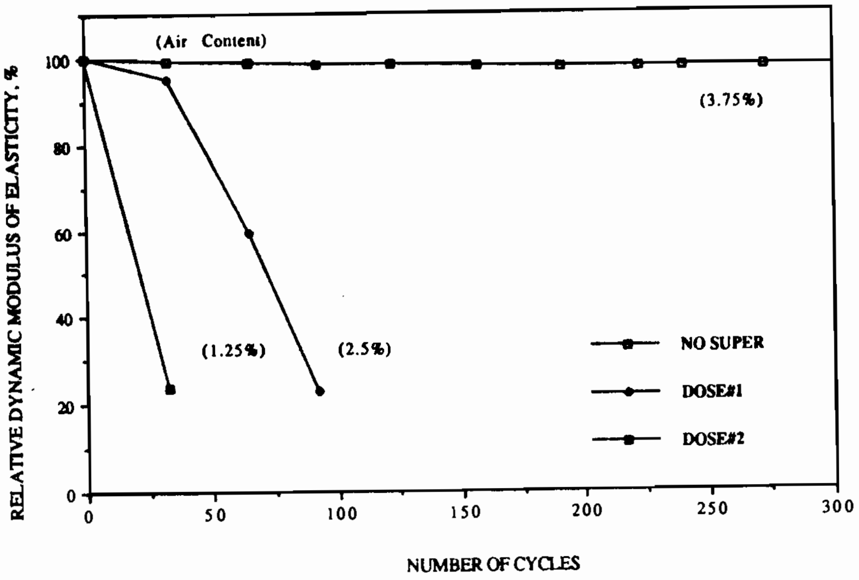
FREEZE-THAW RESISTANCE OF MIX 9

5 Sks,3/4"Gravel,Initial slump 1-2in.,5oz/cwt 300R Retarder,MB 400N SUPER



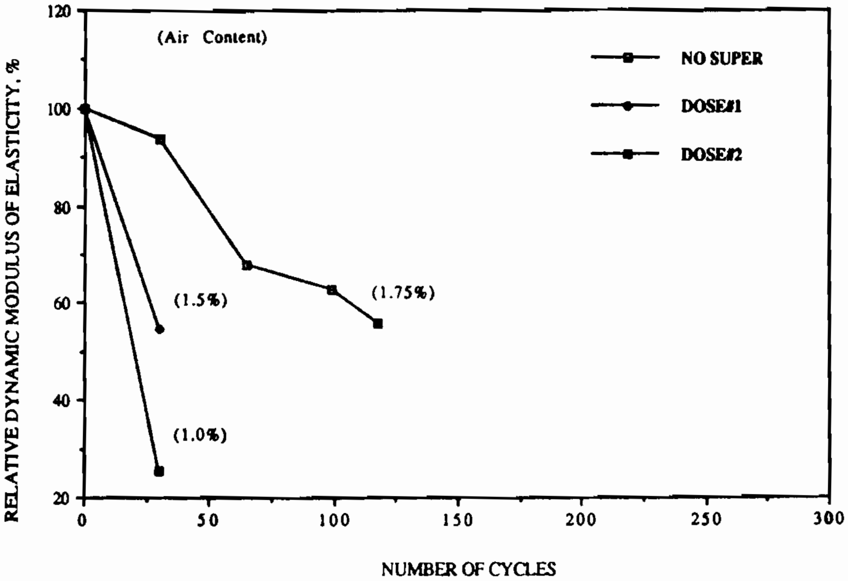
FREEZE-THAW RESISTANCE OF MIX 10

7 Sks,3/4"Gravel,300R Retarder,MB 400N SUPER



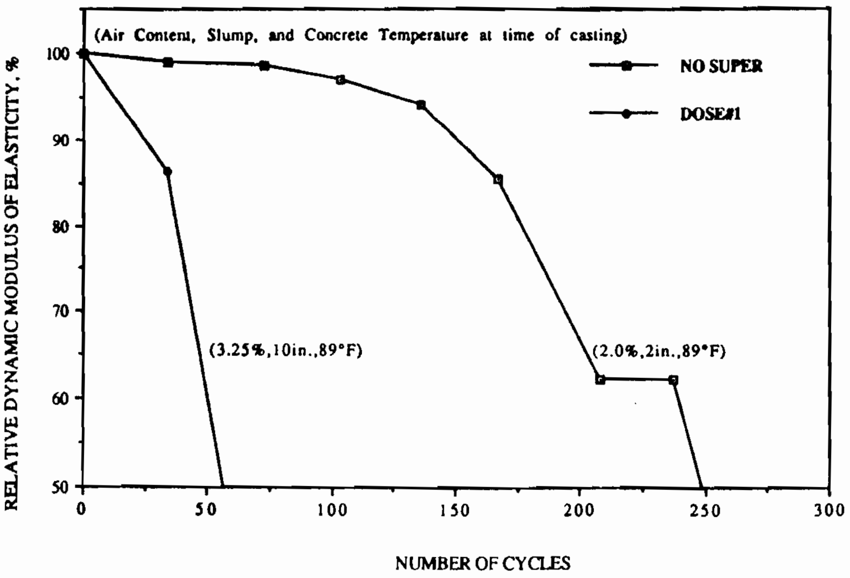
FREEZE-THAW RESISTANCE OF MIX 11

5 Sks,3/4"Limestone,300R Retarder,MB 400N SUPER



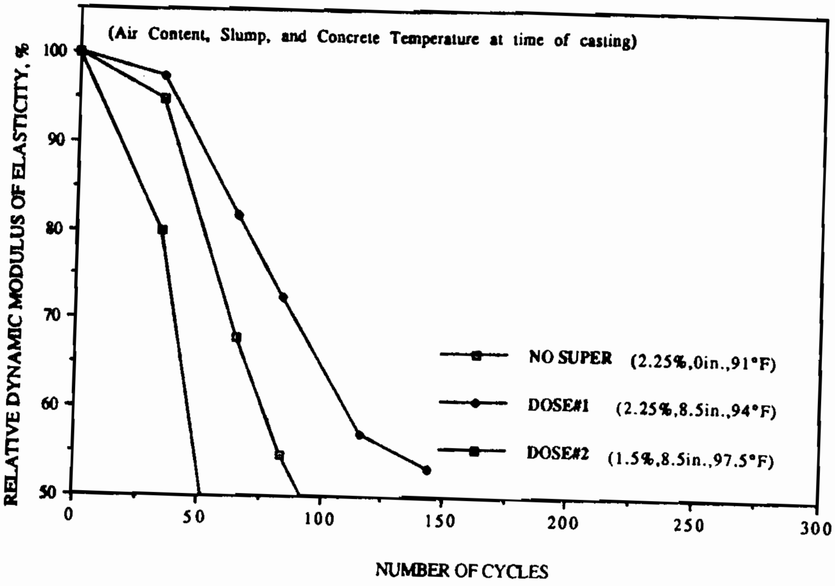
FREEZE-THAW RESISTANCE OF MIX 12

7 Sks,3/4"Limestone,Initial slump 1-2in.,3oz/cwt 300R Retarder,MB 400N SUPER



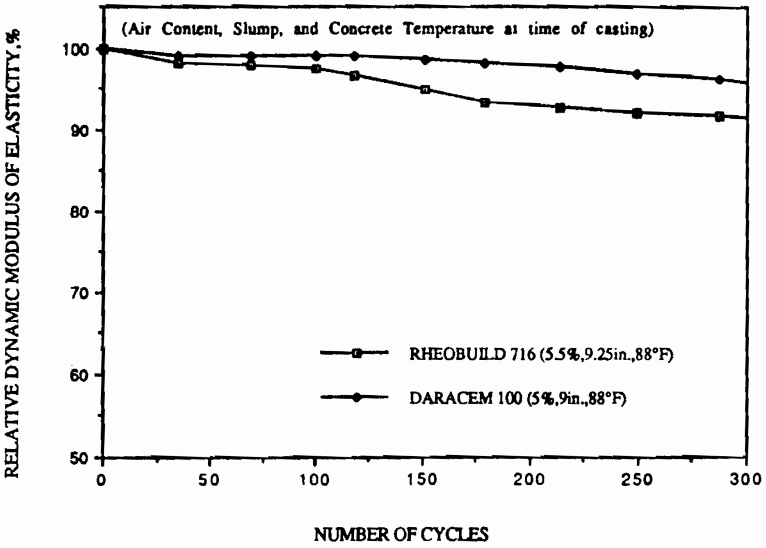
FREEZE-THAW RESISTANCE OF MIX 13

7 Sks,3/4"Gravel,Initial slump 1-2in.,5oz/cwt 300R Retarder,MB 400N SUPER



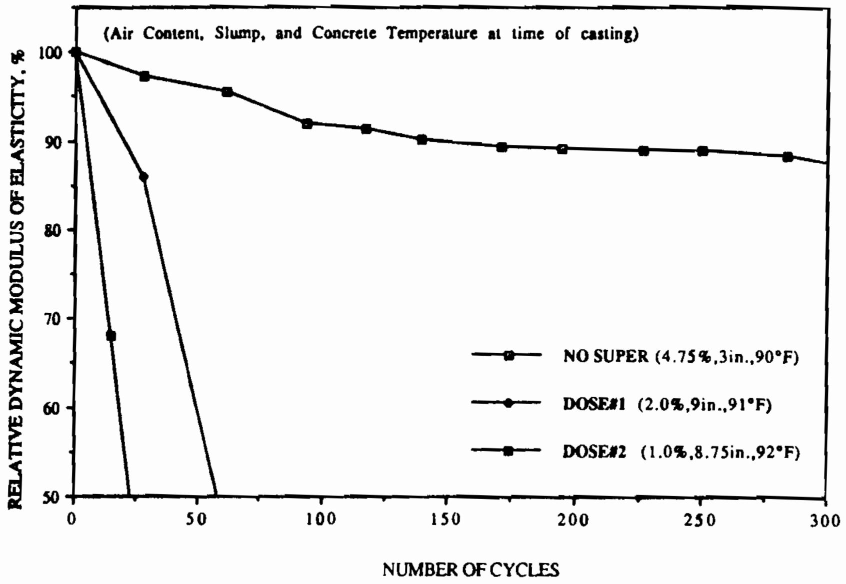
FREEZE-THAW RESISTANCE OF MIX 14 AND 15

5 Sks,3/4"Gravel,Initial slump 1-2in.,No Retarder,Second Generation Superplasticizers



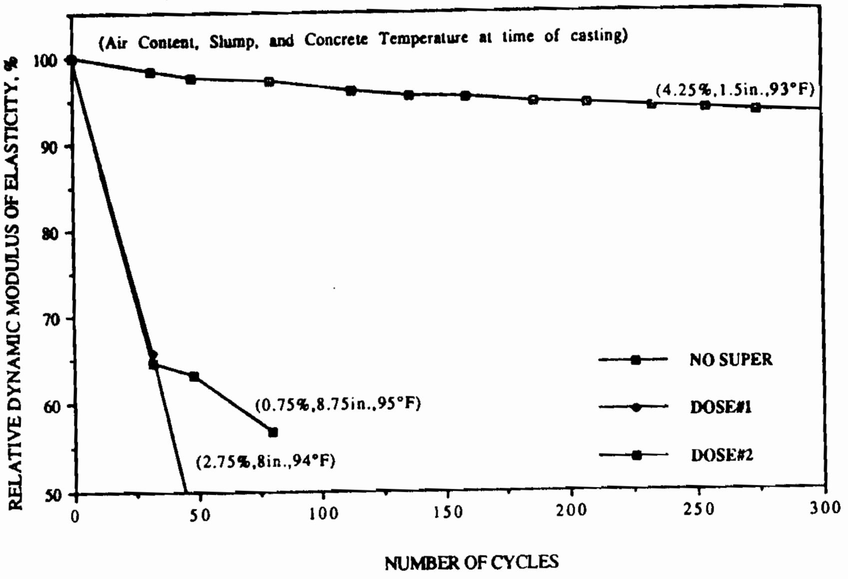
FREEZE-THAW RESISTANCE OF MIX L2

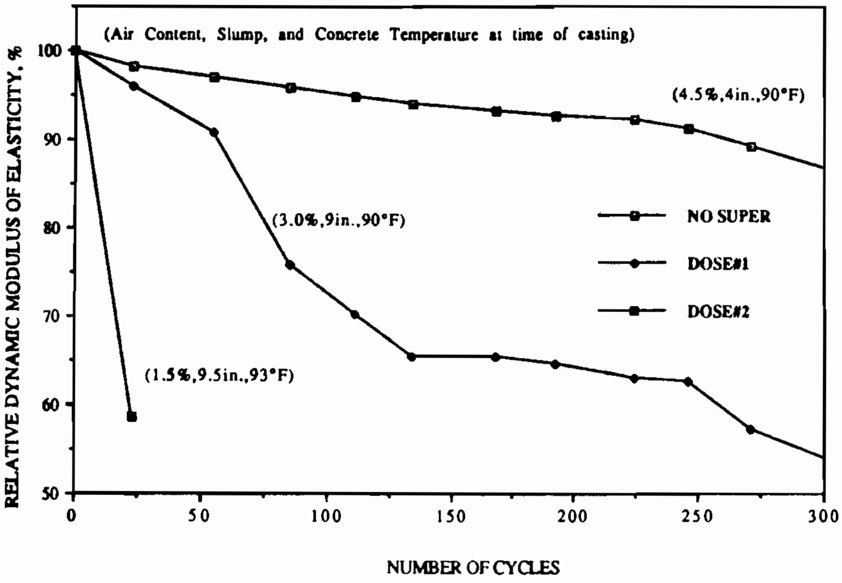
5 Sks,3/4"Gravel,Initial slump 4-5in.,3oz/cwt 300R Retarder,MB 400N SUPER



FREEZE-THAW RESISTANCE OF MIX L3

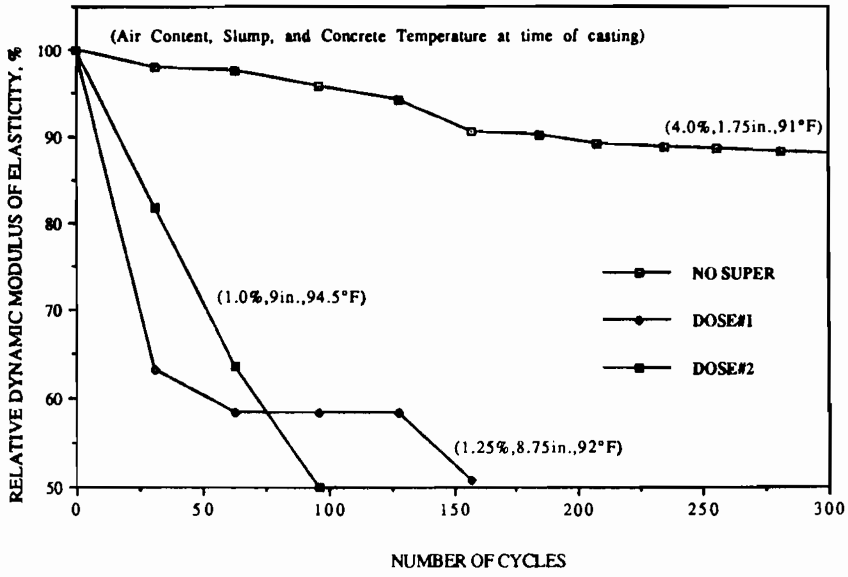
5 Sks,3/4"Limestone,Initial slump 1-2in.,3oz/cwt 300R Retarder,MB 400N SUPER





FREEZE-THAW RESISTANCE OF MIX L4

5 Sks,3/4"Limestone,Initial slump 6-7in.,3oz/cwt 300R Retarder,MB 400N SUPER

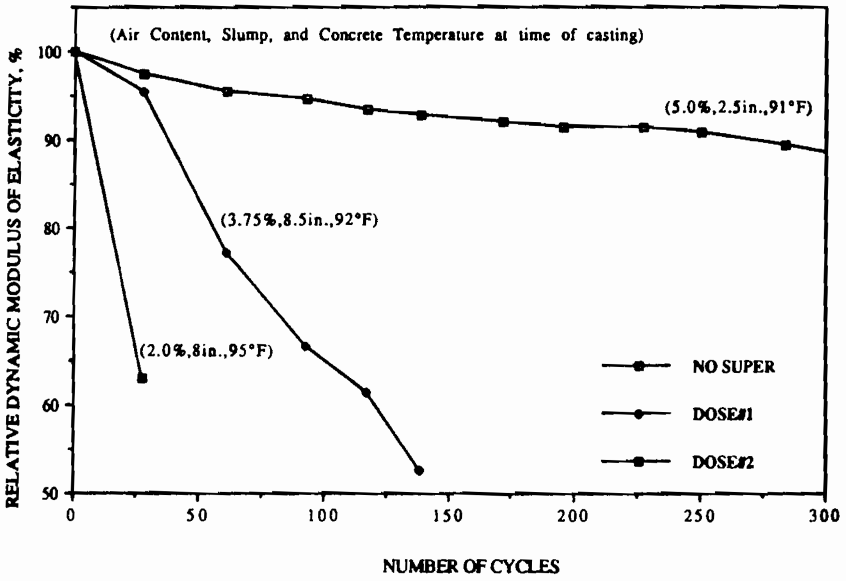


FREEZE-THAW RESISTANCE OF MIX L5

5 Sks,3/4"Limestone,Initial slump 4-5in.,3oz/cwt 300R Retarder,MB 400N SUPER

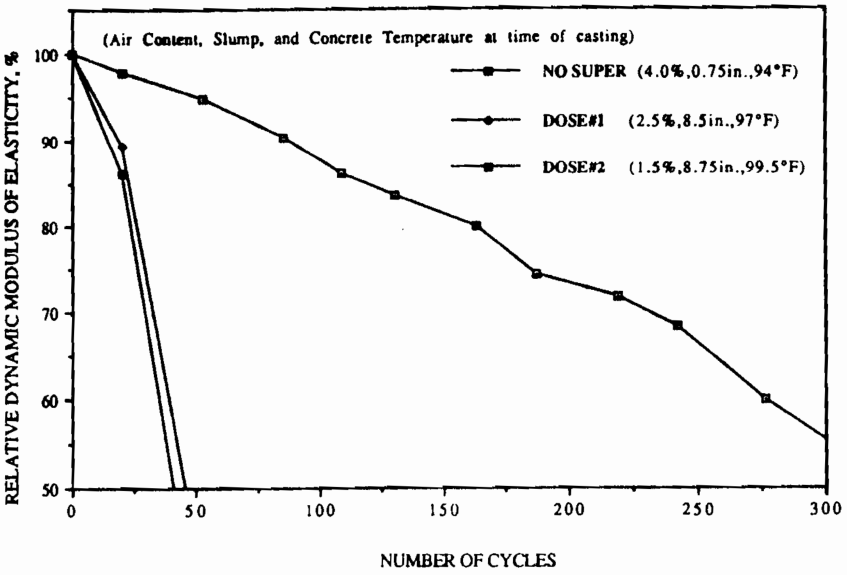
FREEZE-THAW RESISTANCE OF MIX L6

5 Sks,3/4"Gravel,Initial slump 4-5in.,5oz/cwt 300R Retarder,MB 400N SUPER



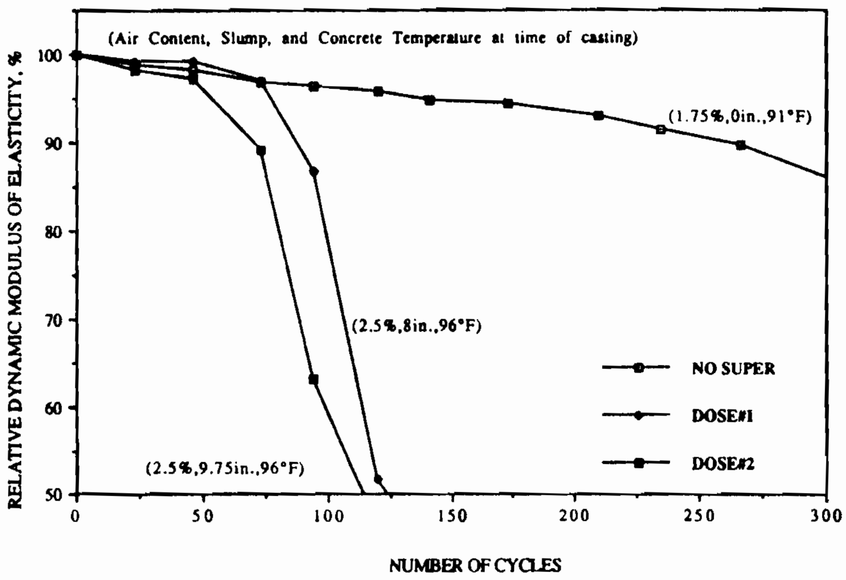
FREEZE-THAW RESISTANCE OF MIX L7

5 Sks,3/4"Gravel,Initial slump 1-2in.,5oz/cwt 300R Retarder,MB 400N SUPER



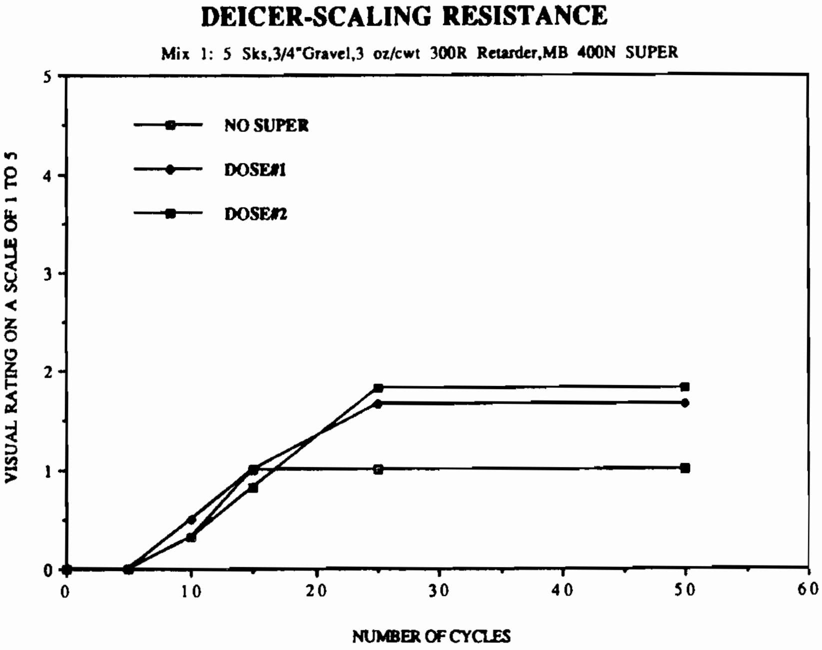
FREEZE-THAW RESISTANCE OF MIX L8

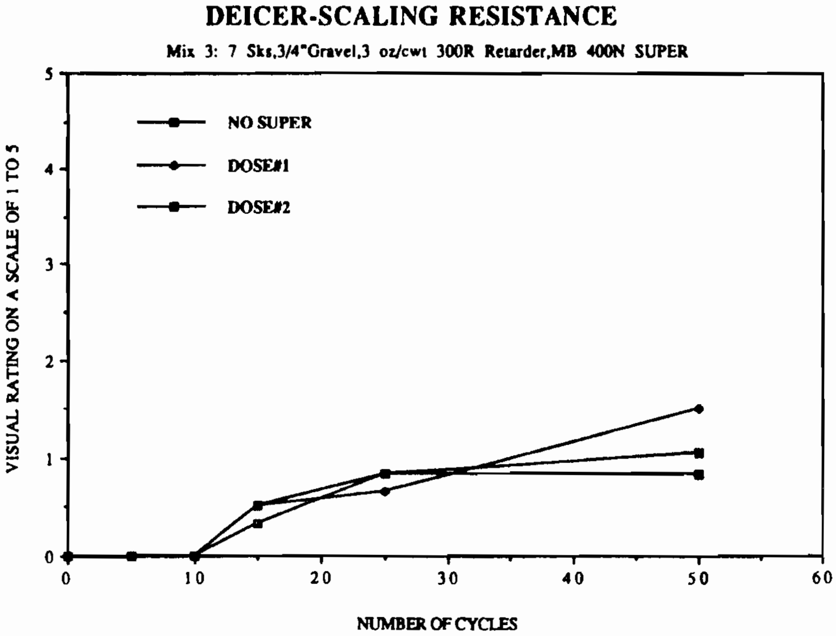
7 Sks,3/4"Gravel,Initial slump 1-2in.,3oz/cwt 300R Retarder,MB 400N SUPER

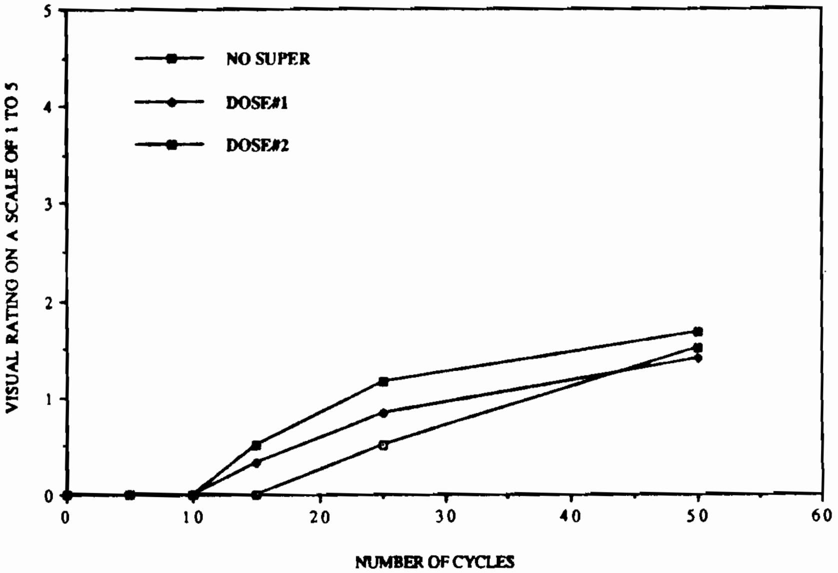


APPENDIX B10

DEICER-SCALING RESISTANCE OF ALL MIXES

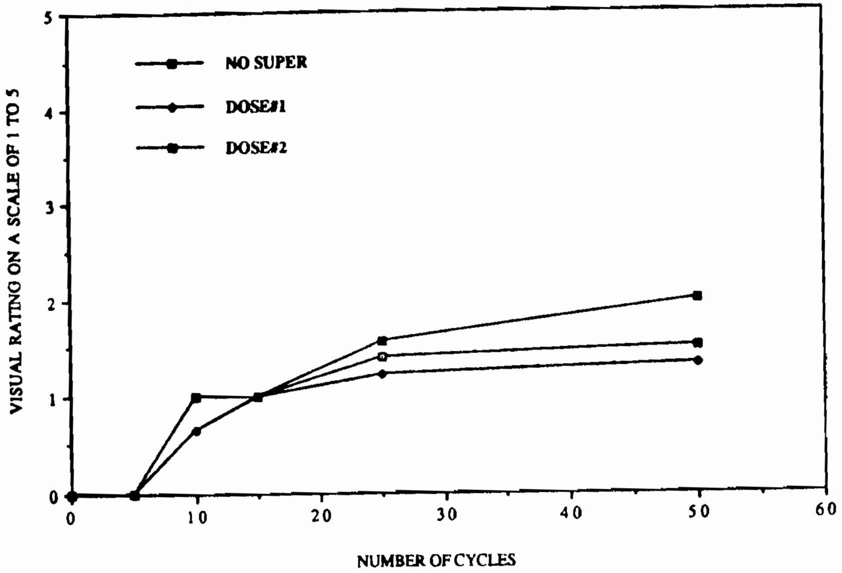

DEICER-SCALING RESISTANCE
Mix 1: 5 Sks,3/4"Gravel,3 oz/cwt 300R Retarder,MB 400N SUPER
NO SUPER
DOSE#1
DOSE#2
VISUAL RATING ON A SCALE OF 1 TO 5
0
1
2
3
4
5
0
10
20
30
40
50
60
NUMBER OF CYCLES


DEICER-SCALING RESISTANCE
Mix 3: 7 Sks,3/4"Gravel,3 oz/cwt 300R Retarder,MB 400N SUPER
NO SUPER
DOSE#1
DOSE#2
VISUAL RATING ON A SCALE OF 1 TO 5
0
1
2
3
4
5
0
10
20
30
40
50
60
NUMBER OF CYCLES



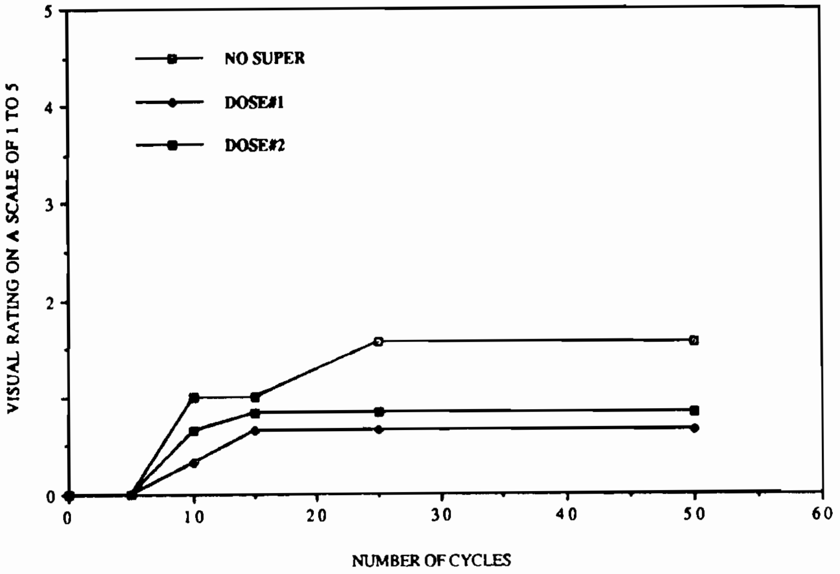
DEICER-SCALING RESISTANCE

Mix 4: 7 Sks,3/4"Gravel,No Retarder,MB 400N SUPER



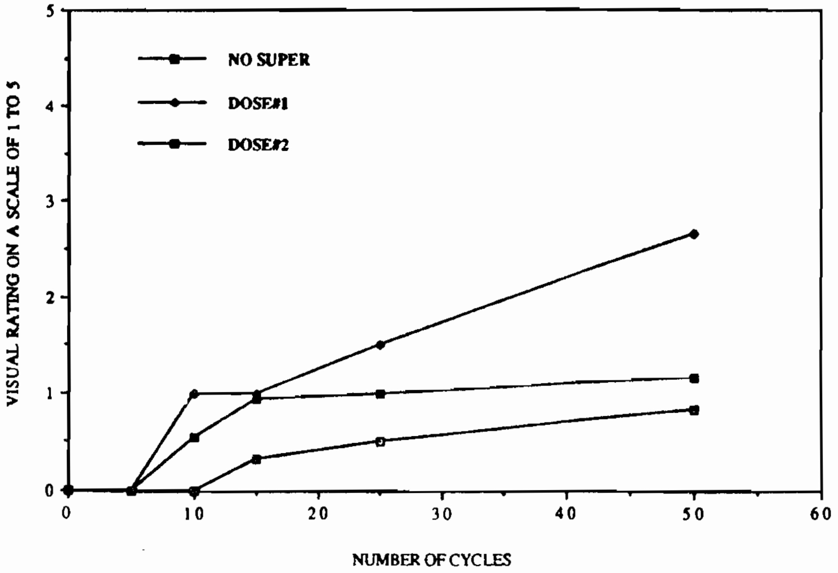
DEICER-SCALING RESISTANCE

Mix 5: 5 Sks,3/4"Gravel,3 oz/cwt 300R Retarder,MELMENT L10 SUPER



DEICER-SCALING RESISTANCE

Mix 6: 5 Sks,3/4"Gravel,No Retarder,MELMENT L10 SUPER

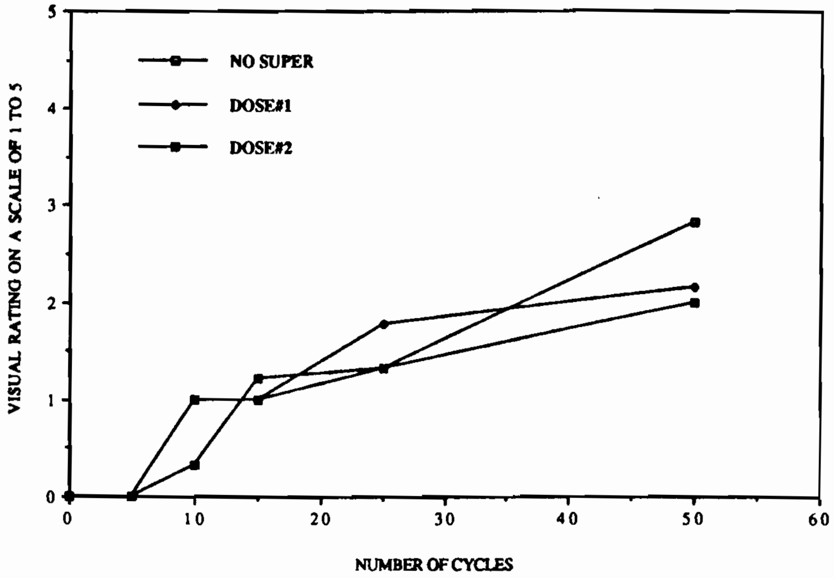


DEICER-SCALING RESISTANCE

Mix 7: 7 Sks,3/4"Gravel,No Retarder,MELMENT L10 SUPER

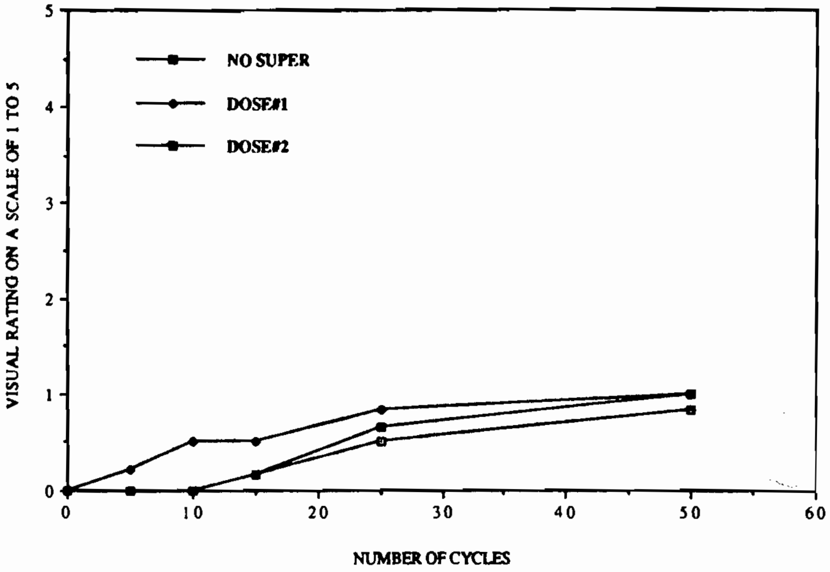
DEICER-SCALING RESISTANCE

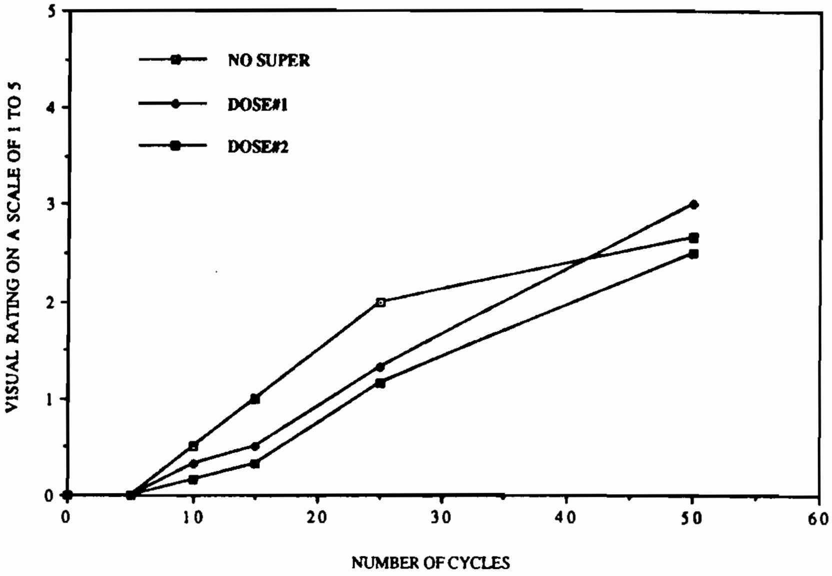
Mix 8: 7 Sks,3/4"Gravel,3 oz /cwt 300R Retarder,MELMENT L10 SUPER



DEICER-SCALING RESISTANCE

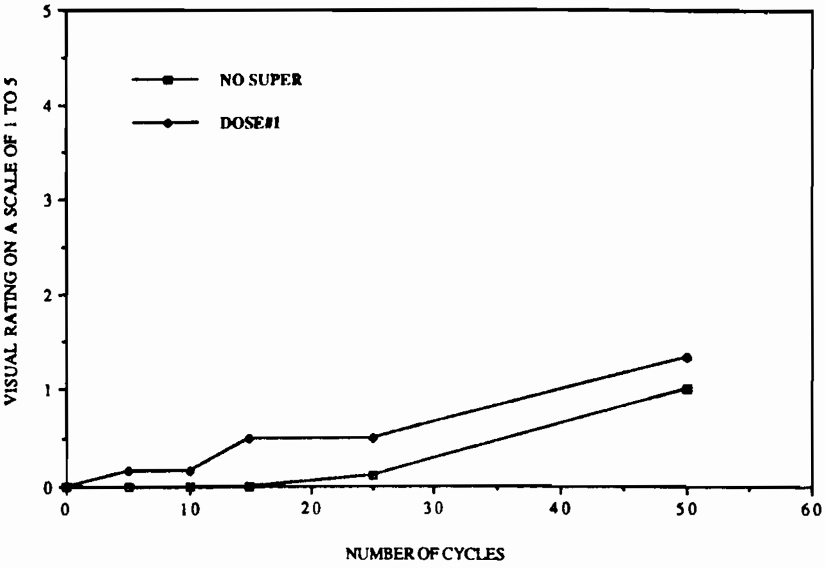
Mix 10: 7 Sks,3/4"Gravel,5 oz/cwt 300R Retarder,MB 400N SUPER





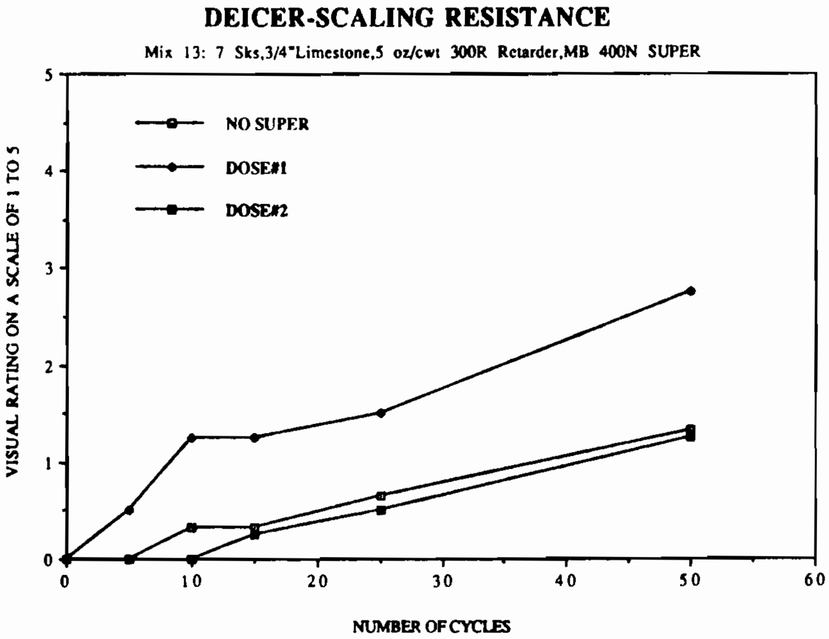
DEICER-SCALING RESISTANCE

Mix 11: 5 Sks,3/4"Limestone,5 oz/cwt 300R Retarder,MB 400N SUPER



DEICER-SCALING RESISTANCE

Mix 12: 7 Sks,3/4"Limestone,3 oz/cwt 300R Retarder,MB 400N SUPER

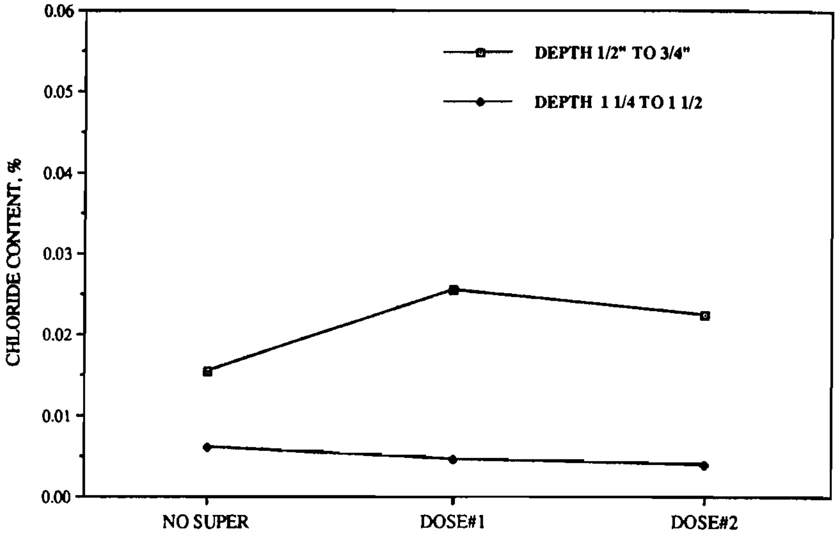

DEICER-SCALING RESISTANCE
Mix 13: 7 Sks,3/4"Limestone,5 oz/cwt 300R Retarder,MB 400N SUPER
NO SUPER
DOSE#1
DOSE#2
VISUAL RATING ON A SCALE OF 1 TO 5
0
1
2
3
4
5
0
10
20
30
40
50
60
NUMBER OF CYCLES

APPENDIX B11

CHLORIDE PENETRATION RESISTANCE OF ALL MIXES

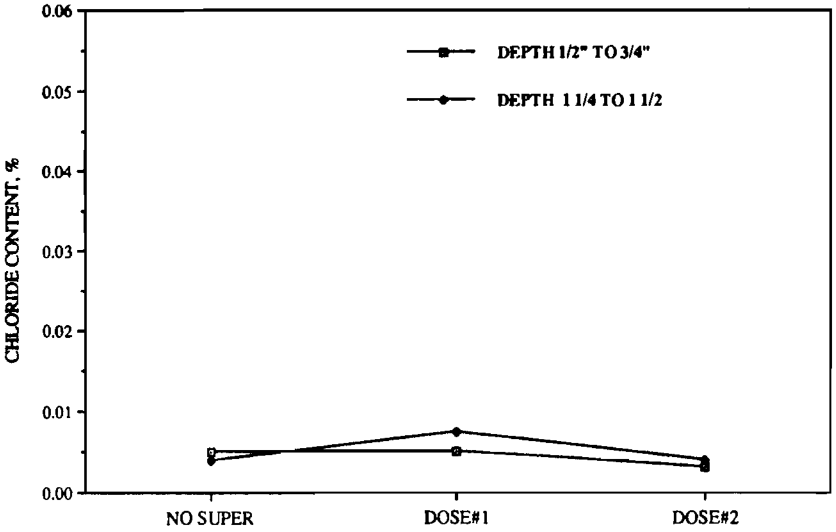
CHLORIDE PENETRATION RESISTANCE OF MIX 1

5 Sks, 3/4"Gravel,300R Retarder, MB 400N SUPER



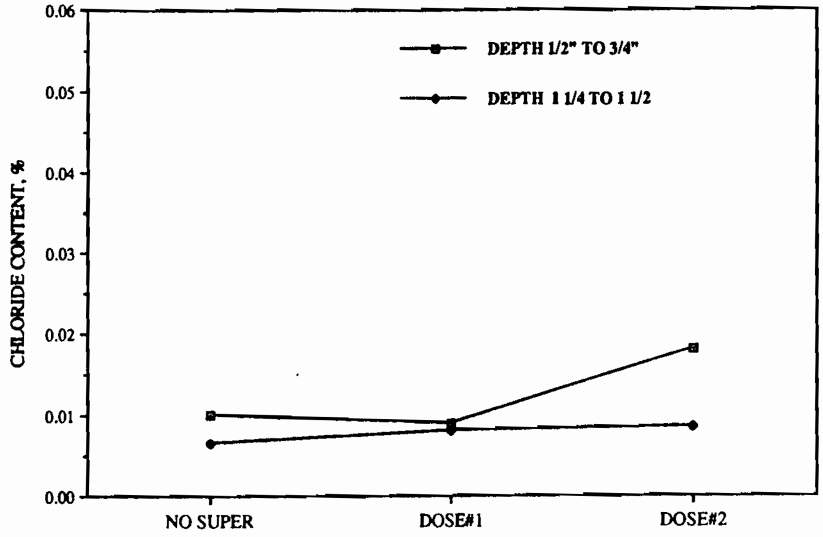
CHLORIDE PENETRATION RESISTANCE OF MIX 3

7 Sks, 3/4"Gravel,300R Retarder, MB 400N SUPER



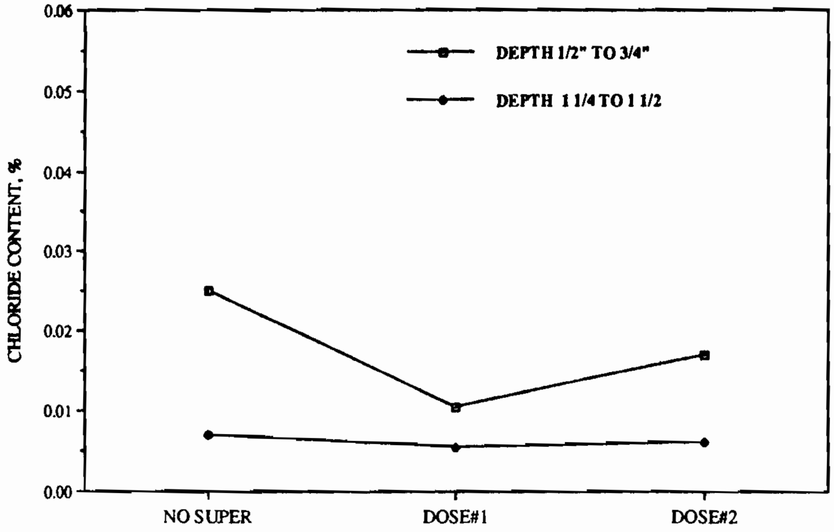
CHLORIDE PENETRATION RESISTANCE OF MIX 4

7 Sks, 3/4"Gravel,No Retarder, MB 400N SUPER



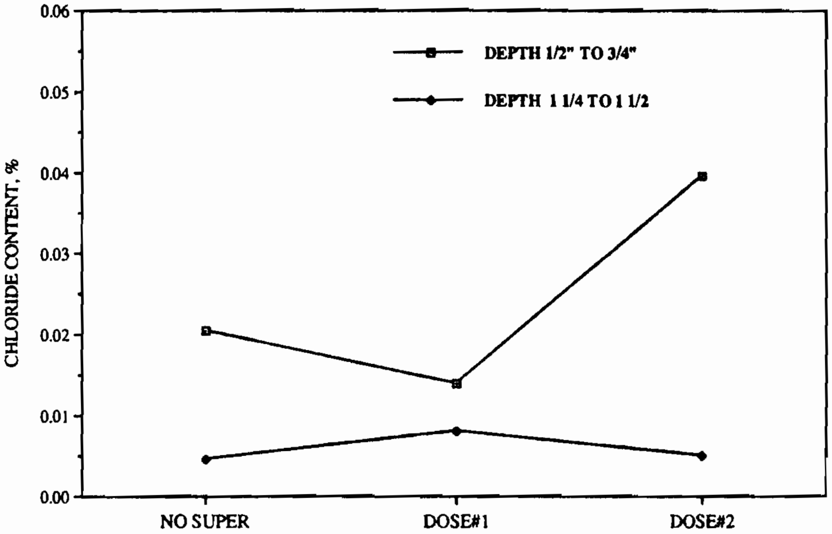
CHLORIDE PENETRATION RESISTANCE OF MIX 5

5 Sks, 3/4"Gravel,300R Retarder, MELMENT L10 SUPER



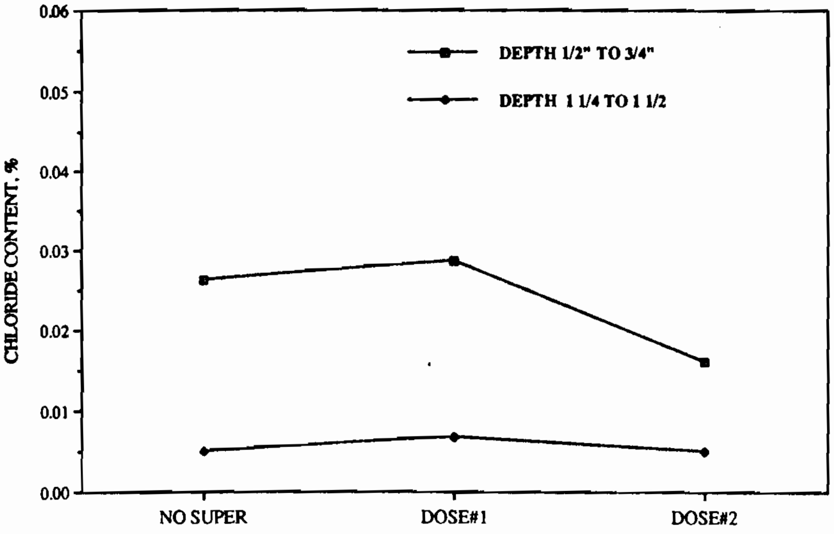
CHLORIDE PENETRATION RESISTANCE OF MIX 6

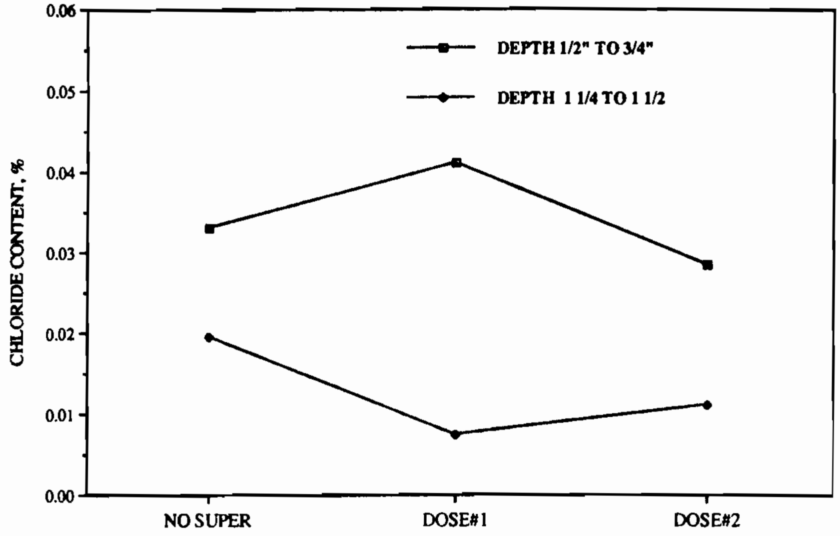
5 Sks, 3/4"Gravel,No Retarder, MELMENT L10 SUPER



CHLORIDE PENETRATION RESISTANCE OF MIX 7

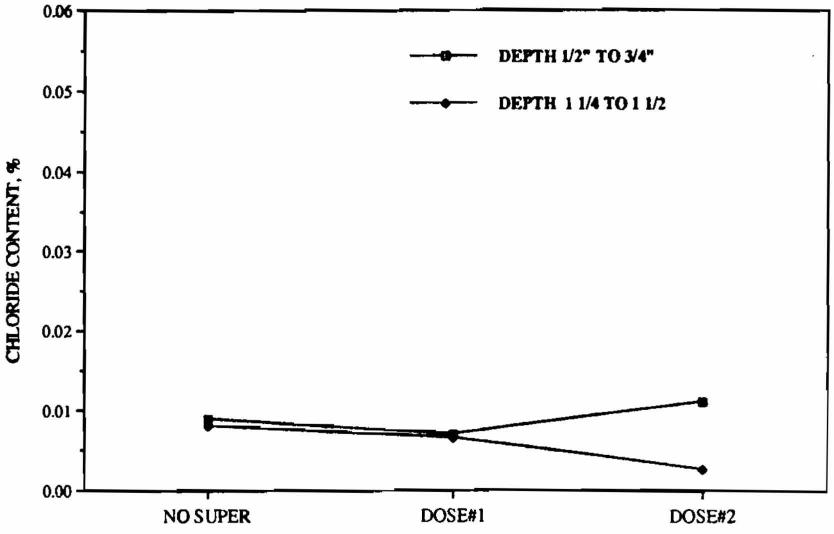
7 Sks, 3/4"Gravel,No Retarder, MELMENT L10 SUPER





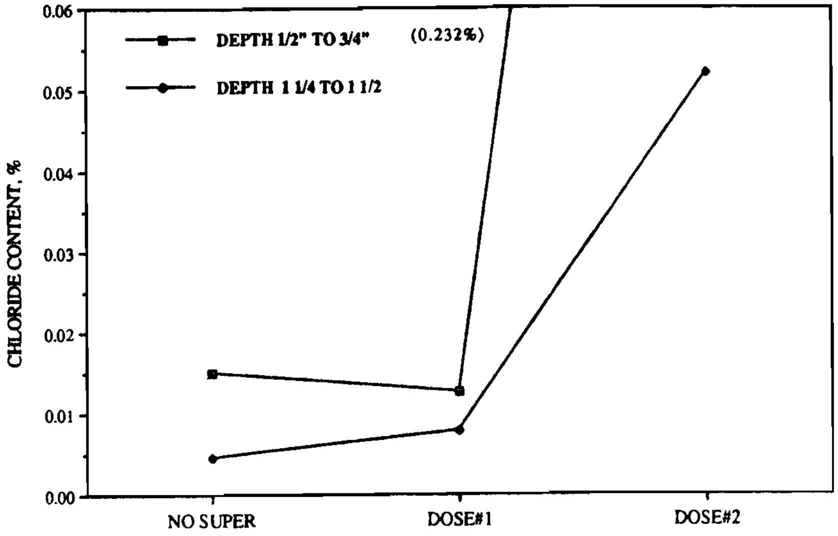
CHLORIDE PENETRATION RESISTANCE OF MIX 8

7 Sks, 3/4"Gravel,300R Retarder, MELMENT L10 SUPER



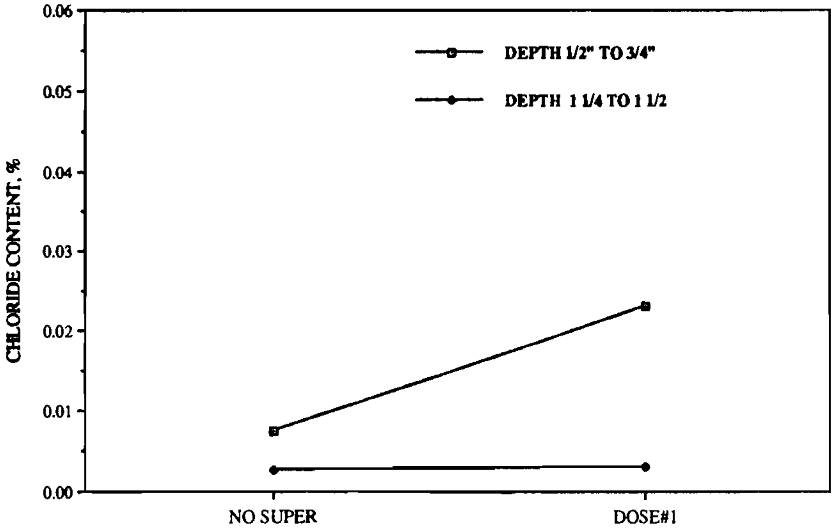
CHLORIDE PENETRATION RESISTANCE OF MIX 9

5 Sks, 3/4"Gravel,300R Retarder, MB 400N SUPER



CHLORIDE PENETRATION RESISTANCE OF MIX 10

7 Sks, 3/4"Gravel,300R Retarder, MB 400N SUPER

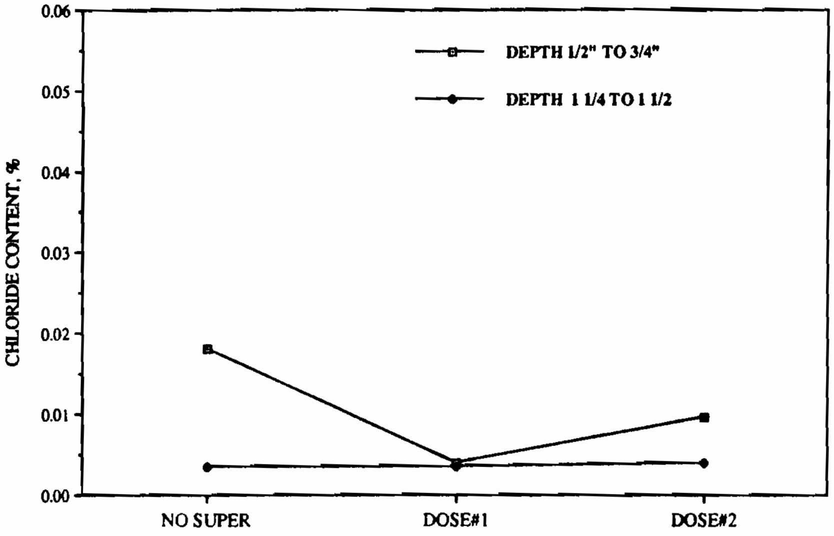


CHLORIDE PENETRATION RESISTANCE OF MIX 12

7 Sks, 3/4"Limestone,300R Retarder, MB 400N SUPER

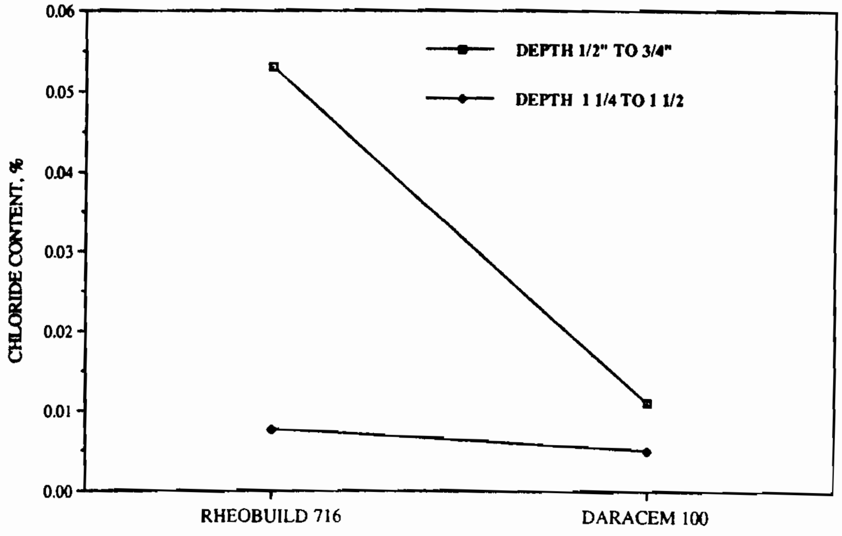
CHLORIDE PENETRATION RESISTANCE OF MIX 13

7 Sks, 3/4"Limestone,300R Retarder, MB 400N SUPER



CHLORIDE PENETRATION RESISTANCE OF MIXES 14 AND 15

5 Sks, 3/4"Gravel,Second Generation Superplasticizers



APPENDIX C1

TABULATED RESULTS OF COMPRESSIVE STRENGTH TESTS OF 7 AND 28 DAYS OF ALL MIXES

Mix #1	COMPRESSIVE STRENGTH (psi)					
5 Sks Gravel	7-Days			28-Days		
300R, 400N	No Super	Dose#1	Dose#2	No Super	Dose#1	Dose#2
Specimen 1	5443.4	6103.7	7062.8	6182.1	7968.7	8144.2
Specimen 2	5335.8	6609.4	7310.5	6183.1	7760.8	7960.3
Specimen 3	5386.9	6542.5	6990.7	6244.7	7599.9	8065.8
Average	5388.7	6418.5	7121.3	6203.3	7776.5	8056.8
Stand. Deviation	53.8	274.7	167.7	35.9	184.9	92.3
Coef. of Variation	1.0	4.3	2.4	0.6	2.4	1.1

Mix #2	COMPRESSIVE STRENGTH (psi)					
5 Sks Gravel	7-Days			28-Days		
No Ret., 400N	No Super	Dose#1	Dose#2	No Super	Dose#1	Dose#2
Specimen 1	5189.5	7376.3	7611.4	6191.5	6916.6	9081.4
Specimen 2	5252.2	7005.4	8264.4	5968.9	7992.7	8525.6
Specimen 3	5214.9	7142.9	7989.2	6152.0	7750.7	8864.8
Average	5218.9	7174.9	7955.0	6104.1	7553.3	8823.9
Stand. Deviation	31.5	187.5	327.8	118.8	564.5	280.1
Coef. of Variation	0.6	2.6	4.1	1.9	7.5	3.2

Mix #3	COMPRESSIVE STRENGTH (psi)					
7 Sks Gravel	7-Days			28-Days		
300R, 400N	No Super	Dose#1	Dose#2	No Super	Dose#1	Dose#2
Specimen 1	6464.2	8712.6	8981.1	7072.2	10622.5	9800.0
Specimen 2	6437.0	8542.3	8416.9	7233.1	9882.7	9799.2
Specimen 3	6398.0	9131.5	8599.7	7054.5	10140.8	8968.6
Average	6433.1	8795.5	8665.9	7119.9	10215.3	9522.6
Stand. Deviation	33.3	303.2	287.9	98.4	375.5	479.8
Coef. of Variation	0.5	3.4	3.3	1.4	3.7	5.0

Mix #4	COMPRESSIVE STRENGTH (psi)					
7 Sks Gravel	7-Days			28-Days		
No Ret., 400N	No Super	Dose#1	Dose#1*	No Super	Dose#1	Dose#1*
Specimen 1	7283.3	6148.6	7053.4	7933.2	6337.7	7551.8
Specimen 2	7143.3	5905.2	6913.4	8063.8	6436.0	7321.9
Specimen 3	7389.8	5935.5	6636.6	7884.1	6618.8	6961.5
Average	7272.1	5996.4	6867.8	7960.4	6464.2	7278.4
Stand. Deviation	123.6	132.6	212.1	92.9	142.7	297.5
Coef. of Variation	1.7	2.2	3.1	1.2	2.2	4.1

* Specimens cast from the same concrete as Dose#1, 70 minutes later when the concrete was 2 1/2 hours old.

Mix #5	COMPRESSIVE STRENGTH (psi)					
5 Sks Gravel	7-Days			28-Days		
300R, Mel. L10	No Super	Dose#1	Dose#2	No Super	Dose#1	Dose#2
Specimen 1	4932.5	6689.8	7519.4	6300.0	8311.4	8874.5
Specimen 2	4892.8	6976.1	7509	6168.5	8489.0	8836.9
Specimen 3	5085.0	7004.3	7144.3	6078.6	8627.9	8932.0
Average	4970.1	6890.1	7390.9	6182.4	8476.1	8881.1
Stand. Deviation	101.5	174.0	213.6	111.3	158.6	47.9
Coef. of Variation	2.0	2.5	2.9	1.8	1.9	0.5

Mix #6	COMPRESSIVE STRENGTH (psi)					
5 Sks Gravel	7-Days			28-Days		
No Ret., Mel. L10	No Super	Dose#1	Dose#2	No Super	Dose#1	Dose#2
Specimen 1	4953.4	5367.1	5773.6	5998.2	6664.8	7170.5
Specimen 2	4789.4	5342.1	5941.8	5928.2	6831.9	7046.1
Specimen 3	4422.6	5411.3	6083.9	5954.3	6770.3	7128.7
Average	4721.8	5373.5	5933.1	5960.2	6755.7	7115.1
Stand. Deviation	271.8	35.0	155.3	35.4	84.5	63.3
Coef. of Variation	5.8	0.7	2.6	0.6	1.3	0.9

Mix #7	COMPRESSIVE STRENGTH (psi)					
7 Sks Gravel	7-Days			28-Days		
No Ret., Mel. L10	No Super	Dose#1	Dose#2	No Super	Dose#1	Dose#2
Specimen 1	7234.2	7011.65	8407.5	7914.4	9073.0	9426.2
Specimen 2	7537.2	8104.51	8223.61	8015.7	8881.8	9506.6
Specimen 3	7454.6	8167.19	8218.39	8829.6	8549.6	9634.1
Average	7408.7	7761.1	8283.2	8253.2	8834.8	9522.3
Stand. Deviation	156.6	649.8	107.7	501.7	264.8	104.8
Coef. of Variation	2.1	8.4	1.3	6.1	3.0	1.1

Mix #8	COMPRESSIVE STRENGTH (psi)					
7 Sks Gravel	7-Days			28-Days		
300R, Mel. L10	No Super	Dose#1	Dose#2	No Super	Dose#1	Dose#2
Specimen 1	5769.4	6322.1	7005.4	6649.1	7186.1	7724.2
Specimen 2	5797.6	6287.6	7032.5	6302.2	6851.8	7933.2
Specimen 3	5667.0	6011.8	6628.2	6317.9	7128.7	7754.5
Average	5744.7	6207.2	6888.7	6423.1	7055.5	7804.0
Stand. Deviation	68.7	170.1	226.0	195.9	178.8	112.9
Coef. of Variation	1.2	2.7	3.3	3.1	2.5	1.4

Mix #9	COMPRESSIVE STRENGTH (psi)					
5 Sks Gravel 300R, 400N	7-Days			28-Days		
	No Super	Dose#1	Dose#2	No Super	Dose#1	Dose#2
Specimen 1	6535.2	6567.61	7057.62	7473.5	7594.7	8272.7
Specimen 2	6363.9	6640.75	7100.46	7474.5	7411.8	8387.7
Specimen 3	6624.0	6248.95	6838.21	7359.6	7579.0	8047.1
Average	6507.7	6485.8	6998.8	7435.8	7528.5	8235.8
Stand. Deviation	132.2	208.3	140.7	66.1	101.3	173.3
Coef. of Variation	2.0	3.2	2.0	0.9	1.3	2.1

Mix #10	COMPRESSIVE STRENGTH (psi)					
7 Sks Gravel 300R, 400N	7-Days			28-Days		
	No Super	Dose#1	Dose#2	No Super	Dose#1	Dose#2
Specimen 1	6073.4	6123.57	7250.91	6819.4	6235.4	8428.4
Specimen 2	5799.7	6248.94	7549.72	6789.1	6982.4	8172.4
Specimen 3	5835.7	6400.44	7364.79	7148.5	7677.2	8412.7
Average	5902.9	6257.7	7388.5	6919.0	6965.0	8337.9
Stand. Deviation	148.7	138.6	150.8	199.3	721.1	143.5
Coef. of Variation	2.5	2.2	2.0	2.9	10.4	1.7

Mix #11	COMPRESSIVE STRENGTH (psi)					
5 Sks Limestone 300R, 400N	7-Days			28-Days		
	No Super	Dose#1	Dose#2	No Super	Dose#1	Dose#2
Specimen 1	5924.0	6474.62	6942.69	6861.2	7221.7	7979.1
Specimen 2	5772.5	6367.01	6734.78	6992.8	7217.5	7853.8
Specimen 3	5904.2	6102.67	6802.69	6877.9	7525.7	7953.0
Average	5866.9	6314.8	6826.7	6910.7	7321.6	7928.6
Stand. Deviation	82.3	191.4	106.0	71.7	176.8	66.2
Coef. of Variation	1.4	3.0	1.6	1.0	2.4	0.8

Mix #12	COMPRESSIVE STRENGTH (psi)					
7 Sks Limestone 300R, 400N	7-Days			28-Days		
	No Super	Dose#1	Dose#2	No Super	Dose#1	Dose#2
Specimen 1	7029.4	6769.3	N/A	8072.1	7805.7	N/A
Specimen 2	6993.9	6415.1	N/A	8077.4	7737.8	N/A
Specimen 3	6974.0	7083.7	N/A	8260.2	7722.1	N/A
Average	6999.1	6756.0	N/A	8136.6	7755.2	N/A
Stand. Deviation	28.1	334.5	N/A	107.1	44.4	N/A
Coef. of Variation	0.4	5.0	N/A	1.3	0.6	N/A

N/A: A second dosage was not needed due to extended workability after the first dosage

Mix #13	COMPRESSIVE STRENGTH (psi)					
7 Sks Limestone 300R, 400N	7-Days			28-Days		
	No Super	Dose#1	Dose#2	No Super	Dose#1	Dose#2
Specimen 1	7636.4	8391.83	8802.44	7887.2	9809.6	10196.2
Specimen 2	7356.4	8344.81	2.448687	9120.1	9756.3	10138.7
Specimen 3	7920.6	8186.01	8415.86	9010.4	9344.7	9585.0
Average	7637.8	8307.6	8609.2	8672.5	9636.9	9973.3
Stand. Deviation	282.1	107.9	273.4	682.3	254.4	337.5
Coef. of Variation	3.7	1.3	3.2	7.9	2.6	3.4

Mix #14	COMPRESSIVE STRENGTH (psi)					
5 Sks Gravel Rheobuild 716	7-Days			28-Days		
	No Super	Dose#1*	Dose#2	No Super	Dose#1*	Dose#2
Specimen 1	N/A	4421.59	N/A	N/A	5793.4	N/A
Specimen 2	N/A	4867.72	N/A	N/A	5636.7	N/A
Specimen 3	N/A	4956.53	N/A	N/A	5349.4	N/A
Average	N/A	4748.6	N/A	N/A	5593.2	N/A
Stand. Deviation	N/A	286.7	N/A	N/A	225.2	N/A
Coef. of Variation	N/A	6.0	N/A	N/A	4.0	N/A

* Specimens cast with a second generation Superplasticizer. No redosage was needed.

Mix #15	COMPRESSIVE STRENGTH (psi)					
5 Sks Gravel Daracem 100	7-Days			28-Days		
	No Super	Dose#1*	Dose#2	No Super	Dose#1*	Dose#2
Specimen 1	N/A	5557.29	N/A	N/A	6457.9	N/A
Specimen 2	N/A	5687.87	N/A	N/A	6211.3	N/A
Specimen 3	N/A	5865.5	N/A	N/A	6343.0	N/A
Average	N/A	5703.6	N/A	N/A	6337.4	N/A
Stand. Deviation	N/A	154.7	N/A	N/A	123.4	N/A
Coef. of Variation	N/A	2.7	N/A	N/A	1.9	N/A

* Specimens cast with a second generation Superplasticizer. No redosage was needed.

Mix #16	COMPRESSIVE STRENGTH AT 28 DAYS (psi)				
5 Sks Gravel 300R, 400N	No Super Air=8.75%	Dose#1 Air=5.5%	Dose#1 Air=4%	Dose#1 Air=4%	Dose#2 Air=2.25%
Specimen 1	4082.0	5800.73	5920.9	6317.9	6686.7
Specimen 2	4207.4	5879.1	5941.8	6129.8	6562.4
Specimen 3	4114.4	5815.36	5898.9	6299.1	6301.2
Average	4134.6	5831.7	5920.5	6249.0	6516.8
Stand. Deviation	65.1	41.7	21.4	103.6	196.8
Coef. of Variation	1.6	0.7	0.4	1.7	3.0

APPENDIX C2

TABULATED RESULTS OF FLEXURAL STRENGTH TESTS OF 7 AND 28 DAYS OF ALL MIXES

Mix #1	FLEXURAL STRENGTH (psi)					
5 Sks Gravel 300R, 400N	7-Days			28-Days		
	No Super	Dose#1	Dose#2	No Super	Dose#1	Dose#2
Specimen 1	815.0	760	860	775.0	840.0	845.0
Specimen 2	780.0	775	860	795.0	780.0	900.0
Specimen 3	755.0	750	865	740.0	895.0	870.0
Average	783.3	761.7	861.7	770.0	838.3	871.7
Stand. Deviation	30.1	12.6	2.9	27.8	57.5	27.5
Coef. of Variation	3.8	1.7	0.3	3.6	6.9	3.2

Mix #2	FLEXURAL STRENGTH (psi)					
5 Sks Gravel No Ret., 400N	7-Days			28-Days		
	No Super	Dose#1	Dose#2	No Super	Dose#1	Dose#2
Specimen 1	705.0	825	805	800.0	840.0	820.0
Specimen 2	730.0	805	815	825.0	900.0	810.0
Specimen 3	720.0	750	785	755.0	835.0	880.0
Average	718.3	793.3	801.7	793.3	858.3	836.7
Stand. Deviation	12.6	38.8	15.3	35.5	36.2	37.9
Coef. of Variation	1.8	4.9	1.9	4.5	4.2	4.5

Mix #3	FLEXURAL STRENGTH (psi)					
7 Sks Gravel 300R, 400N	7-Days			28-Days		
	No Super	Dose#1	Dose#2	No Super	Dose#1	Dose#2
Specimen 1	890.0	1125	1058.3	1125.0	1220.8	1045.8
Specimen 2	910.0	966.6	970.8	1012.5	1179.2	1083.3
Specimen 3	985.0	962.5	916.6	1020.8	1016.6	1102.1
Average	928.3	1018.0	981.9	1052.8	1138.9	1077.1
Stand. Deviation	50.1	92.7	71.5	62.7	107.9	28.7
Coef. of Variation	5.4	9.1	7.3	6.0	9.5	2.7

Mix #4	FLEXURAL STRENGTH (psi)					
7 Sks Gravel No Ret., 400N	7-Days			28-Days		
	No Super	Dose#1	Dose#1*	No Super	Dose#1	Dose#1*
Specimen 1	879.2	833.3	904.2	1041.7	875.0	1008.3
Specimen 2	845.8	737.5	937.5	1079.2	841.7	1100.0
Specimen 3	-	854.2	895.8	1008.3	987.5	1083.3
Average	862.5	808.3	912.5	1043.1	901.4	1063.9
Stand. Deviation	23.6	62.2	22.1	35.5	76.4	48.8
Coef. of Variation	2.7	7.7	2.4	3.4	8.5	4.6

* Specimens cast from the same concrete as Dose#1, 70 minutes later when the concrete was 2 1/2 hours old.

Mix #5	FLEXURAL STRENGTH (psi)					
5 Sks Gravel	7-Days			28-Days		
300R, Mel. L10	No Super	Dose#1	Dose#2	No Super	Dose#1	Dose#2
Specimen 1	735.0	755	765	805.0	895.0	850.0
Specimen 2	680.0	755	735	740.0	872.0	905.0
Specimen 3	780.0	810	750	825.0	870.0	845.0
Average	731.7	773.3	750.0	790.0	879.0	866.7
Stand. Deviation	50.1	31.8	15.0	44.4	13.9	33.3
Coef. of Variation	6.8	4.1	2.0	5.6	1.6	3.8

Mix #6	FLEXURAL STRENGTH (psi)					
5 Sks Gravel	7-Days			28-Days		
No Ret., Mel. L10	No Super	Dose#1	Dose#2	No Super	Dose#1	Dose#2
Specimen 1	590.0	685	685	720.0	810.0	795.0
Specimen 2	605.0	700	665	785.0	875.0	870.0
Specimen 3	605.0	645	720	800.0	820.0	865.0
Average	600.0	676.7	690.0	768.3	835.0	843.3
Stand. Deviation	8.7	28.4	27.8	42.5	35.0	41.9
Coef. of Variation	1.4	4.2	4.0	5.5	4.2	5.0

Mix #7	FLEXURAL STRENGTH (psi)					
7 Sks Gravel	7-Days			28-Days		
No Ret., Mel. L10	No Super	Dose#1	Dose#2	No Super	Dose#1	Dose#2
Specimen 1	995.8	966.6	1054.2	1104.2	1141.7	1216.7
Specimen 2	1008.3	808.3	895.8	1066.7	1091.7	1179.2
Specimen 3	870.8	1100	1004.2	1137.5	1141.7	1145.8
Average	958.3	958.3	984.7	1102.8	1125.0	1180.6
Stand. Deviation	76.0	146.0	81.0	35.4	28.9	35.5
Coef. of Variation	7.9	15.2	8.2	3.2	2.6	3.0

Mix #8	FLEXURAL STRENGTH (psi)					
7 Sks Gravel	7-Days			28-Days		
300R, Mel. L10	No Super	Dose#1	Dose#2	No Super	Dose#1	Dose#2
Specimen 1	840.0	785	795	845.0	855.0	890.0
Specimen 2	820.0	775	860	845.0	830.0	848*
Specimen 3	840.0	725	785	870.0	880.0	-
Average	833.3	761.7	813.3	853.3	855.0	869.0
Stand. Deviation	11.5	32.1	40.7	14.4	25.0	29.7
Coef. of Variation	1.4	4.2	5.0	1.7	2.9	3.4

* Value obtained from compression test on 3x6 in. cylinder cores based on MOR= K (f'c^ 1/2), where K is a constant determined from the actual compressive strength at 28 days.

Mix #9	FLEXURAL STRENGTH AT 7 DAYS, (psi)					
5 Sks Gravel 300R, 400N	Specimen 1	Specimen 2	Specimen 3	Average	Standard Deviation	Coeff. of Variation
No Super	780.0	750	725	751.7	27.5	3.7
Dose#1	770.0	785	760	771.7	12.6	1.6
Dose#2	785.0	790	715	763.3	41.9	5.5

Mix #10	FLEXURAL STRENGTH AT 7 DAYS, (psi)					
7 Sks Gravel 300R, 400N	Specimen 1	Specimen 2	Specimen 3	Average	Standard Deviation	Coeff. of Variation
No Super	695.0	755	690	713.3	36.2	5.1
Dose#1	770.0	885	825	826.7	57.5	7.0
Dose#2	760.0	780	790	776.7	15.3	2.0

Mix #11	FLEXURAL STRENGTH AT 7 DAYS, (psi)					
5 Sks Limestone 300R, 400N	Specimen 1	Specimen 2	Specimen 3	Average	Standard Deviation	Coeff. of Variation
No Super	745.0	735	705	728.3	20.8	2.9
Dose#1	760.0	765	775	766.7	7.6	1.0
Dose#2	745.0	780	760	761.7	17.6	2.3

Mix #12	FLEXURAL STRENGTH AT 7 DAYS, (psi)					
7 Sks Limestone 300R, 400N	Specimen 1	Specimen 2	Specimen 3	Average	Standard Deviation	Coeff. of Variation
No Super	855.0	865	875	865.0	10.0	1.2
Dose#1	855.0	880	855	863.3	14.4	1.7
Dose#2	N/A	N/A	N/A	N/A	N/A	N/A

N/A: A second dosage was not needed due to
extended workability after the first dosage

Mix #13	FLEXURAL STRENGTH AT 7 DAYS, (psi)					
7 Sks Limestone 300R, 400N	Specimen 1	Specimen 2	Specimen 3	Average	Standard Deviation	Coeff. of Variation
No Super	835.0	945	910	896.7	56.2	6.3
Dose#1	900.0	940	900	913.3	23.1	2.5
Dose#2	975.0	940	925	946.7	25.7	2.7

Mixes # 14 and 15	FLEXURAL STRENGTH AT 7 DAYS, (psi)					
5 Sks Gravel 2nd Generation	Specimen 1	Specimen 2	Specimen 3	Average	Standard Deviation	Coeff. of Variation
Rheobuild 716	600.0	700	665	655.0	50.7	7.7
Daracem 100	700.0	695	765	720.0	39.1	5.4

APPENDIX C3

TABULATED RESULTS OF FREEZE-THAW RESISTANCE FOR MIXES 1 THROUGH 16

MIX 1 (NO SUPER)								DURABILITY FACTOR= 97.18			
No. of Cycles	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1848.00	1917.00	1850.00	7.419	7.548	7.448	7.472	100.00	100.00	100.00	100.00
31	1844.00	1911.00	1847.00	7.430	7.557	7.464	7.484	99.57	99.38	99.68	99.54
67	1830.00	1901.00	1840.00	7.429	7.557	7.466	7.484	98.06	98.34	98.92	98.44
95	1830.00	1899.00	1840.00	7.427	7.554	7.462	7.481	98.06	98.13	98.92	98.37
120	1830.00	1897.00	1838.00	7.426	7.554	7.464	7.481	98.06	97.92	98.71	98.23
147	1825.00	1895.00	1838.00	7.421	7.553	7.463	7.479	97.53	97.72	98.71	97.98
177	1825.00	1895.00	1838.00	7.416	7.549	7.461	7.475	97.53	97.72	98.71	97.98
198	1825.00	1893.00	1834.00	7.413	7.548	7.462	7.474	97.53	97.51	98.28	97.77
244	1825.00	1893.00	1834.00	7.413	7.550	7.461	7.475	97.53	97.51	98.28	97.77
292	1824.00	1893.00	1830.00	7.400	7.550	7.455	7.468	97.42	97.51	97.85	97.59
317	1823.00	1882.00	1830.00	7.397	7.548	7.448	7.464	97.31	96.38	97.85	97.18

MIX 1 (DOSE #1)								DURABILITY FACTOR= 67.04			
No. of Cycles	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1909.00	1892.00	1883.00	7.660	7.589	7.638	7.629	100.00	100.00	100.00	100.00
31	1892.00	1866.00	1862.00	7.675	7.606	7.654	7.645	98.23	97.27	97.78	97.76
67	1877.00	1852.00	1846.00	7.682	7.614	7.663	7.653	96.68	95.82	96.11	96.20
95	1866.00	1830.00	1822.00	7.686	7.621	7.669	7.659	95.55	93.55	93.63	94.24
120	1857.00	1823.00	1802.00	7.690	7.624	7.674	7.663	94.63	92.84	91.58	93.02
147	1846.00	1793.00	1779.00	7.690	7.631	7.681	7.667	93.51	89.81	89.26	90.86
177	1825.00	1750.00	1705.00	7.692	7.631	7.682	7.668	91.39	85.55	81.99	86.31
198	1798.00	1704.00	1640.00	7.696	7.634	7.681	7.670	88.71	81.11	75.86	81.89
244	1769.00	1680.00	1588.00	7.693	7.634	7.676	7.668	85.87	78.85	71.12	78.61
292	1741.00	1634.00	1475.00	7.696	7.632	7.676	7.668	83.17	74.59	61.36	73.04
317	1679.00	1554.00	1413.00	7.688	7.630	7.670	7.663	77.36	67.46	56.31	67.04

MIX 1 (DOSE #2)								DURABILITY FACTOR= 8.57			
No. of Cycles	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1895.00	1904.00	1902.00	7.657	7.642	7.629	7.643	100.00	100.00	100.00	100.00
31	1661.00	1626.00	1544.00	7.700	7.691	7.681	7.691	76.83	72.93	65.90	71.89
67	1111.00	1246.00	1172.00	7.720	7.696	7.689	7.702	34.37	42.83	37.97	38.39

MIX 2 (NO SUPER)								DURABILITY FACTOR= 94.52			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1892.00	1869.00	1895.00	7.547	7.527	7.549	7.541	100.00	100.00	100.00	100.00
31	1878.00	1854.00	1876.00	7.565	7.543	7.564	7.557	98.53	98.40	98.00	98.31
67	1873.00	1845.00	1876.00	7.567	7.541	7.567	7.558	98.00	97.45	98.00	97.82
95	1873.00	1836.00	1869.00	7.568	7.540	7.567	7.558	98.00	96.50	97.27	97.26
120	1871.00	1827.00	1868.00	7.566	7.535	7.567	7.556	97.79	95.56	97.17	96.84
147	1870.00	1823.00	1861.00	7.568	7.533	7.567	7.556	97.69	95.14	96.44	96.42
177	1870.00	1823.00	1860.00	7.565	7.525	7.564	7.551	97.69	95.14	96.34	96.39
198	1860.00	1818.00	1860.00	7.564	7.520	7.561	7.548	96.65	94.62	96.34	95.87
244	1855.00	1818.00	1860.00	7.568	7.515	7.561	7.548	96.13	94.62	96.34	95.69
292	1854.00	1818.00	1860.00	7.558	7.513	7.558	7.543	96.02	94.62	96.34	95.66
317	1844.00	1810.00	1845.00	7.554	7.510	7.553	7.539	94.99	93.79	94.79	94.52

MIX 2 (DOSE #1)								DURABILITY FACTOR= 6.01			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1922.00	1949.00	1928.00	7.617	7.718	7.636	7.657	100.00	100.00	100.00	100.00
31	1666.00	1683.00	1706.00	7.650	7.760	7.674	7.695	75.14	74.57	78.30	76.00
67	964.00	1078.00	963.00	7.680	7.781	7.708	7.723	25.16	30.59	24.95	26.90

MIX 2 (DOSE #2)								DURABILITY FACTOR= 5.23			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1918.00	1944.00	1946.00	7.700	7.657	7.709	7.689	100.00	100.00	100.00	100.00
31	1390.00	1413.00	1329.00	7.754	7.711	7.767	7.744	52.52	52.83	46.64	50.66

MIX 3 (NO SUPER)								DURABILITY FACTOR= 97.61			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1915.00	1923.00	1894.00	7.775	7.725	7.668	7.723	100.00	100.00	100.00	100.00
31	1898.00	1919.00	1885.00	7.783	7.731	7.673	7.729	98.23	99.58	99.05	98.96
67	1892.00	1917.00	1883.00	7.780	7.731	7.673	7.728	97.61	99.38	98.84	98.61
95	1898.00	1914.00	1881.00	7.779	7.726	7.675	7.727	98.23	99.07	98.63	98.64
120	1886.00	1912.00	1881.00	7.779	7.726	7.673	7.726	96.99	98.86	98.63	98.16
147	1886.00	1910.00	1881.00	7.781	7.725	7.674	7.727	96.99	98.65	98.63	98.09
177	1885.00	1910.00	1880.00	7.779	7.724	7.673	7.725	96.89	98.65	98.53	98.02
198	1881.00	1910.00	1879.00	7.779	7.724	7.673	7.725	96.48	98.65	98.42	97.85
244	1880.00	1910.00	1878.00	7.779	7.724	7.674	7.726	96.38	98.65	98.32	97.78
292	1879.00	1910.00	1877.00	7.781	7.724	7.674	7.726	96.28	98.65	98.21	97.71
317	1879.00	1908.00	1876.00	7.782	7.725	7.674	7.727	96.28	98.45	98.11	97.61

MIX 3 (DOSE #1)								DURABILITY FACTOR= 29.49			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1919.00	1956.00	1960.00	7.684	7.858	7.826	7.789	100.00	100.00	100.00	100.00
31	1916.00	1951.00	1956.00	7.689	7.861	7.829	7.793	99.69	99.49	99.59	99.59
67	1911.00	1948.00	1956.00	7.692	7.862	7.830	7.795	99.17	99.18	99.59	99.31
95	1905.00	1941.00	1956.00	7.696	7.868	7.832	7.799	98.55	98.47	99.59	98.87
120	1877.00	1787.00	1946.00	7.703	7.882	7.837	7.807	95.67	83.47	98.58	92.57
147	1781.00	1318.00	1822.00	7.718	7.909	7.852	7.826	86.13	45.40	86.41	72.65
177	1367.00	N/A	1375.00	7.743	N/A	7.866	7.805	50.74	N/A	49.21	49.98

MIX 3 (DOSE #2)								DURABILITY FACTOR= 25.70			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1907.00	1902.00	1948.00	7.678	7.625	7.715	7.673	100.00	100.00	100.00	100.00
31	1900.00	1897.00	1909.00	7.683	7.630	7.721	7.678	99.27	99.47	96.04	98.26
67	1905.00	1897.00	1909.00	7.684	7.630	7.720	7.678	99.79	99.47	96.04	98.43
95	1905	1897	1906	7.683	7.634	7.724	7.680	99.79	99.47	95.73	98.33
120	1905	1892	1899	7.684	7.634	7.731	7.683	100.00	98.95	95.03	97.99
147	1893	1871	1795	7.688	7.645	7.757	7.697	98.54	96.77	84.91	93.40
177	1859	1653	1160	7.702	7.672	7.792	7.722	95.03	75.53	35.46	68.67
198	1616	1193	N/A	7.720	7.693	N/A	7.707	71.81	39.34	N/A	55.58
244	1072	N/A	"	7.761	N/A	"	7.761	31.60	N/A	N/A	31.60

N/A: Specimen was removed out of the freezer
because its dynamic modulus dropped below 60%.

MIX 4 (NO SUPER)								DURABILITY FACTOR= 97.67			
No. of Cycles	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1892.00	1894.00	1923.00	7.550	7.622	7.665	7.612	100.00	100.00	100.00	100.00
28	1886.00	1880.00	1909.00	7.556	7.626	7.672	7.618	99.37	98.53	98.55	98.81
58	1878.00	1878.00	1908.00	7.559	7.628	7.676	7.621	98.53	98.32	98.45	98.43
79	1873.00	1873.00	1900.00	7.557	7.628	7.676	7.620	98.00	97.79	97.62	97.81
125*	1880.00	1883.00	1904.00	7.559	7.630	7.680	7.623	98.74	98.84	98.03	98.54
173	1880.00	1875.00	1894.00	7.560	7.631	7.680	7.624	98.74	98.00	97.01	97.92
198	1880.00	1873.00	1894.00	7.560	7.630	7.677	7.622	98.74	97.79	97.01	97.85
227	1880.00	1872.00	1894.00	7.562	7.631	7.675	7.623	98.74	97.69	97.01	97.81
266	1880.00	1872.00	1894.00	7.562	7.631	7.672	7.622	98.74	97.69	97.01	97.81
304	1880.00	1872.00	1890.00	7.561	7.631	7.667	7.620	98.74	97.69	96.60	97.67

MIX 4 (DOSE #1)								DURABILITY FACTOR= 98.54			
No. of Cycles	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1846.00	1868.00	1871.00	7.311	7.468	7.401	7.393	100.00	100.00	100.00	100.00
28	1832.00	1864.00	1861.00	7.314	7.471	7.405	7.397	98.49	99.57	98.93	99.00
58	1831.00	1859.00	1862.00	7.316	7.472	7.406	7.398	98.38	99.04	99.04	98.82
79	1827.00	1856.00	1857.00	7.316	7.472	7.406	7.398	97.95	98.72	98.51	98.39
125*	1835.00	1856.00	1861.00	7.319	7.476	7.409	7.401	98.81	98.72	98.93	98.82
173	1834.00	1856.00	1861.00	7.319	7.476	7.410	7.402	98.70	98.72	98.93	98.79
198	1834.00	1856.00	1858.00	7.320	7.475	7.410	7.402	98.70	98.72	98.62	98.68
227	1834.00	1856.00	1856.00	7.321	7.478	7.410	7.403	98.70	98.72	98.40	98.61
266	1834.00	1856.00	1856.00	7.320	7.478	7.410	7.403	98.70	98.72	98.40	98.61
304	1833.00	1855.00	1856.00	7.318	7.478	7.410	7.402	98.60	98.61	98.40	98.54

MIX 4 (DOSE #1**)								DURABILITY FACTOR= 97.44			
No. of Cycles	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1883.00	1889.00	1902.00	7.505	7.524	7.621	7.550	100.00	100.00	100.00	100.00
28	1865.00	1884.00	1894.00	7.511	7.528	7.624	7.554	98.10	99.47	99.16	98.91
58	1866.00	1877.00	1887.00	7.511	7.529	7.626	7.555	98.20	98.73	98.43	98.45
79	1862.00	1874.00	1880.00	7.512	7.530	7.627	7.556	97.78	98.42	97.70	97.97
125*	1864.00	1878.00	1884.00	7.514	7.534	7.630	7.559	97.99	98.84	98.12	98.32
173	1864.00	1878.00	1884.00	7.514	7.534	7.630	7.559	97.99	98.84	98.12	98.32
198	1856.00	1877.00	1881.00	7.514	7.535	7.629	7.559	97.15	98.73	97.80	97.90
227	1856.00	1875.00	1881.00	7.515	7.535	7.631	7.560	97.15	98.52	97.80	97.83
266	1856.00	1875.00	1880.00	7.514	7.536	7.631	7.560	97.15	98.52	97.70	97.79
304	1855.00	1870.00	1876.00	7.514	7.536	7.630	7.560	97.05	98.00	97.28	97.44

* The test was interrupted. The specimens were submerged in water for 1 day.

** Specimens cast from same concrete as Dose#1, 70 minutes later when the concrete was 2 1/2 hours old.

MIX 5 (NO SUPER)								DURABILITY FACTOR= 98.43			
No. of Cycles	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1871.00	1873.00	1843.00	7.534	7.597	7.457	7.529	100.00	100.00	100.00	100.00
32	1856.00	1861.00	1836.00	7.545	7.607	7.467	7.540	98.40	98.72	99.24	98.79
68	1853.00	1859.00	1836.00	7.551	7.611	7.472	7.545	98.09	98.51	99.24	98.61
104	1853.00	1859.00	1836.00	7.554	7.613	7.471	7.546	98.09	98.51	99.24	98.61
135	1853.00	1859.00	1834.00	7.557	7.616	7.474	7.549	98.09	98.51	99.03	98.54
165	1853.00	1856.00	1834.00	7.556	7.618	7.474	7.549	98.09	98.19	99.03	98.43
199	1853.00	1856.00	1834.00	7.557	7.618	7.474	7.550	98.09	98.19	99.03	98.43
237	1853.00	1856.00	1834.00	7.557	7.617	7.472	7.549	98.09	98.19	99.03	98.43
268	1853.00	1856.00	1834.00	7.561	7.622	7.474	7.552	98.09	98.19	99.03	98.43
301	1853.00	1856.00	1834.00	7.561	7.622	7.473	7.552	98.09	98.19	99.03	98.43

MIX 5 (DOSE #1)								DURABILITY FACTOR= 16.73			
No. of Cycles	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1905.00	1874.00	1862.00	7.640	7.607	7.557	7.601	100.00	100.00	100.00	100.00
32	1817.00	1808.00	1793.00	7.666	7.631	7.581	7.626	90.97	93.08	92.73	92.26
68	1635.00	1708.00	1656.00	7.693	7.652	7.604	7.650	73.66	83.07	79.10	78.61
104	1353.00	1214.00	1347.00	7.697	7.662	7.615	7.658	50.44	41.97	52.33	48.25

MIX 5 (DOSE #2)								DURABILITY FACTOR= 5.43			
No. of Cycles	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1920.00	1882.00	1864.00	7.648	7.562	7.638	7.616	100.00	100.00	100.00	100.00
32	1611.00	1616.00	1421.00	7.693	7.605	7.684	7.661	70.40	73.73	58.12	67.42
68	961.00	930.00	881.00	7.511	7.529	7.626	7.555	25.05	24.42	22.34	23.94

MIX 6 (NO SUPER)								DURABILITY FACTOR= 96.17			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1855.00	1835.00	1841.00	7.510	7.474	7.434	7.473	100.00	100.00	100.00	100.00
29	1846.00	1824.00	1823.00	7.518	7.481	7.440	7.480	99.03	98.80	98.05	98.63
59	1846.00	1816.00	1816.00	7.518	7.483	7.442	7.481	99.03	97.94	97.30	98.09
93	1846.00	1816.00	1816.00	7.520	7.485	7.442	7.482	99.03	97.94	97.30	98.09
131	1846.00	1815.00	1813.00	7.520	7.483	7.440	7.481	99.03	97.83	96.98	97.95
162	1846.00	1807.00	1813.00	7.522	7.482	7.434	7.479	99.03	96.97	96.98	97.66
195	1845.00	1806.00	1806.00	7.521	7.481	7.429	7.477	98.92	96.86	96.23	97.34
226	1842.00	1792.00	1806.00	7.517	7.477	7.428	7.474	98.60	95.37	96.23	96.74
267	1842.00	1784.00	1804.00	7.521	7.477	7.429	7.476	98.60	94.52	96.02	96.38
296*	1847.00	1799.00	1809.00	7.516	7.470	7.424	7.470	99.14	96.11	96.55	97.27
311	1841.00	1780.00	1803.00	7.516	7.470	7.419	7.468	98.50	94.10	95.91	96.17

MIX 6 (DOSE #1)								DURABILITY FACTOR= 85.15			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1917.00	1876.00	1871.00	7.556	7.583	7.500	7.546	100.00	100.00	100.00	100.00
29	1883.00	1846.00	1825.00	7.567	7.596	7.520	7.561	96.48	96.83	95.14	96.15
59	1871.00	1824.00	1802.00	7.571	7.599	7.528	7.566	95.26	94.53	92.76	94.18
93	1869.00	1813.00	1788.00	7.575	7.605	7.534	7.571	95.05	93.40	91.32	93.26
131	1869.00	1798.00	1767.00	7.579	7.608	7.534	7.574	95.05	91.86	89.19	92.03
162	1868.00	1798.00	1767.00	7.582	7.612	7.539	7.578	94.95	91.86	89.19	92.00
195	1863.00	1777.00	1767.00	7.585	7.613	7.540	7.579	94.45	89.72	89.19	91.12
226	1853.00	1757.00	1739.00	7.584	7.613	7.540	7.579	93.43	87.72	86.39	89.18
267	1844.00	1720.00	1711.00	7.588	7.618	7.541	7.582	92.53	84.06	83.63	86.74
296*	1854.00	1742.00	1719.00	7.59	7.612	7.530	7.576	93.54	86.22	84.41	88.06
311	1843.00	1704.00	1679.00	7.590	7.619	7.538	7.582	92.43	82.50	80.53	85.15

MIX 6 (DOSE #2)								DURABILITY FACTOR= 14.66			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1847.00	1886.00	1899.00	7.464	7.576	7.587	7.542	100.00	100.00	100.00	100.00
29	1744.00	1770.00	1776.00	7.498	7.615	7.623	7.579	89.16	88.08	87.47	88.23
59	1495.00	1585.00	1661.00	7.519	7.634	7.637	7.597	65.52	70.63	76.50	70.88
93	1181.00	1368.00	1321.00	7.522	7.636	7.649	7.602	40.89	52.61	48.39	47.30

* The test was interrupted. The specimens
were submerged in water for 2 days.

MIX 7 (NO SUPER)								DURABILITY FACTOR= 78.51			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1834.00	1855.00	1954.00	7.721	7.764	7.809	7.765	100.00	100.00	100.00	100.00
29	1818.00	1826.00	1951.00	7.744	7.772	7.815	7.777	98.26	96.90	99.69	98.28
59	1796.00	1807.00	1940.00	7.745	7.777	7.819	7.780	95.90	94.89	98.57	96.45
93	1738.00	1772.00	1933.00	7.748	7.779	7.819	7.782	89.81	91.25	97.86	92.97
131	1682.00	1752.00	1931.00	7.750	7.783	7.822	7.785	84.11	89.20	97.66	90.32
162	1659.00	1710.00	1928.00	7.751	7.784	7.822	7.786	81.83	84.98	97.36	88.05
195	1599.00	1691.00	1924.00	7.754	7.790	7.825	7.790	76.01	83.10	96.95	85.36
226	1550.00	1631.00	1913.00	7.754	7.792	7.824	7.790	71.43	77.31	95.85	81.53
267	1508.00	1584.00	1911.00	7.752	7.795	7.822	7.790	67.61	72.92	95.65	78.72
296*	1588.00	1642.00	1919.00	7.748	7.792	7.825	7.788	74.97	78.35	96.45	83.26
311	1495.00	1583.00	1917.00	7.749	7.796	7.825	7.790	66.45	72.82	96.25	78.51

MIX 7 (DOSE #1)								DURABILITY FACTOR= 49.10			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1930.00	1888.00	1858.00	7.773	7.575	7.556	7.635	100.00	100.00	100.00	100.00
29	1921.00	1874.00	1858.00	7.778	7.576	7.562	7.639	99.07	98.52	100.00	99.20
59	1910.00	1861.00	1845.00	7.780	7.580	7.563	7.641	97.94	97.16	98.61	97.90
93	1898.00	1849.00	1845.00	7.783	7.583	7.563	7.643	96.71	95.91	98.61	97.08
131	1898.00	1814.00	1844.00	7.786	7.589	7.565	7.647	96.71	92.31	98.50	95.84
162	1888.00	1710.00	1836.00	7.792	7.597	7.570	7.653	95.70	82.03	97.65	91.79
195	1866.00	1518.00	1822.00	7.797	7.610	7.575	7.661	93.48	64.65	96.16	84.76
226	1719.00	1327.00	1754.00	7.804	7.607	7.575	7.662	79.33	49.40	89.12	72.62
267	1498.00	N/A	1642.00	7.822	N/A	7.590	7.706	60.24	N/A	78.10	69.17
296*	1521.00	"	1650.00	7.82	"	7.595	7.708	62.11	"	78.86	70.49
311	1236.00	"	1405.00	7.831	"	7.605	7.718	41.01	"	57.18	49.10

MIX 7 (DOSE #2)								DURABILITY FACTOR= 30.34			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1965.00	1945.00	1935.00	7.868	7.880	7.788	7.845	100.00	100.00	100.00	100.00
29	1961.00	1933.00	1926.00	7.871	7.886	7.794	7.850	99.59	98.77	99.07	99.15
59	1948.00	1914.00	1917.00	7.872	7.891	7.796	7.853	98.28	96.84	98.15	97.75
93	1942.00	1884.00	1894.00	7.872	7.895	7.800	7.856	97.67	93.83	95.81	95.77
131	1930.00	1496.00	1809.00	7.880	7.922	7.812	7.871	96.47	59.16	87.40	81.01
162	1845.00	1141.00	1519.00	7.891	7.939	7.833	7.888	88.16	34.41	61.62	61.40
195	1324.00	N/A	1340.00	7.915	N/A	7.851	7.883	45.40	N/A	47.96	46.68

N/A: Specimen was removed out of the freezer
because its dynamic modulus dropped below 60%.

* The test was interrupted. The specimens
were submerged in water for 2 days.

MIX 8 (NO SUPER)								DURABILITY FACTOR= 95.10			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1989.00	1870.00	1886.00	7.868	7.623	7.807	7.766	100.00	100.00	100.00	100.00
36	1935.00	1865.00	1886.00	7.873	7.629	7.823	7.775	94.64	99.47	100.00	98.04
70	1918.00	1865.00	1880.00	7.871	7.628	7.823	7.774	92.99	99.47	99.36	97.27
97	1907.00	1864.00	1877.00	7.871	7.631	7.822	7.775	91.92	99.36	99.05	96.78
130	1903.00	1864.00	1875.00	7.873	7.634	7.826	7.778	91.54	99.36	98.84	96.58
162	1900.00	1860.00	1872.00	7.872	7.630	7.825	7.776	91.25	98.93	98.52	96.24
189	1898.00	1856.00	1870.00	7.871	7.629	7.824	7.775	91.06	98.51	98.31	95.96
219	1898.00	1856.00	1870.00	7.875	7.632	7.828	7.778	91.06	98.51	98.31	95.96
254	1898.00	1854.00	1868.00	7.876	7.631	7.830	7.779	91.06	98.30	98.10	95.82
288	1898.00	1854.00	1868.00	7.877	7.630	7.830	7.779	91.06	98.30	98.10	95.82
306	1894.00	1854.00	1851.00	7.876	7.627	7.816	7.773	90.68	98.30	96.32	95.10

MIX 8 (DOSE #1)								DURABILITY FACTOR= 97.20			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1831.00	1816.00	1802.00	7.489	7.282	7.377	7.383	100.00	100.00	100.00	100.00
36	1821.00	1802.00	1794.00	7.481	7.290	7.390	7.387	98.91	98.46	99.11	98.83
70	1821.00	1799.00	1793.00	7.478	7.284	7.387	7.383	98.91	98.14	99.00	98.68
97	1819.00	1791.00	1790.00	7.481	7.291	7.393	7.388	98.69	97.27	98.67	98.21
130	1819.00	1791.00	1790.00	7.483	7.291	7.391	7.388	98.69	97.27	98.67	98.21
162	1819.00	1791.00	1788.00	7.481	7.289	7.390	7.387	98.69	97.27	98.45	98.14
189	1819.00	1791.00	1786.00	7.480	7.287	7.388	7.385	98.69	97.27	98.23	98.06
219	1816.00	1785.00	1786.00	7.482	7.287	7.391	7.387	98.37	96.62	98.23	97.74
254	1812.00	1788.00	1786.00	7.479	7.284	7.390	7.384	97.94	96.94	98.23	97.70
288	1803.00	1788.00	1786.00	7.48	7.285	7.391	7.386	96.96	96.94	98.23	97.38
306	1803.00	1787.00	1782.00	7.480	7.282	7.389	7.384	96.96	96.83	97.79	97.20

MIX 8 (DOSE #2)								DURABILITY FACTOR= 95.45			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1824.00	1868.00	1823.00	7.404	7.553	7.396	7.451	100.00	100.00	100.00	100.00
36	1817.00	1862.00	1813.00	7.410	7.560	7.409	7.460	99.23	99.36	98.91	99.17
70	1816.00	1859.00	1813.00	7.411	7.564	7.412	7.462	99.12	99.04	98.91	99.02
97	1816.00	1855.00	1806.00	7.412	7.564	7.410	7.462	99.12	98.61	98.14	98.63
130	1816.00	1852.00	1803.00	7.416	7.565	7.413	7.465	99.12	98.29	97.82	98.41
162	1814.00	1847.00	1798.00	7.415	7.565	7.414	7.465	98.91	97.76	97.28	97.98
189	1811.00	1842.00	1790.00	7.415	7.565	7.416	7.465	98.58	97.24	96.41	97.41
219	1809.00	1840.00	1790.00	7.414	7.567	7.416	7.466	98.36	97.02	96.41	97.27
254	1797.00	1830.00	1777.00	7.417	7.566	7.419	7.467	97.06	95.97	95.02	96.02
288	1797.00	1825.00	1774.00	7.416	7.566	7.422	7.468	97.06	95.45	94.70	95.74
306	1797.00	1825.00	1766.00	7.415	7.564	7.422	7.467	97.06	95.45	93.84	95.45

MIX 9 (NO SUPER)								DURABILITY FACTOR= 24.45			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1875.00	1910.00	1901.00	7.677	7.840	7.808	7.775	100.00	100.00	100.00	100.00
33	1847.00	1848.00	1730.00	7.698	7.858	7.839	7.798	97.04	93.61	82.82	91.16
69	1765.00	1579.00	1470.00	7.716	7.879	7.859	7.818	88.61	68.34	59.80	72.25
107	1559.00	1354.00	1297.00	7.727	7.889	7.859	7.825	69.13	50.25	46.55	55.31
137	1372.00	N/A	N/A	7.734	N/A	N/A	7.734	53.54	N/A	N/A	53.54

MIX 9 (DOSE #1)								DURABILITY FACTOR= 3.25			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1914.00	1873.00	1887.00	7.839	7.650	7.712	7.734	100.00	100.00	100.00	100.00
33	920.00	887.00	1238.00	7.902	7.715	7.775	7.797	23.10	22.43	43.04	29.52

MIX 9 (DOSE #2)								DURABILITY FACTOR= 3.26			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1857.00	1872.00	1829.00	7.607	7.674	7.534	7.605	100.00	100.00	100.00	100.00
33	887.00	887.00	1208.00	7.663	7.732	7.593	7.663	22.82	22.45	43.62	29.63

N/A: Specimen was removed out of the freezer
because its dynamic modulus dropped below 60%.

MIX 10 (NO SUPER)								DURABILITY FACTOR= 97.43			
No. of Cycles	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1758.00	1783.00	1825.00	7.210	7.272	7.502	7.328	100.00	100.00	100.00	100.00
33	1752.00	1772.00	1814.00	7.228	7.293	7.522	7.348	99.32	98.77	98.80	98.96
65	1752.00	1765.00	1810.00	7.228	7.293	7.523	7.348	99.32	97.99	98.36	98.56
92	1750.00	1764.00	1805.00	7.227	7.294	7.524	7.348	99.09	97.88	97.82	98.26
122	1750.00	1764.00	1803.00	7.229	7.295	7.521	7.348	99.09	97.88	97.60	98.19
157	1750.00	1760.00	1797.00	7.229	7.299	7.521	7.350	99.09	97.44	96.96	97.83
191	1750.00	1759.00	1796.00	7.231	7.296	7.515	7.347	99.09	97.33	96.85	97.76
222	1750.00	1758.00	1792.00	7.231	7.294	7.513	7.346	99.09	97.22	96.42	97.57
240	1750.00	1758.00	1792.00	7.231	7.283	7.507	7.340	99.09	97.22	96.42	97.57
273	1750.00	1758.00	1792.00	7.231	7.280	7.503	7.338	99.09	97.22	96.42	97.57
301	1750.00	1758.00	1788.00	7.231	7.279	7.497	7.336	99.09	97.22	95.99	97.43

MIX 10 (DOSE #1)								DURABILITY FACTOR= 7.02			
No. of Cycles	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1823.00	1879.00	1874.00	7.459	7.605	7.717	7.594	100.00	100.00	100.00	100.00
33	1753.00	1809.00	1795.00	7.489	7.644	7.752	7.628	92.47	92.69	91.75	92.30
65	1403.00	1490.00	1411.00	7.499	7.656	7.762	7.639	59.23	62.88	56.69	59.60
92	889.00	889.00	889.00	7.535	7.679	7.805	7.673	23.78	22.38	22.50	22.89

MIX 10 (DOSE #2)								DURABILITY FACTOR= 2.62			
No. of Cycles	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1890.00	1880.00	1896.00	7.714	7.655	7.706	7.692	100.00	100.00	100.00	100.00
33	924.00	888.00	953.00	7.777	7.727	7.774	7.759	23.90	22.31	25.26	23.83

MIX 11 (NO SUPER)								DURABILITY FACTOR= 21.77			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1777.00	1775.00	1822.00	7.611	7.584	7.647	7.614	100.00	100.00	100.00	100.00
30	1763.00	1717.00	1725.00	7.645	7.624	7.685	7.651	98.43	93.57	89.64	93.88
65	1627.00	1491.00	1281.00	7.669	7.647	7.705	7.674	83.83	70.56	49.43	67.94
99	1411.00	1405.00	N/A	7.673	7.647	N/A	7.660	63.05	62.66	N/A	62.85
117	1337.00	1317.00	•	7.674	7.649	•	7.662	56.61	55.05	•	55.83

MIX 11 (DOSE #1)								DURABILITY FACTOR= 3.07			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1852.00	1876.00	1786.00	7.762	7.890	7.574	7.742	100.00	100.00	100.00	100.00
30	918.00	1174.00	953.00	7.853	7.974	7.659	7.829	24.57	39.16	28.47	30.73

MIX 11 (DOSE #2)								DURABILITY FACTOR= 2.56			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1781.00	1807.00	1781.00	7.538	7.560	7.587	7.562	100.00	100.00	100.00	100.00
30	885.00	904.00	927.00	7.614	7.639	7.674	7.642	24.69	25.03	27.09	25.60

N/A: Specimen was removed out of the freezer
because its dynamic modulus dropped below 60%.

MIX 12 (NO SUPER)								DURABILITY FACTOR= 39.04			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1792.00	1786.00	1777.00	7.458	7.464	7.406	7.443	100.00	100.00	100.00	100.00
34	1777.00	1780.00	1769.00	7.476	7.480	7.422	7.459	98.33	99.33	99.10	98.92
72	1777.00	1773.00	1767.00	7.478	7.486	7.429	7.464	98.33	98.55	98.88	98.59
103	1769.00	1757.00	1747.00	7.484	7.488	7.434	7.469	97.45	96.78	96.65	96.96
136	1728.00	1743.00	1728.00	7.492	7.490	7.437	7.473	92.98	95.24	94.56	94.26
167	1584.00	1693.00	1673.00	7.505	7.492	7.443	7.480	78.13	89.86	88.64	85.54
208	1091.00	1537.00	1547.00	7.525	7.514	7.463	7.501	37.07	74.06	75.79	62.30
237	N/A	1520.00	1485.00	N/A	7.506	7.459	7.483	N/A	72.43	69.84	71.13
252	•	1326.00	1093.00	•	7.516	7.479	7.498	•	55.12	37.83	46.48

MIX 12 (DOSE #1)								DURABILITY FACTOR= 5.92			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1773.00	1774.00	1814.00	7.486	7.570	7.586	7.547	100.00	100.00	100.00	100.00
34	1642.00	1517.00	1636.00	7.532	7.625	7.623	7.593	85.77	73.12	81.34	80.08
72	888.00	887.00	887.00	7.573	7.654	7.670	7.632	25.08	25.00	23.91	24.66

N/A: Specimen was removed out of the freezer
because its dynamic modulus dropped below 60%.

MIX 13 (NO SUPER)								DURABILITY FACTOR= 14.40			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1870.00	1878.00	1860.00	7.699	7.760	7.684	7.714	100.00	100.00	100.00	100.00
34	1777.00	1844.00	1838.00	7.736	7.788	7.704	7.743	90.30	96.41	97.65	94.79
65	1388.00	1682.00	1537.00	7.767	7.810	7.738	7.772	55.09	80.22	68.28	67.86
83	N/A	1468.00	1291.00	N/A	7.820	7.752	7.786	N/A	61.10	48.18	54.64
116	"	1146.00	N/A	"	7.838	N/A	7.838	"	37.24	N/A	37.24

MIX 13 (DOSE #1)								DURABILITY FACTOR= 25.51			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1857.00	1861.00	1861.00	7.570	7.574	7.596	7.580	100.00	100.00	100.00	100.00
34	1823.00	1822.00	1818.00	7.591	7.594	7.612	7.599	96.37	95.85	95.43	95.89
65	1588.00	1752.00	1700.00	7.621	7.611	7.629	7.620	73.13	88.63	83.45	81.73
83	1448.00	1669.00	1623.00	7.633	7.621	7.636	7.630	60.80	80.43	76.06	72.43
116	1219.00	1480.00	1496.00	7.637	7.628	7.644	7.636	43.09	63.25	64.62	56.99
144	N/A	1342.00	1371.00	N/A	7.627	7.649	7.638	N/A	52.00	54.27	53.14

MIX 13 (DOSE #2)								DURABILITY FACTOR= 6.02			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1901.00	1858.00	1775.00	7.672	7.507	7.442	7.540	100.00	100.00	100.00	100.00
34	1788.00	1805.00	1340.00	7.707	7.533	7.475	7.572	88.46	94.38	56.99	79.94
65	899.00	1071.00	N/A	7.757	7.584	N/A	7.671	22.36	33.23	N/A	27.80

N/A: Specimen was removed out of the freezer
because its dynamic modulus dropped below 60%.

MIX 14 (DOSE#1)								DURABILITY FACTOR= 91.04			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1751.00	1777.00	1744.00	7.297	7.411	7.371	7.360	100.00	100.00	100.00	100.00
35	1730.00	1764.00	1732.00	7.320	7.434	7.396	7.383	97.62	98.54	98.63	98.26
69	1726.00	1759.00	1735.00	7.325	7.442	7.400	7.389	97.16	97.98	98.97	98.04
100	1715.00	1759.00	1735.00	7.327	7.443	7.403	7.391	95.93	97.98	98.97	97.63
118	1700.00	1755.00	1732.00	7.327	7.442	7.402	7.390	94.26	97.54	98.63	96.81
151	1660.00	1751.00	1728.00	7.331	7.442	7.406	7.393	89.88	97.10	98.17	95.05
179	1626.00	1748.00	1720.00	7.334	7.439	7.405	7.393	86.23	96.76	97.27	93.42
214	1615.00	1751.00	1710.00	7.332	7.441	7.404	7.392	85.07	97.10	96.14	92.77
249	1597.00	1749.00	1710.00	7.323	7.439	7.404	7.389	83.18	96.87	96.14	92.07
287	1584.00	1748.00	1710.00	7.325	7.440	7.408	7.391	81.83	96.76	96.14	91.58
325	1577.00	1743.00	1707.00	7.325	7.443	7.409	7.392	81.11	96.21	95.80	91.04

MIX 15 (DOSE #1)								DURABILITY FACTOR= 95.18			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1819.00	1824.00	1862.00	7.454	7.431	7.539	7.475	100.00	100.00	100.00	100.00
35	1815.00	1814.00	1852.00	7.474	7.452	7.558	7.495	99.56	98.91	98.93	99.13
69	1815.00	1813.00	1852.00	7.475	7.453	7.560	7.496	99.56	98.80	98.93	99.10
100	1814.00	1813.00	1853.00	7.478	7.457	7.563	7.499	99.45	98.80	99.04	99.09
118	1812.00	1812.00	1853.00	7.479	7.459	7.566	7.501	99.23	98.69	99.04	98.99
151	1804.00	1812.00	1852.00	7.482	7.462	7.567	7.504	98.36	98.69	98.93	98.66
179	1800.00	1809.00	1849.00	7.481	7.461	7.567	7.503	97.92	98.36	98.61	98.30
214	1793.00	1805.00	1846.00	7.486	7.465	7.567	7.506	97.16	97.93	98.29	97.79
249	1790.00	1785.00	1846.00	7.482	7.462	7.565	7.503	96.84	95.77	98.29	96.97
287	1784.00	1775.00	1842.00	7.488	7.465	7.570	7.508	96.19	94.70	97.86	96.25
325	1774.00	1760.00	1837.00	7.490	7.470	7.578	7.513	95.11	93.11	97.33	95.18

MIX 16 (NO SUPER, AIR=8.75%)								DURABILITY FACTOR= 85.34			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1739.00	1739.00	1710.00	7.168	7.274	7.094	7.179	100.00	100.00	100.00	100.00
31	1737.00	1731.00	1704.00	7.174	7.285	7.108	7.189	99.77	99.08	99.30	99.38
64	1734.00	1725.00	1698.00	7.173	7.286	7.108	7.189	99.43	98.40	98.60	98.81
92	1731.00	1725.00	1697.00	7.176	7.287	7.107	7.190	99.08	98.40	98.49	98.65
127	1731.00	1724.00	1697.00	7.178	7.290	7.112	7.193	99.08	98.28	98.49	98.62
162	1731.00	1724.00	1700.00	7.174	7.284	7.103	7.187	99.08	98.28	98.83	98.73
200	1730.00	1590.00	1700.00	7.180	7.291	7.111	7.194	98.97	83.60	98.83	93.80
238	1727.00	1340.00	1693.00	7.187	7.298	7.118	7.201	98.62	59.38	98.02	85.34
267	1727.00	N/A	1693.00	7.181	N/A	7.116	7.149	98.62	N/A	98.02	85.34
300	1725.00	N/A	1695.00	7.182	N/A	7.115	7.149	98.40	N/A	98.25	85.34

MIX 16 (DOSE #1, AIR=5.5%)								DURABILITY FACTOR= 91.83			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1792.00	1824.00	1840.00	7.357	7.457	7.529	7.448	100.00	100.00	100.00	100.00
31	1776.00	1813.00	1832.00	7.370	7.469	7.539	7.459	98.22	98.80	99.13	98.72
64	1775.00	1804.00	1821.00	7.372	7.474	7.543	7.463	98.11	97.82	97.95	97.96
92	1772.00	1803.00	1820.00	7.375	7.475	7.549	7.466	97.78	97.71	97.84	97.78
127	1773.00	1801.00	1811.00	7.378	7.475	7.553	7.469	97.89	97.49	96.87	97.42
162	1763.00	1794.00	1797.00	7.374	7.472	7.554	7.467	96.79	96.74	95.38	96.30
200	1760.00	1782.00	1778.00	7.380	7.477	7.560	7.472	96.46	95.45	93.37	95.09
238	1756.00	1770.00	1763.00	7.389	7.484	7.570	7.481	96.02	94.17	91.81	94.00
267	1747.00	1772.00	1750.00	7.390	7.483	7.571	7.481	95.04	94.38	90.46	93.29
300	1736.00	1766.00	1725.00	7.388	7.485	7.571	7.481	93.85	93.74	87.89	91.83

MIX 16 (DOSE #1, AIR=5%)								DURABILITY FACTOR= 86.83			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1839.00	1804.00	1805.00	7.445	7.330	7.361	7.379	100.00	100.00	100.00	100.00
31	1826.00	1783.00	1782.00	7.455	7.340	7.375	7.390	98.59	97.69	97.47	97.91
64	1812.00	1786.00	1785.00	7.460	7.342	7.377	7.393	97.09	98.01	97.80	97.63
92	1811.00	1774.00	1780.00	7.460	7.345	7.378	7.394	96.98	96.70	97.25	96.98
127	1798.00	1774.00	1764.00	7.464	7.347	7.380	7.397	95.59	96.70	95.51	95.93
162	1756.00	1766.00	1764.00	7.460	7.346	7.378	7.395	91.18	95.83	95.51	94.17
200	1760.00	1753.00	1764.00	7.467	7.352	7.382	7.400	91.59	94.43	95.51	93.84
238	1672.00	1735.00	1757.00	7.477	7.361	7.389	7.409	82.66	92.50	94.75	89.97
267	1650.00	1729.00	1750.00	7.475	7.360	7.394	7.410	80.50	91.86	94.00	88.79
300	1610.00	1718.00	1742.00	7.470	7.358	7.392	7.407	76.65	90.69	93.14	86.83

N/A: Specimen was removed out of the freezer
because its dynamic modulus dropped below 60%.

MIX 16 (DOSE#1, AIR=4%)								DURABILITY FACTOR= 92.85			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1793.00	1813.00	1796.00	7.401	7.537	7.554	7.497	100.00	100.00	100.00	100.00
18	1779.00	1789.00	1777.00	7.409	7.549	7.564	7.507	98.44	97.37	97.90	97.90
51	1786.00	1782.00	1766.00	7.418	7.551	7.569	7.513	99.22	96.61	96.69	97.51
79	1770.00	1773.00	1752.00	7.416	7.551	7.571	7.513	97.45	95.64	95.16	96.08
114	1757.00	1772.00	1752.00	7.419	7.553	7.571	7.514	96.02	95.53	95.16	95.57
149	1755.00	1765.00	1744.00	7.416	7.549	7.567	7.511	95.81	94.78	94.29	94.96
200	1755.00	1763.00	1742.00	7.420	7.551	7.571	7.514	95.81	94.56	94.08	94.81
225	1750.00	1759.00	1736.00	7.430	7.563	7.578	7.524	95.26	94.13	93.43	94.27
254	1750.00	1757.00	1718.00	7.428	7.561	7.577	7.522	95.26	93.92	91.50	93.56
287	1746.00	1745.00	1715.00	7.425	7.556	7.574	7.518	94.83	92.64	91.18	92.88
314	1744.00	1746.00	1715.00	7.422	7.553	7.570	7.515	94.61	92.75	91.18	92.85

MIX 16 (DOSE#2, AIR=2.75%)								DURABILITY FACTOR= 3.68			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1819.00	1830.00	1808.00	7.623	7.582	7.560	7.588	100.00	100.00	100.00	100.00
33	951.00	1056.00	1139.00	7.682	7.633	7.593	7.636	27.33	33.30	39.69	33.44

APPENDIX C4

TABULATED RESULTS OF FREEZE-THAW RESISTANCE FOR MIXES L1 THROUGH L9

MIX L1 (NO SUPER)								DURABILITY FACTOR= 83.59			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1782.00	1771.00	1803.00	7.323	7.105	7.377	7.268	100.00	100.00	100.00	100.00
28	1753.00	1740.00	1771.00	7.354	7.282	7.423	7.353	96.77	96.53	96.48	96.59
61	1732.00	1720.00	1740.00	7.377	7.304	7.432	7.371	94.47	94.32	93.13	93.97
93	1731.00	1714.00	1732.00	7.382	7.300	7.432	7.371	94.36	93.67	92.28	93.43
117	1730.00	1714.00	1732.00	7.377	7.291	7.423	7.364	94.25	93.67	92.28	93.40
139	1722.00	1706.00	1716.00	7.377	7.282	7.414	7.358	93.38	92.79	90.58	92.25
171	1701.00	1692.00	1714.00	7.364	7.273	7.409	7.349	91.12	91.28	90.37	90.92
195	1697.00	1703.00	1695.00	7.364	7.264	7.395	7.341	90.69	92.47	88.38	90.51
227	1694.00	1697.00	1674.00	7.359	7.245	7.391	7.332	90.37	91.82	86.20	89.46
250	1682.00	1700.00	1675.00	7.341	7.105	7.373	7.273	89.09	92.14	86.31	89.18
284	1670.00	1701.00	1659.00	7.309	7.223	7.341	7.291	87.82	92.25	84.66	88.25
302	1664.00	1693.00	1532.00	7.305	7.232	7.345	7.294	87.19	91.39	72.20	83.59

MIX L1 (DOSE #1)								DURABILITY FACTOR= 5.84			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1871.00	1863.00	1878.00	7.709	7.682	7.641	7.677	100.00	100.00	100.00	100.00
28	1445.50	1587.00	1400.00	7.814	7.800	7.750	7.788	59.69	72.57	55.57	62.61

MIX L1 (DOSE #2)								DURABILITY FACTOR= 3.77			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1888.00	1854.00	1861.00	7.786	7.673	7.705	7.721	100.00	100.00	100.00	100.00
28	1285.00	1132.00	1142.00	7.882	7.773	7.805	7.820	46.32	37.28	37.66	40.42

MIX L2 (NO SUPER)								DURABILITY FACTOR= 86.81			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1820.00	1821.00	1833.00	7.432	7.432	7.500	7.455	100.00	100.00	100.00	100.00
28	1795.00	1798.00	1808.00	7.473	7.482	7.555	7.503	97.27	97.49	97.29	97.35
61	1780.00	1784.00	1783.00	7.477	7.486	7.559	7.507	95.65	95.98	94.62	95.42
93	1751.00	1756.00	1740.00	7.491	7.500	7.564	7.518	92.56	92.99	90.11	91.89
117	1744.00	1747.00	1737.00	7.482	7.486	7.550	7.506	91.82	92.04	89.80	91.22
139	1732.00	1739.00	1723.00	7.473	7.486	7.550	7.503	90.56	91.20	88.36	90.04
171	1729.00	1724.00	1723.00	7.473	7.482	7.536	7.497	90.25	89.63	88.36	89.41
195	1727.00	1721.00	1718.00	7.473	7.477	7.523	7.491	90.04	89.32	87.85	89.07
227	1727.00	1719.00	1718.00	7.463	7.468	7.523	7.485	90.04	89.11	87.85	89.00
250	1727.00	1716.00	1717.00	7.454	7.454	7.500	7.469	90.04	88.80	87.74	88.86
284	1727.00	1711.00	1704.00	7.441	7.427	7.473	7.447	90.04	88.28	86.42	88.25
316	1714.00	1696.00	1690.00	7.441	7.436	7.482	7.453	88.69	86.74	85.01	86.81

MIX L2 (DOSE #1)								DURABILITY FACTOR= 9.58			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1835.00	1822.00	1816.00	7.591	7.568	7.477	7.545	100.00	100.00	100.00	100.00
28	1692.00	1682.00	1697.00	7.664	7.636	7.541	7.614	85.02	85.22	87.32	85.86
61	1238.00	1217.00	1300.00	7.682	7.641	7.554	7.626	45.52	44.62	51.25	47.13

MIX L2 (DOSE #2)								DURABILITY FACTOR= 3.78			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1867.00	1893.00	1844.00	7.682	7.795	7.705	7.727	100.00	100.00	100.00	100.00
28	1202.00	1169.00	1196.00	7.777	7.910	7.805	7.831	41.45	38.14	42.07	40.55

MIX L3 (NO SUPER)								DURABILITY FACTOR= 92.97			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1774.00	1758.00	1780.00	7.332	7.214	7.364	7.303	100.00	100.00	100.00	100.00
32	1765.00	1745.00	1762.00	7.355	7.259	7.414	7.342	98.99	98.53	97.99	98.50
48	1761.00	1745.00	1744.00	7.364	7.264	7.414	7.347	98.54	98.53	96.00	97.69
80	1754.00	1745.00	1738.00	7.373	7.273	7.418	7.355	97.76	98.53	95.34	97.21
113	1737.00	1736.00	1731.00	7.377	7.273	7.423	7.358	95.87	97.51	94.57	95.99
136	1731.00	1736.00	1720.00	7.386	7.286	7.436	7.370	95.21	97.51	93.37	95.37
159	1731.00	1733.00	1719.00	7.386	7.277	7.423	7.362	95.21	97.18	93.26	95.22
186	1722.00	1727.00	1715.00	7.368	7.268	7.427	7.355	94.22	96.50	92.83	94.52
207	1722.00	1727.00	1710.00	7.368	7.264	7.409	7.347	94.22	96.50	92.29	94.34
233	1722.00	1727.00	1701.00	7.368	7.268	7.400	7.345	94.22	96.50	91.32	94.02
254	1717.00	1726.00	1700.00	7.373	7.268	7.395	7.345	93.68	96.39	91.21	93.76
274	1712.00	1721.00	1698.00	7.359	7.259	7.382	7.333	93.13	95.83	91.00	93.32
322	1712.00	1721.00	1688.00	7.359	7.259	7.373	7.330	93.13	95.83	89.93	92.97

MIX L3 (DOSE #1)								DURABILITY FACTOR= 7.25			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1825.00	1790.00	1834.00	7.600	7.491	7.618	7.570	100.00	100.00	100.00	100.00
32	1478.00	1502.00	1434.00	7.691	7.559	7.714	7.655	65.59	70.41	61.14	65.71
48	1128.00	1219.00	1315.00	7.714	7.582	7.741	7.679	38.20	46.38	51.41	45.33

MIX L3 (DOSE #2)								DURABILITY FACTOR= 15.14			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1819.00	1817.00	1841.00	7.632	7.600	7.718	7.650	100.00	100.00	100.00	100.00
32	1434.00	1462.00	1508.00	7.755	7.736	7.850	7.780	62.15	64.74	67.10	64.66
48	1419.00	1441.00	1497.00	7.768	7.755	7.859	7.794	60.86	62.90	66.12	63.29
80	1325	1434	1365	7.800	7.768	7.868	7.812	53.06	62.29	54.97	56.77

MIX L4 (NO SUPER)								DURABILITY FACTOR= 86.62			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1731.00	1717.00	1718.00	7.159	7.132	7.095	7.129	100.00	100.00	100.00	100.00
23	1713.00	1705.00	1703.00	7.191	7.177	7.141	7.170	97.93	98.61	98.26	98.27
55	1705.00	1702.00	1683.00	7.209	7.186	7.145	7.180	97.02	98.26	95.97	97.08
85	1700.00	1691.00	1667.00	7.210	7.191	7.141	7.181	96.45	96.99	94.15	95.87
111	1693.00	1692.00	1646.00	7.205	7.195	7.145	7.182	95.66	97.11	91.79	94.85
134	1686.00	1687.00	1636.00	7.200	7.172	7.118	7.163	94.87	96.54	90.68	94.03
168	1682.00	1682.00	1624.00	7.186	7.159	7.095	7.147	94.42	95.96	89.36	93.25
192	1680.00	1676.00	1612.00	7.173	7.141	7.068	7.127	94.19	95.28	88.04	92.51
224	1680.00	1670.00	1608.00	7.154	7.114	7.032	7.100	94.19	94.60	87.60	92.13
246	1680.00	1668.00	1587.00	7.150	7.114	7.018	7.094	94.19	94.37	85.33	91.30
271	1677.00	1665.00	1534.00	7.136	7.091	6.995	7.074	93.86	94.03	79.73	89.21
302	1670.00	1661.00	1470.00	7.095	7.063	6.954	7.037	93.08	93.58	73.21	86.62

MIX L4 (DOSE #1)								DURABILITY FACTOR= 55.72			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1728.00	1768.00	1750.00	7.214	7.341	7.332	7.296	100.00	100.00	100.00	100.00
23	1688.00	1736.00	1718.00	7.264	7.382	7.368	7.338	95.42	96.41	96.38	96.07
55	1644.00	1690.00	1667.00	7.291	7.409	7.400	7.367	90.51	91.37	90.74	90.87
85	1387.00	1593.00	1583.00	7.309	7.436	7.423	7.389	64.43	81.18	81.82	75.81
111	1324.00	1527.00	1537.00	7.323	7.445	7.436	7.401	58.71	74.60	77.14	70.15
134	1252.00	1490.00	1490.00	7.300	7.441	7.427	7.389	52.50	71.02	72.49	65.34
168	N/A	1461.00	1423.00	N/A	7.450	7.418	7.434	N/A	68.29	66.12	67.20
192	"	1444.00	1423.00	"	7.427	7.382	7.405	"	66.71	66.12	66.41
224	"	1431.00	1402.00	"	7.414	7.364	7.389	"	65.51	64.18	64.85
246	"	1422.00	1402.00	"	7.404	7.332	7.368	"	64.69	64.18	64.44
271	"	1406.00	1294.00	"	7.377	7.322	7.350	"	63.24	54.68	58.96
302	"	1405.00	1216.00	"	7.327	7.254	7.291	"	63.15	48.28	55.72

MIX L4 (DOSE #2)								DURABILITY FACTOR= 4.50			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1823.00	1786.00	1778.00	7.482	7.432	7.409	7.441	100.00	100.00	100.00	100.00
23	1398.00	1331.00	1395.00	7.577	7.523	7.527	7.542	58.81	55.54	61.56	58.64

MIX L5 (NO SUPER)								DURABILITY FACTOR= 88.09			
No. of Cycles	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1770.00	1807.00	1784.00	7.364	7.464	7.373	7.400	100.00	100.00	100.00	100.00
31	1738.00	1794.00	1776.00	7.391	7.491	7.395	7.426	96.42	98.57	99.11	98.03
63	1736.00	1787.00	1775.00	7.391	7.486	7.395	7.424	96.20	97.80	98.99	97.66
96	1712.00	1767.00	1770.00	7.405	7.495	7.395	7.432	93.55	95.62	98.44	95.87
128	1699.00	1767.00	1737.00	7.382	7.482	7.409	7.424	92.14	95.62	94.80	94.19
157	1611.00	1756.00	1735.00	7.323	7.982	7.405	7.570	82.84	94.43	94.58	90.62
184	1605.00	1755.00	1729.00	7.295	7.977	7.386	7.553	82.22	94.33	93.93	90.16
207	1586.00	1752.00	1725.00	7.332	7.468	7.386	7.395	80.29	94.01	93.50	89.26
234	1574.00	1753.00	1721.00	7.318	7.455	7.386	7.386	79.08	94.11	93.06	88.75
255	1566.00	1752.00	1716.00	7.309	7.455	7.382	7.382	79.08	94.11	92.52	88.57
281	1565.00	1752.00	1712.00	7.295	7.445	7.368	7.370	78.28	94.01	92.09	88.12
302	1556.00	1743.00	1712.00	7.286	7.441	7.351	7.359	78.18	94.01	92.09	88.09

MIX L5 (DOSE #1)								DURABILITY FACTOR= 27.97			
No. of Cycles	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1816.00	1842.00	1835.00	7.545	7.605	7.600	7.583	100.00	100.00	100.00	100.00
31	1464.00	1389.00	1513.00	7.605	7.668	7.664	7.645	64.99	56.86	67.98	63.28
63	1377.00	1311.00	1503.00	7.623	7.695	7.682	7.667	57.50	50.66	67.09	58.41
96	1415.00	N/A	1438.00	7.636	N/A	7.700	7.668	60.71	N/A	61.41	61.06
128	1464.00	"	1482.00	7.614	"	7.682	7.648	64.99	"	65.23	65.11
157	1329.00	"	1340.00	7.577	"	7.632	7.605	53.56	"	53.33	53.44

MIX L5 (DOSE #2)								DURABILITY FACTOR= 16.01			
No. of Cycles	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1831.00	1834.00	1847.00	7.636	7.636	7.691	7.654	100.00	100.00	100.00	100.00
31	1473.00	1745.00	1750.00	7.768	7.768	7.814	7.783	64.72	90.53	89.77	81.67
63	1324.00	1370.00	1681.00	7.800	7.777	7.845	7.808	52.29	55.80	82.83	63.64
96	1319.00	1257.00	1322.00	7.727	7.682	7.682	7.697	51.89	46.98	51.23	50.03

N/A: Specimen was removed from the freezer
because its dynamic modulus dropped below 60%.

MIX L6 (NO SUPER)								DURABILITY FACTOR= 87.70			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1788.00	1784.00	1779.00	7.309	7.300	7.286	7.298	100.00	100.00	100.00	100.00
28	1768.00	1761.00	1754.00	7.350	7.341	7.327	7.339	97.78	97.44	97.21	97.47
61	1757.00	1742.00	1729.00	7.364	7.350	7.336	7.350	96.56	95.35	94.46	95.46
93	1748.00	1738.00	1716.00	7.354	7.345	7.327	7.342	95.58	94.91	93.04	94.51
117	1735.00	1732.00	1707.00	7.359	7.350	7.332	7.347	94.16	94.26	92.07	93.49
139	1727.00	1723.00	1706.00	7.341	7.332	7.318	7.330	93.29	93.28	91.96	92.84
171	1727.00	1715.00	1693.00	7.350	7.332	7.318	7.333	93.29	92.41	90.57	92.09
195	1722.00	1703.00	1693.00	7.350	7.332	7.314	7.332	92.75	91.13	90.57	91.48
227	1721.00	1703.00	1693.00	7.345	7.318	7.304	7.322	92.65	91.13	90.57	91.45
250	1710.00	1697.00	1689.00	7.341	7.318	7.291	7.317	91.47	90.48	90.14	90.70
284	1710.00	1674.00	1677.00	7.336	7.304	7.277	7.306	91.47	88.05	88.86	89.46
316	1692.00	1649.00	1670.00	7.350	7.309	7.268	7.309	89.55	85.44	88.12	87.70

MIX L6 (DOSE #1)								DURABILITY FACTOR= 24.40			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1833.00	1844.00	1860.00	7.391	7.400	7.400	7.397	100.00	100.00	100.00	100.00
28	1794.00	1808.00	1808.00	7.445	7.445	7.450	7.447	95.79	96.13	94.49	95.47
61	1601.00	1622.00	1645.00	7.473	7.473	7.473	7.473	76.29	77.37	78.22	77.29
93	1491.00	1531.00	1497.00	7.473	7.468	7.482	7.474	66.17	68.93	64.78	66.63
117	1353.00	1477.00	1505.00	7.486	7.468	7.482	7.479	54.48	64.16	65.47	61.37
139	1301.00	1419.00	1294.00	7.477	7.468	7.486	7.477	50.38	59.22	48.40	52.66

MIX L6 (DOSE #2)								DURABILITY FACTOR= 5.88			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1868.00	1856.00	1854.00	7.500	7.500	7.491	7.497	100.00	100.00	100.00	100.00
28	1488.00	1462.00	1478.00	7.577	7.577	7.573	7.576	63.45	62.05	63.55	63.02

MIX L7 (NO SUPER)								DURABILITY FACTOR= 53.75			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1912.00	1898.00	1904.00	7.682	7.668	7.668	7.673	100.00	100.00	100.00	100.00
20	1888.00	1876.00	1887.00	7.705	7.695	7.727	7.709	97.51	97.70	98.22	97.81
53	1856.00	1857.00	1850.00	7.727	7.714	7.741	7.727	94.23	95.73	94.41	94.79
85	1797.00	1841.00	1793.00	7.732	7.718	7.745	7.732	88.33	94.08	88.68	90.37
109	1731.00	1820.00	1751.00	7.736	7.732	7.750	7.739	81.96	91.95	84.57	86.16
131	1687.00	1799.00	1737.00	7.723	7.714	7.727	7.721	77.85	89.84	83.23	83.64
163	1644.00	1777.00	1684.00	7.723	7.718	7.727	7.723	73.93	87.66	78.23	79.94
187	1583.00	1740.00	1599.00	7.732	7.727	7.736	7.732	68.55	84.04	70.53	74.37
219	1540.00	1715.00	1582.00	7.723	7.723	7.723	7.723	64.87	81.65	69.04	71.85
242	1498.00	1694.00	1522.00	7.718	7.718	7.714	7.717	61.38	79.66	63.90	68.31
276	1348.00	1591.00	1472.00	7.718	7.718	7.709	7.715	49.71	70.27	59.77	59.91
308	1291.00	1533.00	1352.00	7.723	7.718	7.705	7.715	45.59	65.24	50.42	53.75

MIX L7 (DOSE #1)								DURABILITY FACTOR= 7.01			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1920.00	1850.00	1894.00	7.659	7.486	7.636	7.594	100.00	100.00	100.00	100.00
20	1778.00	1765.00	1811.00	7.714	7.541	7.682	7.645	85.76	91.02	91.43	89.40
53	1065.00	1143.00	1341.00	7.732	7.555	7.709	7.665	30.77	38.17	50.13	39.69

MIX L7 (DOSE #2)								DURABILITY FACTOR= 5.75			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1909.00	1944.00	1902.00	7.750	7.750	7.568	7.689	100.00	100.00	100.00	100.00
20	1734.00	1857.00	1753.00	7.809	7.795	7.618	7.741	82.51	91.25	84.95	86.23

MIX L8 (NO SUPER)								DURABILITY FACTOR= 85.85			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1901.00	1962.00	1933.00	7.668	7.818	7.727	7.738	100.00	100.00	100.00	100.00
23	1889.00	1950.00	1922.00	7.672	7.832	7.736	7.747	98.74	98.78	98.87	98.80
46	1887.00	1941.00	1917.00	7.672	7.823	7.727	7.741	98.53	97.87	98.35	98.25
73	1870.00	1934.00	1899.00	7.672	7.827	7.727	7.742	96.77	97.17	96.51	96.81
94	1870.00	1934.00	1889.00	7.668	7.822	7.727	7.739	96.77	97.17	95.50	96.48
120	1861.00	1922.00	1888.00	7.668	7.813	7.723	7.735	95.84	95.96	95.40	95.73
141	1858.00	1913.00	1871.00	7.659	7.813	7.723	7.732	95.53	95.07	93.69	94.76
173	1858.00	1913.00	1863.00	7.659	7.813	7.732	7.735	95.53	95.07	92.89	94.49
209	1856.00	1912.00	1820.00	7.650	7.794	7.718	7.721	95.32	94.97	88.65	92.98
234	1841.00	1912.00	1787.00	7.650	7.794	7.719	7.721	93.79	94.97	85.46	91.41
266	1830.00	1911.00	1742.00	7.653	7.791	7.724	7.723	92.67	94.87	81.21	89.58
302	1800.00	1900.00	1664.00	7.653	7.792	7.726	7.724	89.66	93.78	74.10	85.85

MIX L8 (DOSE #1)								DURABILITY FACTOR= 20.31			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1884.00	1874.00	1868.00	7.486	7.486	7.477	7.483	100.00	100.00	100.00	100.00
23	1870.00	1874.00	1862.00	7.482	7.482	7.486	7.483	98.52	100.00	99.36	99.29
46	1870.00	1874.00	1857.00	7.482	7.482	7.486	7.483	98.52	100.00	98.83	99.12
73	1855.00	1852.00	1832.00	7.477	7.473	7.486	7.479	96.95	97.67	96.18	96.93
94	1760.00	1769.00	1713.00	7.504	7.500	7.504	7.503	87.27	89.11	84.09	86.82
120	1287.00	1492.00	1259.00	7.541	7.523	7.532	7.532	46.67	63.39	45.43	51.83
141	N/A	1232.00	N/A	N/A	7.541	N/A	7.541	N/A	43.22	N/A	43.22

MIX L8 (DOSE #2)								DURABILITY FACTOR= 18.49			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1946.00	1912.00	1960.00	7.664	7.536	7.723	7.641	100.00	100.00	100.00	100.00
23	1928.00	1895.00	1943.00	7.664	7.541	7.719	7.641	98.16	98.23	98.27	98.22
46	1922.00	1885.00	1932.00	7.664	7.541	7.719	7.641	97.55	97.20	97.16	97.30
73	1805	1824	1867	7.664	7.545	7.714	7.641	86.03	91.01	90.74	89.26
94	1279	1618	1452	7.700	7.586	7.773	7.686	N/A	71.61	54.88	63.25
120	N/A	1300	N/A	N/A	7.582	N/A	7.582	N/A	46.23	N/A	46.23

N/A: Specimen was removed out of the freezer
because its dynamic modulus dropped below 60%.

MIX L9 (NO SUPER)								DURABILITY FACTOR= 89.63			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1789.00	1772.00	1778.00	7.459	7.327	7.300	7.362	100.00	100.00	100.00	100.00
24	1765.00	1744.00	1756.00	7.477	0.455	0.455	2.795	97.33	96.86	97.54	97.25
46	1754.00	1738.00	1747.00	7.486	7.350	7.318	7.385	96.13	96.20	96.54	96.29
78	1754.00	1735.00	1746.00	7.477	7.341	7.314	7.377	96.13	95.87	96.43	96.14
102	1746.00	1732.00	1740.00	7.482	7.345	7.318	7.382	95.25	95.54	95.77	95.52
134	1746.00	1725.00	1736.00	7.473	7.345	7.323	7.380	95.25	94.77	95.33	95.12
157	1733.00	1724.00	1735.00	7.464	7.345	7.318	7.376	93.84	94.66	95.22	94.57
191	1733.00	1716.00	1733.00	7.459	7.345	7.323	7.376	93.84	93.78	95.00	94.21
213	1733.00	1718.00	1733.00	7.459	7.345	7.327	7.377	93.84	94.00	95.00	94.28
245	1708.00	1707.00	1720.00	7.468	7.355	7.332	7.385	91.15	92.80	93.58	92.51
268	1695.00	1700.00	1716.00	7.450	7.355	7.327	7.377	89.77	92.04	93.15	91.65
300	1673.00	1666.00	1715.00	7.436	7.332	7.323	7.364	87.45	88.39	93.04	89.63

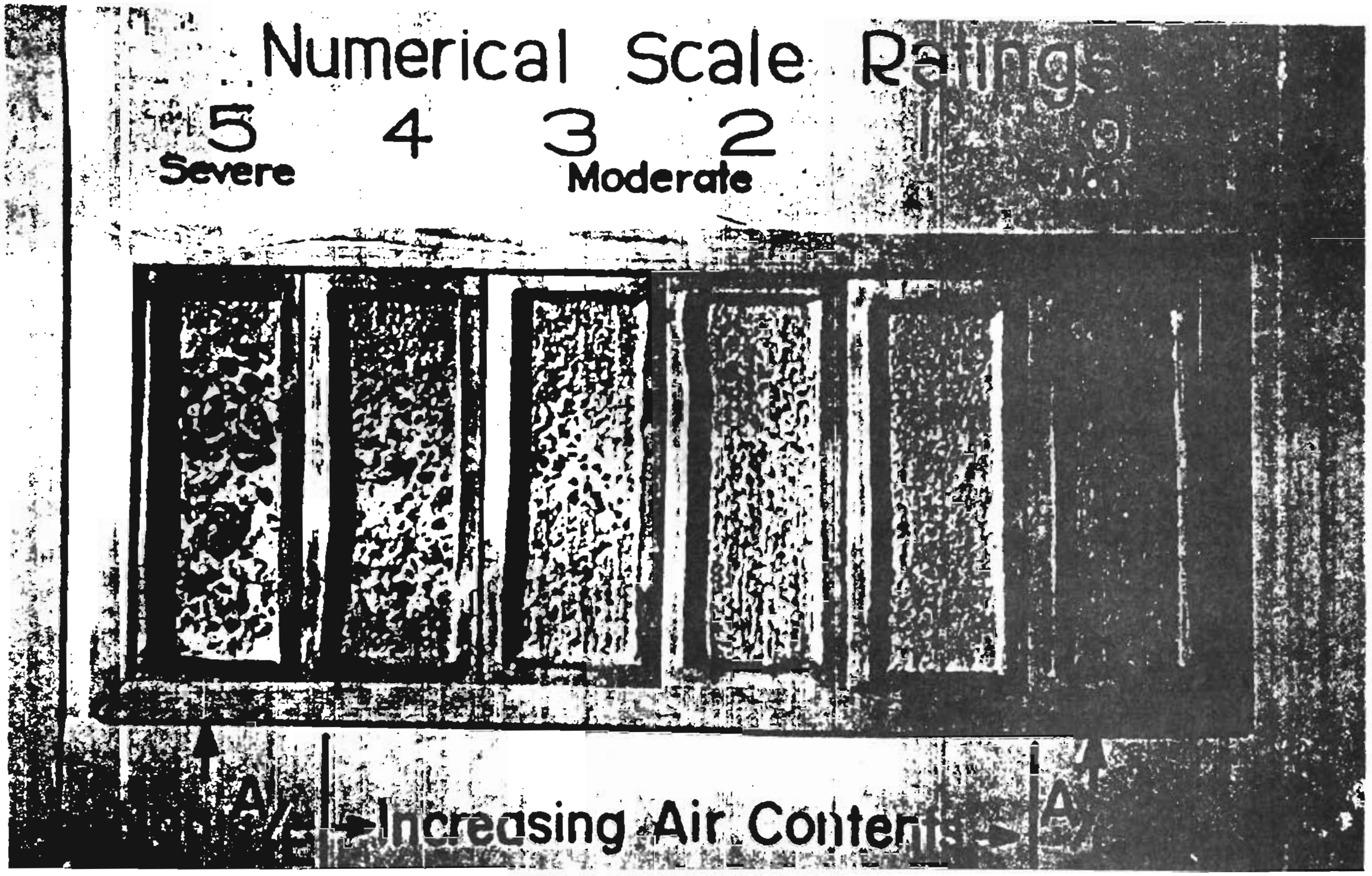
MIX L9 (DOSE #1)								DURABILITY FACTOR= 40.43			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1855.00	1819.00	1834.00	7.573	7.445	7.518	7.512	100.00	100.00	100.00	100.00
24	1792.00	1744.00	1728.00	7.595	7.464	7.555	7.538	93.32	91.92	88.77	91.34
46	1707.00	1684.00	1643.00	7.627	7.500	7.577	7.568	84.68	85.71	80.26	83.55
78	1613.00	1618.00	1507.00	7.636	7.514	7.591	7.580	75.61	79.12	67.52	74.08
102	1541.00	1527.00	1452.00	7.641	7.523	7.600	7.588	69.01	70.47	62.68	67.39
134	1512.00	1471.00	1274.00	7.641	7.509	7.595	7.582	66.44	65.40	48.25	60.03
157	1470.00	1424.00	1262.00	7.641	7.509	7.577	7.576	62.80	61.29	47.35	57.14
191	1394.00	1342.00	N/A	7.627	7.505	N/A	7.566	56.47	54.43	N/A	55.45
213	1394.00	1342.00	"	7.627	7.505	"	7.566	56.47	54.43	"	55.45
245	1319.00	1266.00	"	7.618	7.491	"	7.555	50.56	48.44	"	49.50

MIX L9 (DOSE #2)								DURABILITY FACTOR= 5.83			
No. of	Transverse Frequency, Hz			Weight, Kg				Dynamic Modulus of Elasticity			
Cycles	Spec.#1	Spec.#2	Spec.#3	Spec.#1	Spec.#2	Spec.#3	Average	Spec.#1	Spec.#2	Spec.#3	Average
0	1814.00	1820.00	1823.00	7.391	7.464	7.409	7.421	100.00	100.00	100.00	100.00
24	1450.00	1572.00	1595.00	7.450	7.514	7.455	7.473	63.89	74.60	76.55	71.68
46	N/A	1122	N/A	N/A	7.541	N/A	7.541	N/A	38.01	N/A	38.01

N/A: Specimen was removed out of the freezer
because its dynamic modulus dropped below 60%.

APPENDIX D

MISCELLANEOUS



Reference photograph used for deicer descaling rating

APPENDIX E

DEVELOPMENT OF A WORK PLAN FOR THE USE OF SUPERPLASTICIZERS IN PRODUCING FLOWABLE CONCRETE FOR HIGHWAY CONSTRUCTION

E.1 General

This document contains guidelines for the proper use of superplasticizing admixtures also known as high-range water reducing admixtures in the production of good quality and durable concrete of flowable consistency for use in highway construction in the State of Texas. The guidelines presented herein are intended to assist the field personnel in developing a comprehensive Work Plan for the incorporation of superplasticizers in the concrete.

The decision of whether to use superplasticizers should be based on technical and construction considerations for each specific application. This type of admixture, if used properly, can be an advantageous component of the concrete mixture resulting in increased workability, increased strength and ease of placement. If not properly utilized, these admixtures can result in more problems than the situations that led to the consideration of their use. Among the common problems faced by field personnel when using superplasticizers are rapid slump loss, loss of entrained air, segregation and delayed finishing due to delayed setting times.

A schematic representation of the typical behavior of concrete containing superplasticizer illustrating the problems associated with rapid slump loss and the desired behavior to be achieved through the use of the guidelines presented herein is presented in Figure E.1.

Because the effectiveness of superplasticizers is dependent upon many factors such as field conditions, production equipment, materials and environmental conditions, the Work Plan has to be developed using the same materials and equipment proposed to be used for the job. In addition, field trials must be conducted under similar conditions as those expected during the construction. Most important is conducting the field trials under representative ambient and concrete temperature ranges. The Work Plan must also be developed far enough ahead of the time of construction to allow for full evaluation of the concrete prior to its use in the field.

If the average ambient temperature differs by more than 15 degrees F from that at the time the Work Plan was developed, the contractor must revise the Work Plan in order to ensure the adequate performance of the concrete under the new temperature conditions.

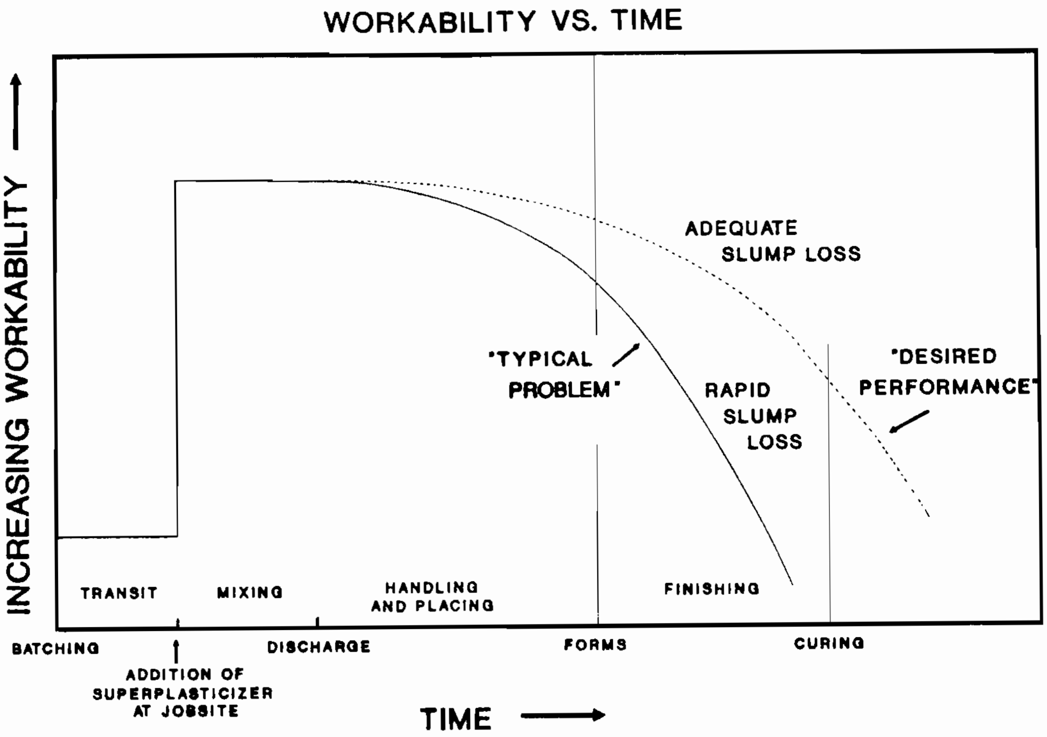


Figure E.1 Schematic representation of the workability vs. time behavior of concrete containing job site-added superplasticizer.

E.2 Scope

The guidelines described herein are applicable to the production of flowable concrete having a slump within the range of 5 to 8 inches after the addition of the superplasticizing admixture.

This document only covers the use of "first generation" superplasticizers meeting the requirements of ASTM C 494 Type F admixtures.

Unless otherwise stated in these guidelines, all existing specifications governing concrete construction practice in highway construction in the State of Texas are applicable to the production of concrete containing superplasticizers.

E.3 Materials

All proposed concrete ingredients must be from an approved source by the Texas State Department of Highways and Public Transportation. A list of pretested and approved sources of concrete ingredients is maintained by the Materials and Tests Division.

The materials or ingredients used in developing the Work Plan should be the same materials or ingredients as those which will be used in the actual construction.

This guidelines is proposed for use with normal weight aggregates consisting of gravel, crushed stone or combinations thereof and either natural or manufactured sand or combinations thereof.

All equipment used must be calibrated and approved by the engineer in particular any admixture dispensing equipment used to measure the amount of the superplasticizer at the construction site.

4. Selection of Mixture Proportions

The concrete mixtures shall be proportioned based on absolute volume as described in Construction Bulletin C-11 and Supplement thereto.

The main objective in the selection of the mixture proportions is to produce a fresh concrete having a slump in the range of 1 to 3 inches prior to the addition of the superplasticizer. Then, develop an adequate Work Plan to be followed in adding the superplasticizer to that concrete to increase its slump to 5 to 8 inches. All of this while ensuring good quality and long term performance of the concrete in service.

If the concrete is exhibiting accelerated slump loss in the field thus requiring multiple additions of superplasticizer or if the performance of the superplasticizer is erratic and unpredictable, it has been found that optimizing the dosage rate of the retarding admixture may restore consistency in the production of the concrete.

Because of the increased workability of the concrete containing superplasticizers, the engineer should consider the use of coarse aggregate factors up to 10 percent lower than those specified in Construction Bulletin C-11, Table 3. This will result in increased cohesiveness and thus decrease the potential for excessive segregation and bleeding of the fresh concrete.

The required dosage of all admixtures including air entraining, retarders, water reducers and superplasticizers is to be determined during the field trial batching procedure in order to ensure that the concrete produced meets or exceeds the requirements for the given class of concrete according to the job specifications.

E.5 Concrete Tests

The following test methods apply for making, curing and testing concrete mixtures:

Slump	Tex-415-A
Entrained Air	Tex-416-A
Flexural Strength	Tex-420-A
Compressive Strength	Tex-418-A
Temperature:	
For mix design	As required herein
For job control	As specified, measured at placement site.
Making and curing concrete test specimens	Tex-447-A
Weight per cut. ft. and yield of concrete	Tex-417-A
Time of set	Tex-440-A

E.6 Work Plan

The main objective in developing a Work Plan is to establish a procedure and practice that will allow the consistent production of superplasticized concrete in agreement with the concrete specifications and specific conditions of a job including materials selection and their proportion and batching, mixing and casting operations. Further, this document will provide the basis for a reference and training manual for field personnel involved in the use of flowable concrete containing superplasticizers.

The first step in the development of the Work Plan is to evaluate the physical properties of the fresh and hardened concrete being produced, in particular, the amount, if any, of entrained air that is required. The use of a superplasticizer poses unusual demands on the concrete producer to ensure adequate air entrainment while producing high slump superplasticized concrete. It is the responsibility of the concrete producer to determine the needed dosage of air entraining admixture for each concrete under the expected job conditions.

In addition, the location of the placement site with respect to the batching facilities must be carefully evaluated for estimating a reasonable transit time in order to establish an adequate time of first addition for the superplasticizer to the fresh concrete at the job site.

In order to obtain maximum efficiency and consistency during mixing, the allowable size concrete batches will be not less the 33 percent nor more than 75 percent of the mixer rated capacity.

The general approach in developing an adequate Work Plan consists of the following:

1. determine the basic mixture proportions including amount of admixtures required, except superplasticizer to produce a fresh concrete that will have a slump in the range of 1 to 3 inches at the time of the first addition of the superplasticizer, and

2. develop a procedure for the addition of superplasticizer to that concrete that will produce 5 to 8 inch slump concrete.

The following is a detailed outline containing suggestions for the development of the Work Plan. As described herein, the term "addition of superplasticizer" refers to the dosification of a concrete batch with the purpose of increasing the slump of the concrete from within the range of 1 to 3 inches to a flowable range of 5 to 8 inches. Each "addition of superplasticizer" may consist of one or two immediate dosifications of the concrete as needed to achieve the desired workability.

E.6.1 Determining the basic mixture proportions. Once a determination has been made of the estimated time when the concrete will be first dosed with superplasticizer, the concrete producer must decide on the concrete mixture proportions needed in order to obtain a 1 to 3 inch slump concrete at that time. The concrete may have to be batched having a higher than 1 to 3 inch slump at the batching plant when high slump loss due to hot weather conditions, extended delivery time or delayed time of addition is expected. Of main importance at this time are the selection of the amount of retarding admixture, air entraining admixture and amount of mixing water.

The full amount of all chemical admixtures except the superplasticizer must be added with the rest of the ingredients at the time of batching. Under no circumstances will the addition of any chemical admixture other than the superplasticizer be allowed after initial mixing.

The amount of retarding admixture used may be varied during the duration of construction as needed to achieve adequate slump concrete at the time of first addition of superplasticizer. Probably the main factors affecting the amount of retarder needed will be the temperature of the concrete and the ambient conditions as well as special considerations requiring specific setting time characteristics of the concrete in-place.

At no time will the amount of mixing water added to the concrete exceed the amount of mixing water specified in the approved mix design for the job, hereinafter referred to as approved mixing water. The approved mixing water shall not exceed the maximum limit allowed under the concrete specifications for the given class of concrete being produced.

The concrete producer could at times hold some of the mixing water at the time of initial batching. In this case, the contractor has the option of adding to the fresh concrete an amount of water equal to or less than that withheld upon arrival to the placement site as long as this addition of water is done prior to the first addition of any superplasticizer and the approved mixing water is not exceeded. Once the first addition of superplasticizer has been done, no water can be added to the concrete.

When the time of first addition exceeds 30 minutes, the use of a retarding admixture is highly recommended especially under hot weather conditions. In cold whether, the retarding admixture may be reduced or eliminated in order to prevent delayed setting times. The use of a retarding admixture typically results in increased effectiveness of the superplasticizer and helps reduce slump loss.

In situations where the travel time exceeds 45 minutes from the time of initial batching, the concrete producer has the option of adding the first addition of superplasticizer at the batching plant after initial mixing has been completed and prior to transporting the concrete to the placement site.

E.6.2 Addition of superplasticizer. Superplasticizer will not be allowed to be added to the concrete until after initial mixing is achieved. If the slump of the concrete prior to the first addition of superplasticizer is below 1 inch, the concrete producer can adjust the slump of the concrete to within the desired slump range of 1 to 3 inches by the addition of hold water as per existing specifications. If not water has been withheld, the concrete batch must be rejected. The addition of withheld water will be done prior to the first addition of superplasticizer. After the addition of the hold water, the concrete shall be mixed a minimum of 25 revolutions.

The addition of superplasticizer shall be done by discharging the admixture on top of the fresh concrete inside the drum. To achieve this, the mixer drum must first be reversed to a point just short of discharge and stopped. Then, the superplasticizer shall be discharged on top of the load through the use of a five-foot or longer rigid pipe extension or wand thus ensuring that the entire amount of admixture is in contact with the fresh concrete.

Immediately after each addition of superplasticizer, the concrete must be thoroughly mixed for 5 minutes at mixing speed prior to evaluating the conditions of the fresh concrete. If the slump of the concrete after the addition of superplasticizer is not that desired within 5 to 8 inch range, the slump of the fresh concrete can be immediately adjusted by redosing with an additional amount of superplasticizer following the same procedure as described above. Immediate redosing of superplasticizer will only be allowed if both additions of superplasticizer are completed within 15 minutes.

If the slump of the concrete after the addition of superplasticizer is between 8 and 9 inches, acceptance of the concrete will be dependent on the material not exhibiting segregation or excessive bleeding as determined by the Engineer. However, it will be the responsibility of the contractor to make the necessary adjustments in superplasticizer dosage rate for subsequent batches in order for the concrete not to exceed the 8 inch slump limit.

Subsequent batches will not be allowed to be placed with over an 8 inch slump during a continuous casting operation.

Concrete having a slump of over 9 inches will be rejected.

During the development of the Work Plan, the contractor shall decided upon the maximum period of time that will elapse between initial batching and the time of the first addition of superplasticizer. Then, he must conduct all the trial batches for determining the acceptance of a given mix design while performing the first addition at the maximum time specified. However, during actual construction, the contractor shall be allowed to perform the first addition at a time earlier than that specified in the Work Plan but never at a later time.

A second addition of superplasticizer will be allowed if the slump of the concrete falls within the 1 to 3 inch range and can still be placed within the allowable time limits. The same procedure as described above for the first addition of superplasticizer including redosing shall be followed.

When superplasticizers are used to produce flowable concrete as intended under this procedure, no concrete shall be discharged and placed having a slump within the range of 1 to 3 inches. As a result, all concrete having a slump of 1 to 3 inches must be dosed with superplasticizer prior to its use in construction.

If the concrete is exhibiting accelerated slump loss in the field thus requiring multiple additions of superplasticizer or if the performance of the superplasticizer is unpredictable, optimizing the dosage rate of the retarding admixture may restore consistency in the production of the concrete.

Superplasticizer will not be allowed to be added to the concrete under any of the following circumstances:

a. after discharge has been initiated,
b. if the temperature of the fresh concrete has increased by more than 5 degrees F since initial testing at the job site, or
c. after two additions of superplasticizer.

Because of the need for thorough mixing after each addition of superplasticizer, concrete containing superplasticizer could exceed the existing limits in the concrete specifications governing the maximum number of drum revolutions prior to concrete placement.

E.6.3 Sampling and testing of concrete. During the development of the Work Plan, slump, air content, temperature, setting time and unit weight should be monitored for the time period during which placement is estimated to be completed. In particular these tests must be performed on the fresh concrete immediately after each addition of superplasticizer and at time intervals not exceeding 20 minutes thereafter until reaching the end of the allowable time limit for placement. One set of strength specimens must be cast prior to the first addition of superplasticizer, immediately after each addition of superplasticizer and at the end of the allowable time limit for placement.

During actual construction, fresh concrete tests shall be made and strength specimens cast from the concrete immediately prior to placement and after all additions of superplasticizer have been completed. It is important that acceptance of the concrete in the field be made on the basis of the characteristics and properties of the concrete being placed and not of the concrete during any of the earlier stages of its production. Any time that a second addition of superplasticizer is made to a concrete load intended to be air entrained, an air content test shall be performed to verify the adequacy of the air content of the concrete being placed.

E.6.4 Trial batches. The contractor/supplier shall prepare and test at least one full batch using the same equipment, mixture proportions, materials and personnel for the proposed job in order to develop the Work Plan. Representatives of the DHT shall witness all the testing conducted during the development of the Work Plan.

E.6.5 Documentation. The contractor must provide the Engineer, as a minimum requirement, the following information as part of the Work Plan:

A. concrete mixture proportions including concrete design work sheet shown in Attachment A,

B. narrative on the proposed batching sequence, mixing procedure, mixing times at the plant and job site, maximum batch size, placement procedure, detailed description of the proposed method for adding the superplasticizer to the concrete, maximum time for first addition of superplasticizer, predicted dosage rate of superplasticizer at each time of addition, if pumping is proposed, indicate the slump and air content before and after pumping, and any other specific details to the job,

C. all test data in tabular form including fresh concrete and hardened concrete test results, results from any other tests on the concrete required for the job, and

D. a graph similar to Attachment B showing the slump loss and concrete temperature change with time in addition to the time of addition, dosage rate and ambient temperature as illustrated in Figure E.2.

E.6.6 Preconstruction training and coordination. The contractor/supplier shall plan, hold and document a special preconstruction and training conference to discuss the

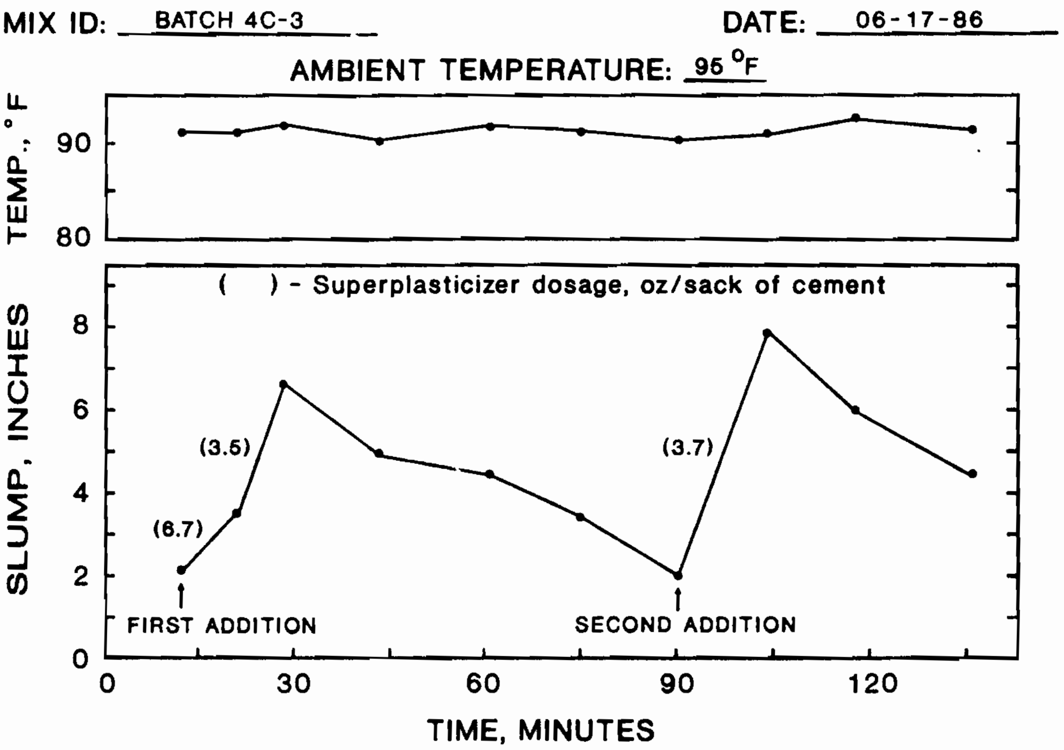


Figure 2. Typical record of slump and temperature vs. time during monitoring of a concrete batch containing superplsticizer in the field.

execution of the Work Plan, results of testing, proposed mix proportions, anticipated site conditions and potential problems and their solution that may occur during construction.

ATTACHMENT A

Construction Form 309

County: ____
Project: ____
Date: ____

Design No: ____

CONCRETE DESIGN WORK SHEET

(NATURAL AGGREGATES)

AGGREGATE CHARACTERISTICS:

	SP. GR	SSD Unit Wt. Lbs./Cu. Ft.	% SOLIDS
Fine Aggregate (FA)	____	____	____
Coarse Aggregate (CA)	____	____	____
Water			
Cement			

DESIGN FACTORS:

Cement Factor (CF), ____ sacks per cubic yard of concrete
Coarse Aggregate Factor (CAF), ____
Water Factor (WF), ____ gal. per sack of cement
Air Factor (AF), ____ %

BATCH FACTOR:

$\frac{\text{Size of Batch (Full Size)}}{\text{Yield for 1-Sk. Batch}}$ = ____ = ____

BATCH DESIGN (ONE SACK)	VOLUMES: 1-SK. BATCH (CU. FT.)		VOL. TO WT. (LB.) VOL. X 62.5 X SP. GR	1-SK. BATCH WTS.	FULL SIZE BATCH FACTOR	FULL SIZE BATCH WTS.
1. Concrete Yield = $\frac{\text{Cu. Ft. per Cu. Yd.}}{\text{CF}}$	$\frac{27}{\_\_\_\_}$ = ____					
2. Volume CA = Yield X CAF X Solids	____ X ____ X ____ =	____	X 62.5 X ____ =	____	____	* ____
3. Volume Mortar = Yield — Vol. CA	____ — ____ = ____					
4. Volume Water = $\frac{\text{WF}}{\text{Gal. Water per Cu. Ft.}}$	$\frac{\_\_\_\_}{7.5}$ =	____	X 62.5 X 1.00 =	____	____	* ____
5. Volume One Sk. Cement	=	0.485	X 62.5 X 3.10 =	94.0	____	____
6. Volume Entrained Air = Yield X AF	____ X ____ =	____				
7. Volume Paste = Vol. Cem. + Water + Air	0.485 + ____ + ____ = ____					
8. Volume FA = Vol. Mortar — Paste	____ — ____ =	____	X 62.5 X ____ =	____	____	* ____

9. Yield (Summation of 2, 4, 5, 6 & 8 to Check No. 1 Above) = ____

10. Fine Aggregate Factor = $\frac{\text{Vol. FA}}{\text{FA Solids X Vol. Mortar}}$ = $\frac{\_\_\_\_}{\_\_\_\_ \text{ X } \_\_\_\_}$ = ____

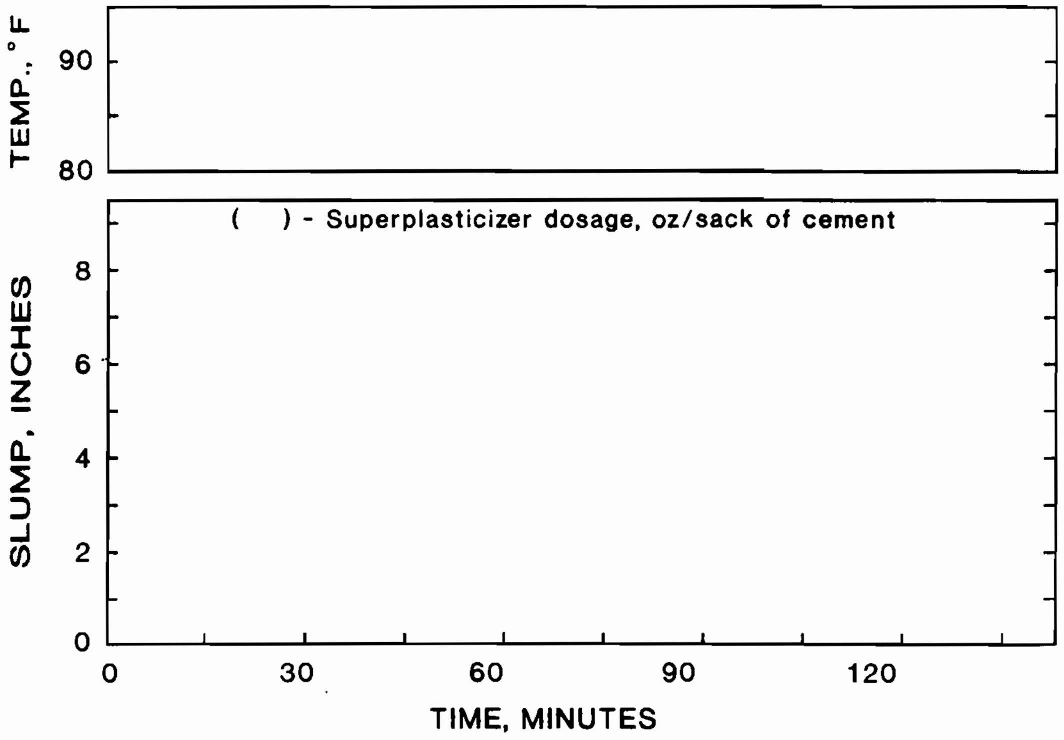
* Correct For Free Moisture or Absorption.

REMARKS: Volumes in Above Are Absolute Unless Otherwise Noted.
Water Added at Mixer Must Include the Liquid of the Admixtures.

ATTACHMENT B

MIX ID: ____________ DATE: ____________

AMBIENT TEMPERATURE: _____



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