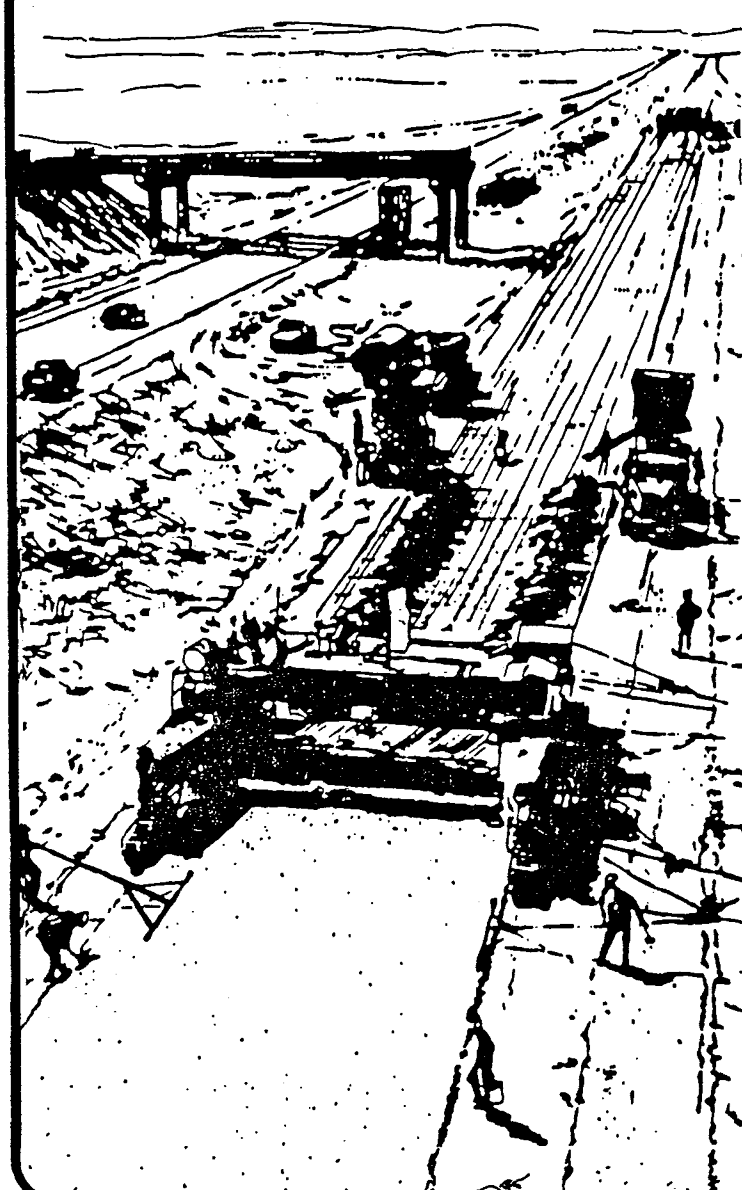
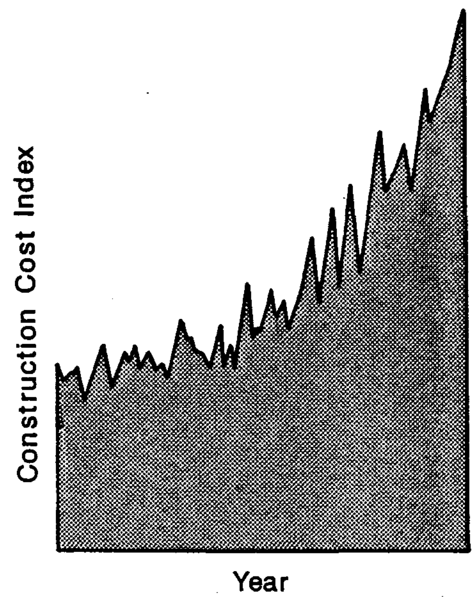
ENGINEERING ECONOMY AND ENERGY CONSIDERATIONS

SUGGESTED GUIDES FOR USE OF LIGHTWEIGHT AGGREGATES
IN PLANT MIXED ASPHALT PAVING MATERIALS

RESEARCH REPORT 214-32

MAY 1980





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2-9-74-214

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CONSIDERATIONS IN DESIGN,
CONSTRUCTION AND MATERIALS"

TEXAS STATE DEPARTMENT
OF HIGHWAYS
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16. Abstract

The use of lightweight aggregate in the production of plant mixed asphalt paving materials requires consideration of specific guides to maximize the success probability of design, construction and maintenance of this surfacing material.

The need, indeed the demand for long term high friction pavement surfaces increases with the ever increasing volume of traffic on the nation's highways. This need can be answered by following the guidelines presented.

Problems have arisen in many instances in the past wherein lightweight aggregates have been used in plant mixed asphalt paving mixtures.

Aggregate selection and evaluation, mixture design, hot plant operations, transport, laydown and compaction considerations plus maintenance of thin overlays made with lightweight asphalt aggregate mixtures are covered in detail.

Further, the author discusses certain pavement distress mechanisms, and how to identify and prevent or correct these problems.

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by

Bob M. Gallaway

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Sponsored by

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May 1980

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha

MASS (weight)

Symbol	When You Know	Multiply By	To Find	Symbol
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

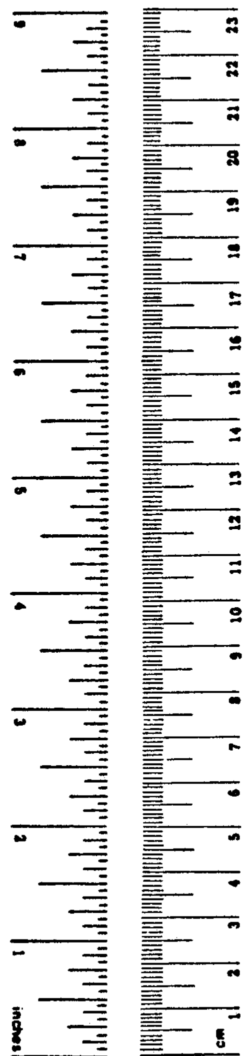
VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac

MASS (weight)

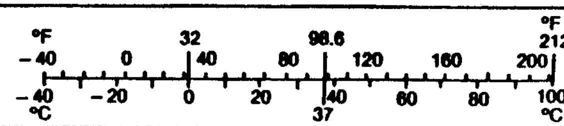
Symbol	When You Know	Multiply By	To Find	Symbol
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

ABSTRACT

The use of lightweight aggregate in the production of plant mixed asphalt paving materials requires consideration of specific guides to maximize the success probability of design, construction and maintenance of this surfacing material.

This need, indeed, the demand for long term friction pavement surfaces increases with ever increasing volume of traffic on the nation's highways. This need can be answered by following the guidelines presented.

Problems have arisen in many instances in the past wherein lightweight aggregates have been used in plant mixed asphalt paving mixtures.

Aggregate selection and evaluation, mixture design, hot plant operations, transport, laydown and compaction considerations, plus maintenance of thin overlays made with lightweight asphalt aggregate mixtures, are covered in detail.

Further, the author discusses certain pavement distress mechanisms, and how to identify and prevent or correct these problems.

KEY WORDS

Pavement Distress, Pavement Maintenance, Lightweight Aggregates, Friction, Mixed Design.

TABLE OF CONTENTS

INTRODUCTION

Demands for high polish value aggregates continue to increase as the State and Federal Agencies work together to improve driving safety by upgrading the desirable surface properties of our highway system.

Lightweight aggregates produced from clays and shales by the rotary kiln process exhibit high polish value properties and have been used on Texas highways since 1961. These aggregates were used initially as cover stone for seal coats or surface treatments. Use of this material has been extended to plant mixes and this practice has prevailed for about ten years during which time some design, construction and maintenance problems have developed. The guides to follow have been prepared in an effort to assist the various agencies using these materials. In the State of Texas the economic availability of natural aggregates with polish values (as per Texas' modification of the British Method) in the general range of 30 to 40 is critical. Texas highway engineers are therefore faced with a particularly difficult problem, one which they are handling with considerable skill and efficiency.

One solution to the problem of supplying prolonged high friction on Texas highways came about more or less by chance. Almost two decades ago TTI was requested by the State to solve the problem of glass damage to highway vehicles, a problem caused by "flying stone" on highways that had been subjected to routine maintenance in the form of seal coats with cover aggregate.

Researchers at TTI reasoned that if the potentially damaging stones that were being thrown by traffic were of low mass, the associated damage would be minimized. Two possible answers surfaced; select a smaller sized stone or locate and substitute a stone of low density. The use of small stone entailed associated unacceptable construction control problems; therefore, the low density particle concept was chosen for further study, and "Presto" lightweight aggregate was introduced to the Texas highway aggregate supply picture.

This was a serendipitous move; for, almost immediately, it was observed that chip seals which utilized lightweght aggregate as cover stone produced high friction surfaces. Skid number measurements made with locked wheel trailers after the method of ASTM E274 were in the range of 50 to 70. Where the aggregate used was in the size range of ½ inch to No. 4, the surface macrotexture was quite high with values of 0.10 to 0.15 quite common.

Although lightweight aggregates are still being selected as a means of reducing damage to glass, this is no longer the primary reason for the choice. Today, Texas looks at lightweight aggregate as a highly desirable and available material to meet its most demanding polish value needs.

METHODS OF USING HIGH POLISH VALUE MATERIALS

Supply and demand of high polish value materials in Texas has raised the cost of friction improvement maintenance as well as the cost of the surface layer on new construction. As a result, several different concepts have evolved to effect the desired end product, Currently used concepts include:

a) Sprinkle treatments,

b) Chip seals or surface treatments,

c) Blended dense graded hot mix and

d) Open graded friction courses, OGFC.

It may be noted that these methods are listed in the general order of increasing amounts of the critical material required for a unit area of pavement being treated. Roughly the quantities required for concepts a, b, c and d are 0.1, 0.3, 0.6 and 0.7 cubic feet of polish resistant aggregate persquare yard of surface. These figures are predicated on Texas' current normal designs for items "a" and "b" and a thickness of about one inch for items"c" and "d" with item "c" containing about 60 volume percent of coarse high polish value material in the aggregate blend.

Although none of these approaches is free of problems, only items "c" and "d" will be considered in this discussion. Additionally, the discussions to follow will be concerned primarily with the coarse lightweight aggregate fraction of the paving mixture. Since the primary source of the problems that have surfaced across the state appears to have centered on lightweight aggregates of the heat-expanded clay of shale type, the major thrust of the paper will be directed toward these materials. However, in the opinion of the author, many of the problems associated with open graded and dense graded plant mixes, which utilize lightweight aggregate in the coarse fraction, cannot be laid solely at the feet of the lightweight material. There are several other important factors which must be considered. Therefore, as time and space permit, these factors will be discussed in an effort to improve the success probability of concerned individuals who choose to use plant mixes with lightweight aggregate in the friction maintenance of Texas highways. Factors that may warrant discussion, as these relate to this type material, are:

a) Aggregate physical properties,
b) Mixture design,
c) Plant handling and batching,
d) Construction associated items,
e) Serviceability and
f) Maintenance.

AGGREGATE PHYSICAL PROPERTIES

Currently, there are two manufacturers of lightweight aggregate in Texas. One of these producers operates two plants, one plant located in Clodine, Texas just west of Houston and one at Streetman located on I 45 southeast of Dallas. The other producer has a plant at Ranger west of Ft. Worth.

The production capacity of these three plants is in the order of 1.4 million cubic yards per year. About 30 percent of this production is used to produce high friction surfaces on Texas highways. Most of this lightweight material is furnished in a size meeting the requirements of Texas Specification Item 303 Grade 4, which grade is sized predominately between the ½ inch and the No. 4 sieves. The aggregate particles are angular and rough textured and the internal makeup of the particles is such as to furnish continuous microtexture as the particles gradually wear under the action of traffic.

Although the polish value as determined by Texas Method Tex-438-A differs somewhat for aggregate from each of the three plants in Texas, all three aggregates may be utilized in mixture designs that will meet service requirements as they are currently defined.

The angular shape and rough surface texture of coarse lightweight aggregate particles affect other facets of mix design, batching, and even placing of the final paving mixture. Additionally, the early performance of surfaces made with this material is indirectly affected. Under optimum design and construction conditions, textured aggregates will retain a heavy film of asphalt, and this can contribute to delayed development of the desired (planned) level of friction for open graded friction courses. The design engineer should be aware of this delayed development of high friction and take the necessary precaution to offset this problem. This inclusion of about 10 percent minus No. 10 mesh crushed material will usually provide interim friction.

Degradation of the coarse aggregate fraction in dense mixtures is not considered a problem and years of service records attest to this; however, this may not be the case for open graded friction courses wherein lightweight aggregate constitutes 85 to 90 volume percent of the aggregate skeleton. Crushing of aggregate particles at points of high stress during construction and during service does happen. This leads to a reduction in the permeable air voids and closing of the drainage channels in the mat which in turn increases splash and spray, reduces high speed friction, and increases the probability of hydroplaning during heavy rains or poor drainage conditions.

It can be theorized with reasonable confidence that lightweight aggregates will crush more readily than hard natural stone or other hard material. This is a "point stress" affair with tire pressure and wheel load contributing strongly to the magnitude of the stress developed. If these points of contact are few, the level of stress at these points will be high and vice versa. Therefore, an avenue of approach to minimize loss of permeable voids (and in extreme cases, flushing of the surface) would be to increase the number of contact points. This may be accomplished by:

a) Reducing the top size of the aggregate,
b) Changing the particle shape,
c) Keeping the top size fixed and adding some intermediately sized material (a chocking action),
d) Altering the construction compaction to improve nesting of the aggregate or
e) Decreasing the design air void content.

Another approach that has been used to minimize mat closing is to increase the binder viscosity or the type of binder.

The pros and cons of these approaches follow:

Since friction improvement is the primary goal via the use of these selected aggregates, one needs to consider certain facts about tire-pavement interactions. Tire-pavement friction in the United States is commonly reported as a skid number, SN, usually measured at 40 mph with a locked wheel trailer generally operated in compliance with ASTM E274 procedures. This method involves the use of a standard ASTM E501 test tire inflated to 24 psi and loaded to 1085 lbs. Texas utilizes this wet pavement testing procedure.

Both small and large scale surface texture contribute to the SN_{40}; however, at this speed the major contribution is from the small scale surface texture. The large scale of macrotexture effect (input) increases with test speed.

Under natural wet weather conditions where the water film thickness may be several times that used in the standard test water drianage capacity made possible with increased macrotexture (larger top sized aggregate in the paving mixture) improves vehicle braking. Therefore, in areas of heavy rain and/or poor drainage one may wisely choose not to decrease particle size as a means of reducing degradation during construction and service.

Lightweight aggregate production methods and market demand influence particle shape, and although it is technically feasible to alter particle shape for that fraction of the production that goes to highway surfaces, the practical aspects of this approach make the event unlikely at this time.

Probably the most practical and effective means of reducing degradation is to include some fine aggregate in the mix. There are other benefits to be derived from this approach, benefits that may be more important than reducing degradation, important as this is. Some Districts in Texas have used small amounts of fines in open graded friction courses, OGFC, and have found an immediate increase in the range of placing temperatures, with this increase being a primary function of the amount of minus No. 200 material added to the mix. The author suggests the addition of 10 to 15 percent of fines with sufficient filler to result in about 3 percent of material passing the No. 200 sieve.. Preferably, the coarser particles in the fines fraction should be sand size, sharp textured and blocky in form. The No. 200 mesh material will permit the contractor to raise the batching and hauling temperature 30° to 40°F without encountering excessive asphalt drain down.

Some of the gritty fines will be held on the exposed surface of the coarse aggregate and thus contribute to friction in the very early service life of the overlay.

By experimenting with roller types and patterns of rolling, a contractor may improve compaction efficiency and thereby create adequate nesting of aggregate particles without adverse crushing at points of aggregate contact. Lightweight vibratory rollers have been effectively used.

Ideally, the permeable air void content of OGFC mixtures should be in the general range of 15 to 20 percent and under adverse conditions of terrain, traffic, and environment, higher voids would be advised. If, however, one wanted to minimize degradation, alteration of aggregate grading is one way this may be done. The route to take would be to reduce the top size of the coarse aggregate and/or go to more dense grading, holding the aggregate top size fixed.

A reduction of aggregate top size of a uniform graded material <u>may</u> reduce water permeability. If, on the other hand, permeability remained essentially constant, drainage time would likely increase.

Increasing the drainage time may or may not cause service problems. For example, on the average in Texas, 92 percent of all rains have a measured intensity of 0.25 in/h or less; hence, this lower rate of drainage would be of little consequence from the time of exposure viewpoint. Heavy rains or long drainage paths do cause flooding of the surface even on the more open designs that have been constructed to date.

MIXTURE DESIGN

Mixture design for OGFC differs from designs for dense graded pavements; however, there are similarities that make for common precautions when dealing with these two mixture types. A volume design concept is recommended for OGFC designs as well as for dense graded blended aggregate mixtures, the coarse aggregate fraction of which is lightweight material, since both designs may include aggregates of distinctly different specific gravities.

Procedures have been developed for handling the problem of volumetric design and these procedures are in use across the state. Details are included in Appendix A.

The mixture design procedures based on volume eliminates problems associated with aggregates of different specific gravities. Since locally available materials may supply the intermediate and/or finer fraction for these designs, this should reduce material costs. Drying and placing problems may also be reduced and an added bonus may be improved and prolonged friction by differential rates of wear under traffic.

PLANT ASSOCIATED CONSIDERATIONS

There are roughly 4,300 hot mix plants in the United States engaged in the production of hot asphalt-aggregate mixtures. The large majority of these plants are the weigh batch type; however, the new plants being purchased today are mostly the drum dryer continuous mix type. The use of this newer type of plant in conjunction with the volumetric mixture design method previously outlined should simplify mixture production and result in a smooth operation.

For contractors who use the weigh batch plants, volume design will have to be presented on a weight basis for batching purposes. However, mixture design specification compliance should be on a volume basis. In reality, the cold feed of a weigh batch plant is generally operated on a volume basis just as it is in a continuous mix type of plant.

Contractor and State personnel are generally aware of the differences in hot mix operations involving the use of lightweight aggregates; however, a review of these differences and suggestions for possible modifications of general practice appear to be in order and is given in the following paragraphs.

Because lightweight aggregates have water absorption capacities ranging from 10 to 25 percent and because the water release rate is often lower for such materials, it is practically impossible to remove all absorbed water in the normal operation of a regular hot-mix plant. Additionally, the absorbed water problem is usually compounded by the presence of free water on the aggregate particles. In the event that poor drying conditions prevail, further complications will naturally be imposed.

PLANT OPERATOR OPTIONS

The plant operator has several alternatives for improving aggregate drying including:

a) Changing the rate at which the material passes through the dryer,

b) Drying and stockpiling material for rerunning,

c) Lowering the exit temperature of the dryer, or

d) Raising the exit temperature of the dryer.

Drying Rate - Let us pause now and direct our attention to the drying efficiency that would be brought about by changing (reducing) the rate at which the material passes through the dryer. This method is often effective, but production is naturally reduced. Not only is production reduced, but also plant down time is necessary to change the rpm and slope of the dryer. A change back to normal operation would then require readjustment of the dryer and another time loss event.

Predrying - drying and stockpiling material for early morning operation is a workable solution and this approach has been successfully practiced. Let us assume a job with stockpiles of wet aggregates and poor drying conditions--low temperature and high humidity. Let us further assume that moisture measurements on the lightweight coarse material indicate 18 percent total water and a similar check on the fine material shows 6 percent water. These are not unusual values; in fact, a moisture content in the 25 percent range for certain lightweight materials is not uncommon. Under such circumstances predrying of the lightweight material will probably solve the moisture problem. Complete drying is not required. With wet lightweight in the 15 to 20 percent moisture content range, drying back to 3 to 6 percent moisture would be satisfactory. Predried material should be stockpiled separately at least one day before it is needed and used only as necessary to produce the desired end product. This will usually mean using all predried lightweight when the plant is "kicked off" in the morning, and then as the air temperature rises and the humidity drops, less and less predried material is charged to the cold bins. By noon or before, it may be feasible to go entirely to the wet aggregate stockpile. Any slack time in the plant operation should be used to stockpile more predried lightweight for the next morning. In the event of rain, predried material should be covered.

It is not advisable to cover predried material to protect it from absorbing water from the air. Lightweight aggregate that leaves the dryer with, say 3 to 6 percent moisture will continue to lose some moisture in the stockpile if left uncovered. Covering the hot material will cause condensation on the cover, and this water will be returned to the aggregate. If the aggregate is not covered, moisture would leave the material as water vapor.

An efficient and workable program of predrying requires planning and good judgement on the part of the plant superintendent. It is, nevertheless, an effective partial solution to the successful placing of lightweight hot-mix.

Lower the Exit Temperature of the Dryer

Although some plants may operate with dual dryers arranged in series, most hot mix plants consist of a single dryer that operates on a fixed slope, flight design, and rotational speed. During normal operations, material passing through the plant does so on a fixed time schedule. This means that drying is controlled primarily by drum gas flow rate and dryer temperature.

Drying of very wet materials may cause delayed moisture release which may in turn result in slumping of the mixture in the haul units and may also cause fat spots on the road. Under some circumstances lowering the dryer temperature rather than raising it will eliminate these problems. Raising the dryer temperature often aggravates the problem. An increase in drum gas velocity associated with lowering of the temperature will also be found helpful. A change in flight design may also be in order.

Raise Dryer Temperature - The natural tendency is to raise the dryer temperature and frequently this has been found effective; however, for most lightweight aggregates with high stockpile moisture contents this will not solve the problem. The release of water from the lightweight material may be too slow, and as a result, the mix is dropped into the haul truck while water is still being evaporated from the pore structure of the coarse material. This evaporation of water cools the mix at a rate of about 40°F for each percent of water evaporated. Since no heat is added to the system after it leaves the dryer, the mix as it drops into the haul truck may be 40° to 90°F cooler than the aggregate leaving the dryer because of evaporative cooling.

Field observations indicate the aggregate at the dryer may be at 350°F while the mix temperature as it drops into the haul unit may be only 260°F. Thus, the evaporative cooling during hot storage and mixing may have a pronounced effect on placing operations.

With this approach to the problem, the question then is--"Can we live with this?"--and we may very well be able to do so. More specific answers will be supplied later in this discussion.

Additional Considerations - Evaporative Cooling, Water Release, Etc.

One additional alternative is that of closing the job and waiting for improved operating conditions. Generally, this is a costly choice and should be avoided if at all practical.

The experienced plant operator is aware of the various approaches to problem drying that have been discussed to this point. He may not, however, be aware of the rates and magnitudes of limiting factors affecting the successful placing of hot mix containing lightweight aggregates.

In this day of scarce supplies and high prices of fuel, a knowledge of efficient aggregate drying and heating is essential. Conservation of fuel is strongly advised.

Referenced in this special discussion dealing with problems of drying lightweight aggregate for hot-mix are two documents available from the National Asphalt Pavement Association (NAPA) (9, 10).

One document is "Heating and Drying of Aggregates -- Btu Requirements and Exhaust Volumes". The other is titled "Fuel Conservation". Both of these publications are available on request from NAPA.

Outlined in the first listed publication are several basic facts which, when understood and put into effect, will improve drying operations and save fuel. The importance of fuel economy and methods of effecting such economy are clearly described in the second publication. One is urged to put this information to work for its potential to save energy and improve plant operations.

TRANSPORT RELATED PROBLEMS

The transportation of lightweight aggregate hot mix asphalt concrete presents no special problems provided the aggregates are dry. For long hauls on cool days covering of the mixture is suggested and/or higher mixing temperatures may be required.

Average temperature drops of 10° to 15°F due to heat losses of water-free hot mix in the haul unit and laydown machine are commonly assumed for the normal operation. Although less heat is carried out in a given volume of lightweight material, the rate of cooling will normally be less than for an equal volume, (truckload) of regular mix.

The presence of water in the aggregate can, however, present special problems. Field evidence exists which indicates that wet aggregate within hot asphalt concrete mixtures continues to lose water by evaporation. This water vapor may condense and collect at localized places within the load or the bed of the truck. At the placing site the asphalt concrete may be extremely fluid and will flush or bleed in the localized area of moisture collection and release. Evidence of this type of distress is apparent in the form of pairs of flushed areas one on either side of the center line of a given pass of the laydown machine and sequenced with each load of material placed. A regular pattern will prevail as long as the problem persists. A great deal of excess moisture in the mixture will produce an asphalt concrete that will readily flow from the haul unit. Difficulty is encountered during the placing and compaction of this "6-inch slump" asphalt concrete.

LAYDOWN AND COMPACTION ASSOCIATED PROBLEMS

Problems with laydown and compaction operations may be functions of mixture properties, but often they are temperature related. Problems with harsh or tender mixtures (relatable to aggregate gradation, shape and surface texture and to certain asphalt setting properties) may be expected, but these problems are relatively few if one follows the present materials and construction control specifications. Consequently, the discussion will move directly to mix temperature as it relates to laydown and compaction operations.

Background on Cessation Requirements - Cessation requirements for rolling hot mix have been developed by a number of agencies and are given in references 1, 3, and 4. These requirements are based on a knowledge of the following:

1. The rate at which the mat cools,
2. Establishment of a "reasonable time" for applying breakdown rolling and
3. The temperature below which breakdown rolling is not very effective in producing mat density.

The National Asphalt Pavement Association's Quality Improvement Committee, through a series of questionnaires, meetings and a review of the literature, has established that breakdown rolling below about 175°F for most dense mixtures produces limited compaction. This same committee suggested that 8 minutes is the minimum time required for passes of the breakdown rolling for thin lifts and 15 minutes is the minimum for thicker lifts of asphalt concrete. These time restrictions thus affect the paver speed as well as plant production rates and associated transportation operations. For roller speeds of 3.5 miles per hour and an 8-minute roller time, one roller will limit the paver to a speed of about 30 feet per minute, while two rollers will allow paver speeds up to 55 feet per minute. For 15-minute roller times the respective paving speeds will be 30 and about 60 feet per minute. Eight-and fifteen-minute available compaction times will be used in the following discussion together with the 175°F temperature below which breakdown rolling is no longer very effective.

Mat cooling curves have been simulated by mathematical models and computer solutions have been developed (2, 4). Field data have verified these solutions for asphalt concrete mixtures made with normal weight aggregate. Typical examples of this type of information are shown in Figures 1,2, and 3 (1). Figure 1 illustrates the tremendous influence of mat thickness on the time necessary to cool to 175°F, while Figure 2 illustrates the influence of base temperature on available compaction time. Figure 3 gives the temperature of the base and mat necessary for paving operations where a 15-minute rolling time is necessary for adequate breakdown rolling. For example, if the temperature of the base is 60°F, the mat temperature should be 270°F to provide the necessary 15-minute compaction time for a 2-inch mat thickness.

<u>Lightweight Aggregate Cooling Curves</u> - Cooling curves have been developed for lightweight aggregate hot mix asphalt concrete by use of a computer program developed by Corlew and Dickson (2) and modified by the Texas Transportation Institute. These curves shown in Figure 4 to 16 were developed for base temperatures of 30°, 50° and 70° and mat temperatures of 200°, 230°, 260°, 290°, and 320°F. A wind velocity of 10

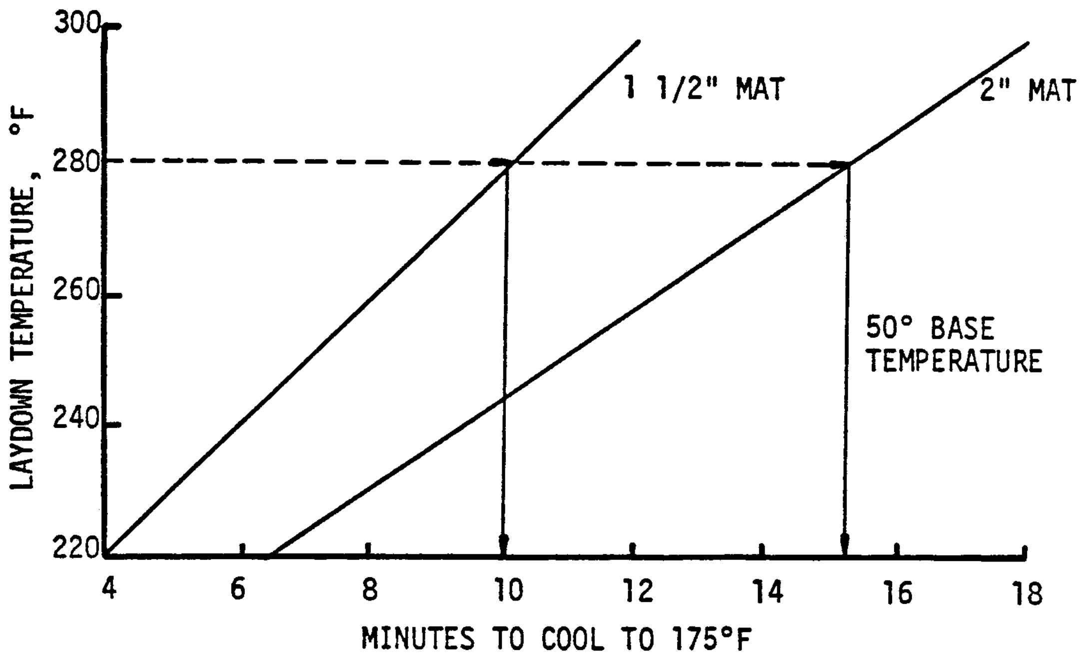


Figure 1. Effect of Mat Thickness on Cooling Rate for Normal Weight Materials.

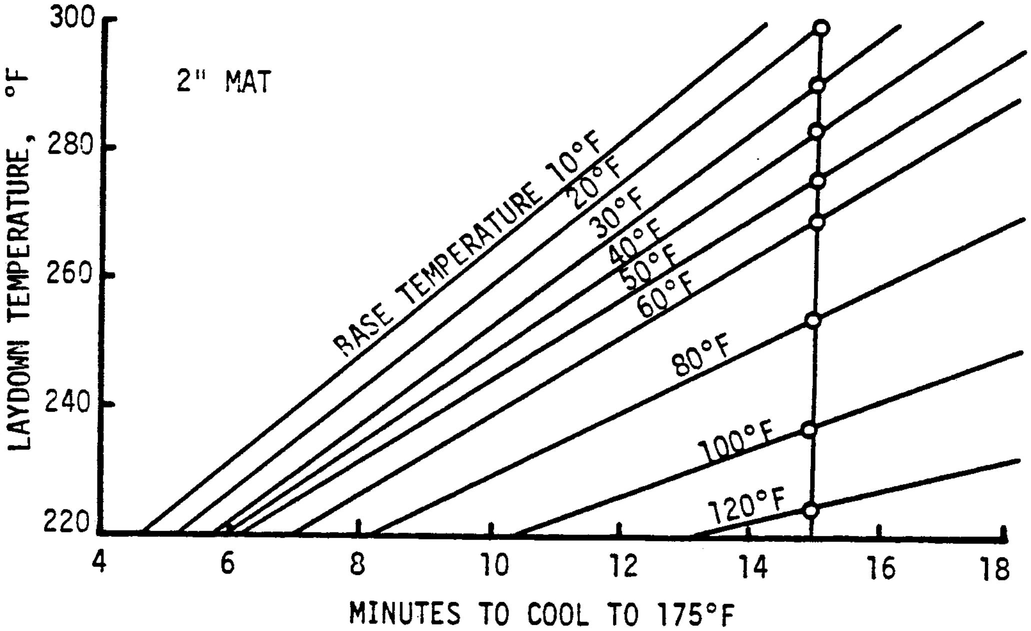


Figure 2. Effect of Base Temperature on Rate of Cooling for Normal Weight Material.

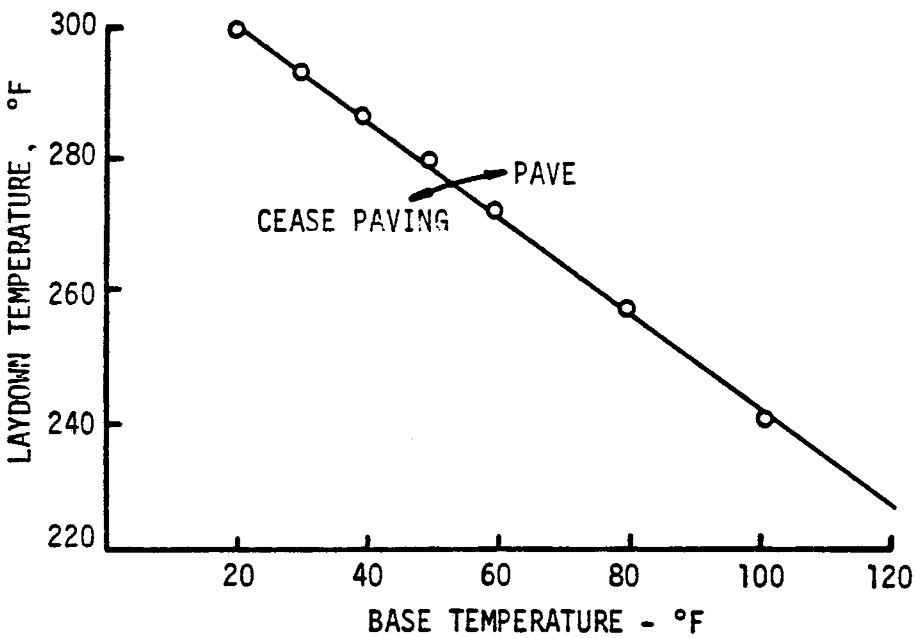


Figure 3 Illustration of Suggested Cessation Requirements - 15 Min. Rolling Time, 2" Mat, Normal Weight Material.

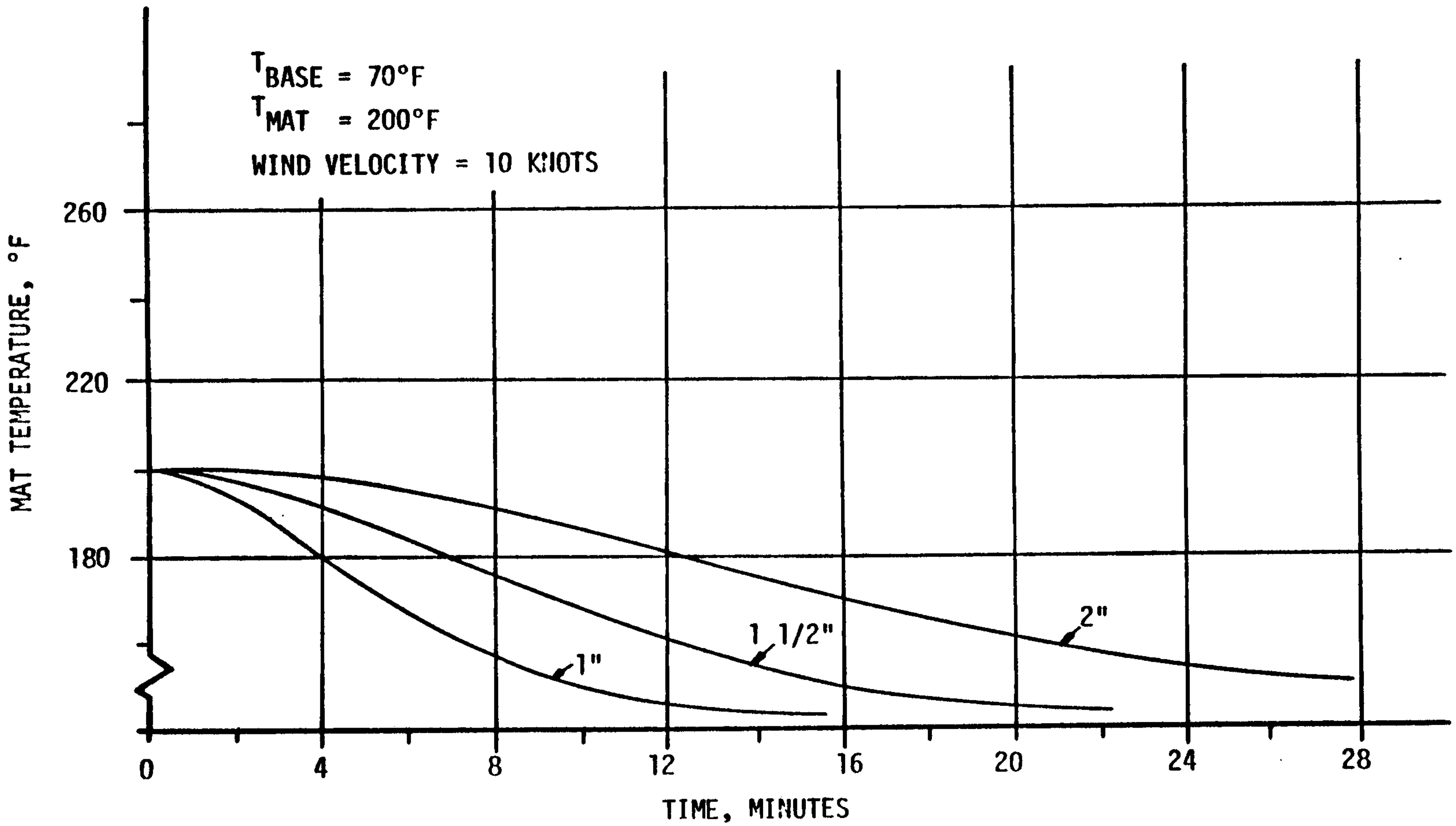


Figure 4. Cooling Curves for Lightweight Aggregate Hot Mix (T_{mat} = 200°F).

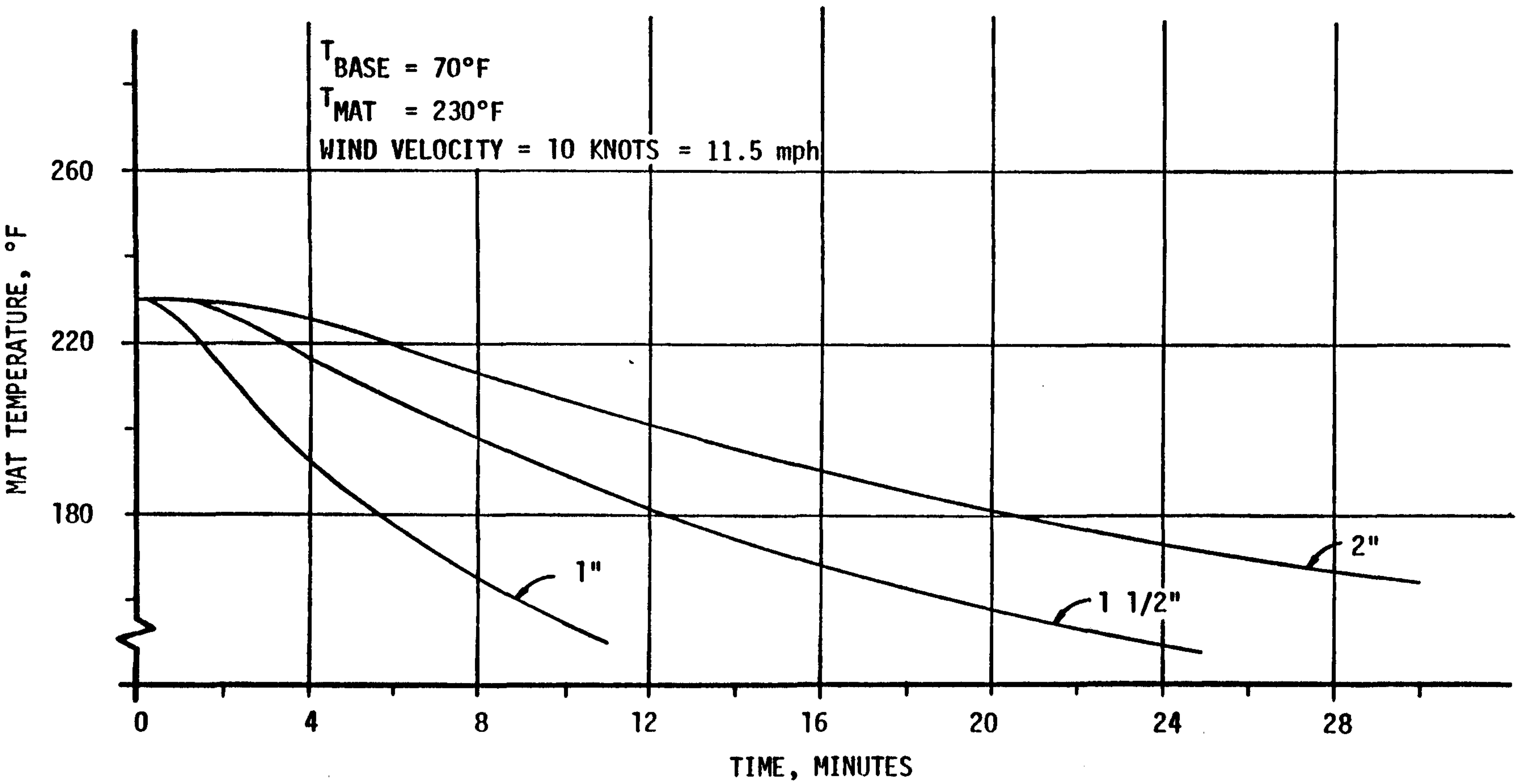


Figure 5. Cooling Curves for Lightweight Aggregate Hot Mix (T_{mat} = 230°F).

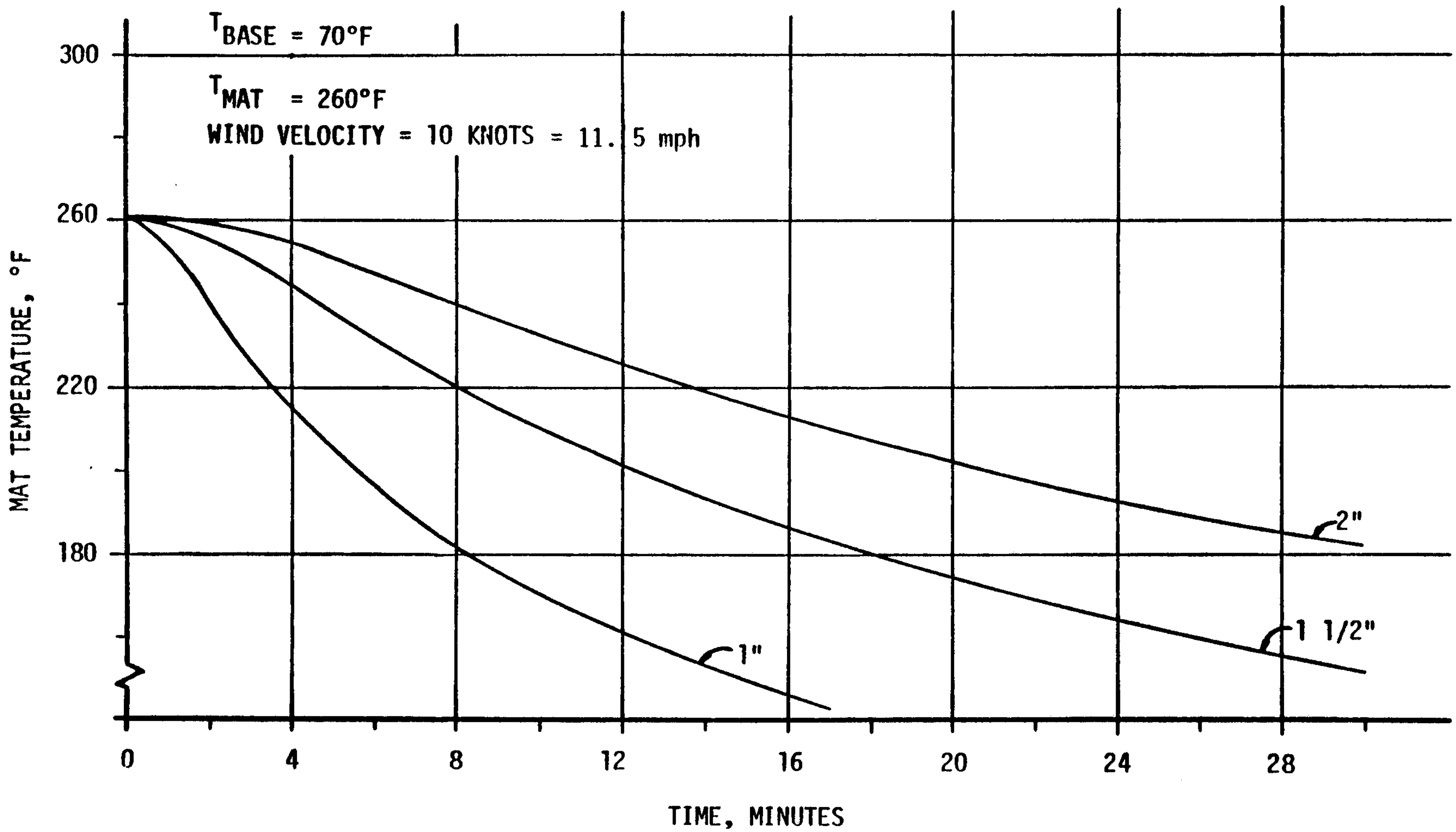


Figure 6. Cooling Curves for Lightweight Aggregate Hot Mix (T_{mat} = 260°F.)

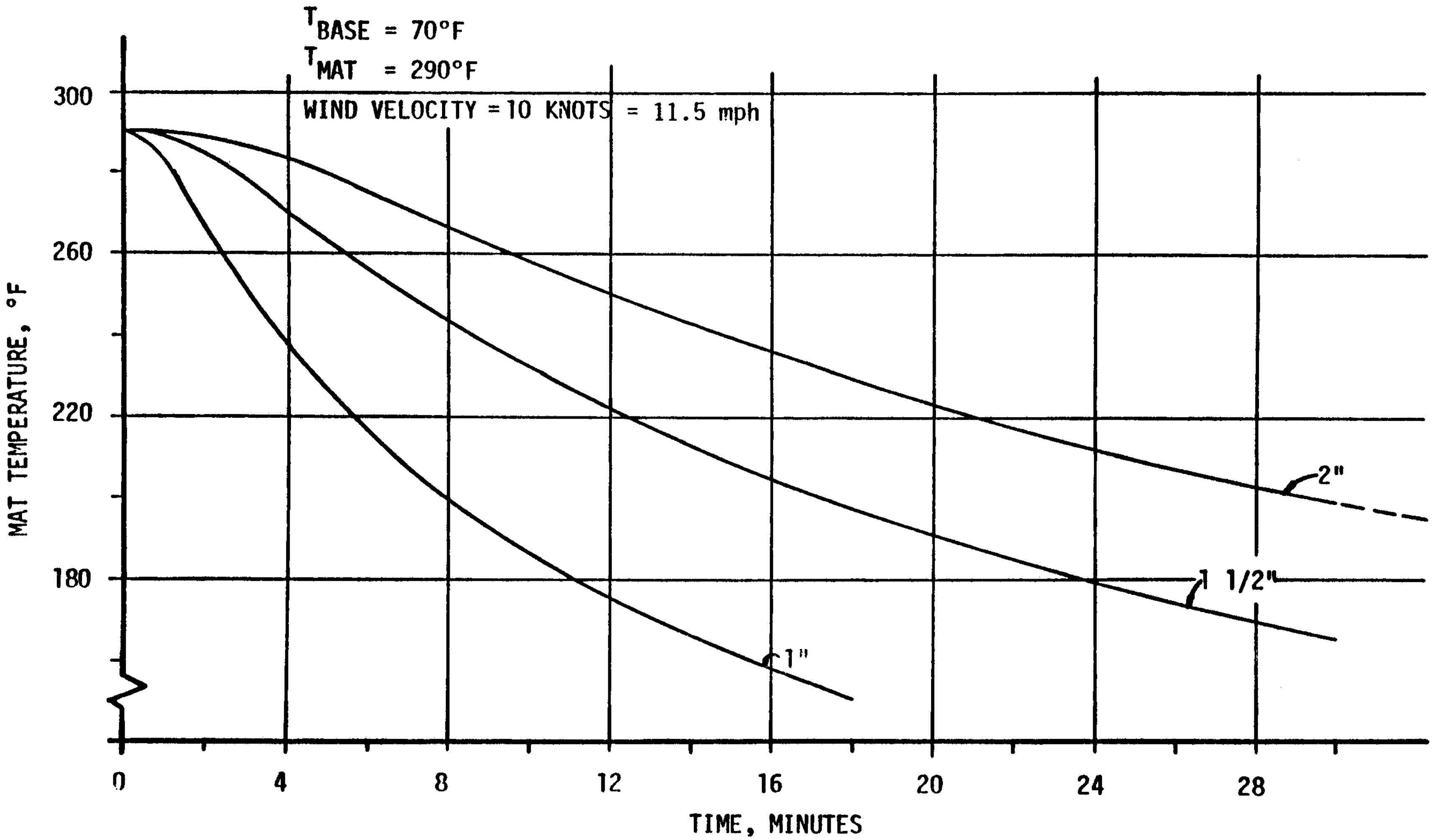


Figure 7. Cooling Curves for Lightweight Aggregate Hot Mix (T_{mat} = 290°F).

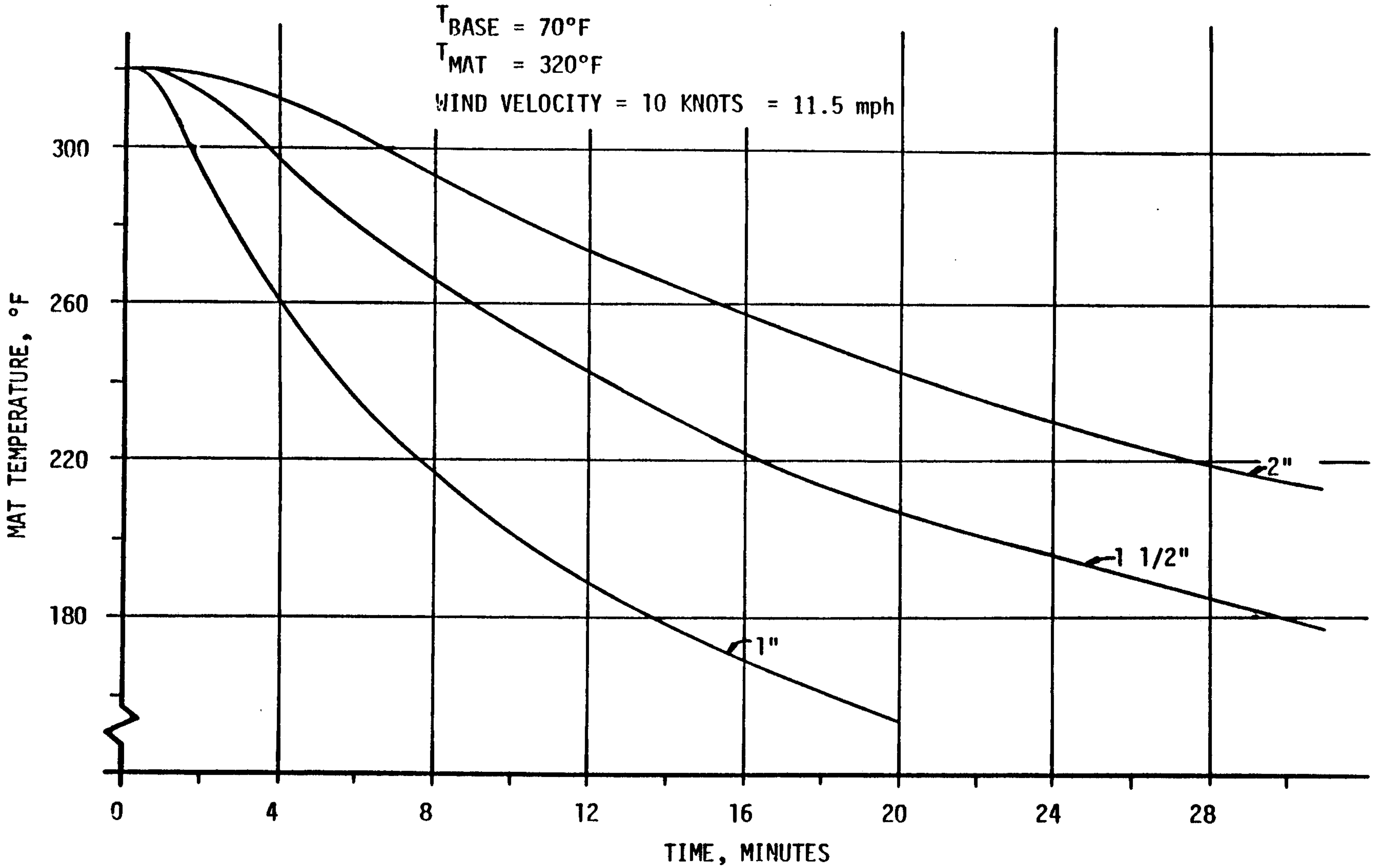


Figure 8. Cooling Curves for Lightweight Aggregate Hot Mix (T_{mat} = 320°F).

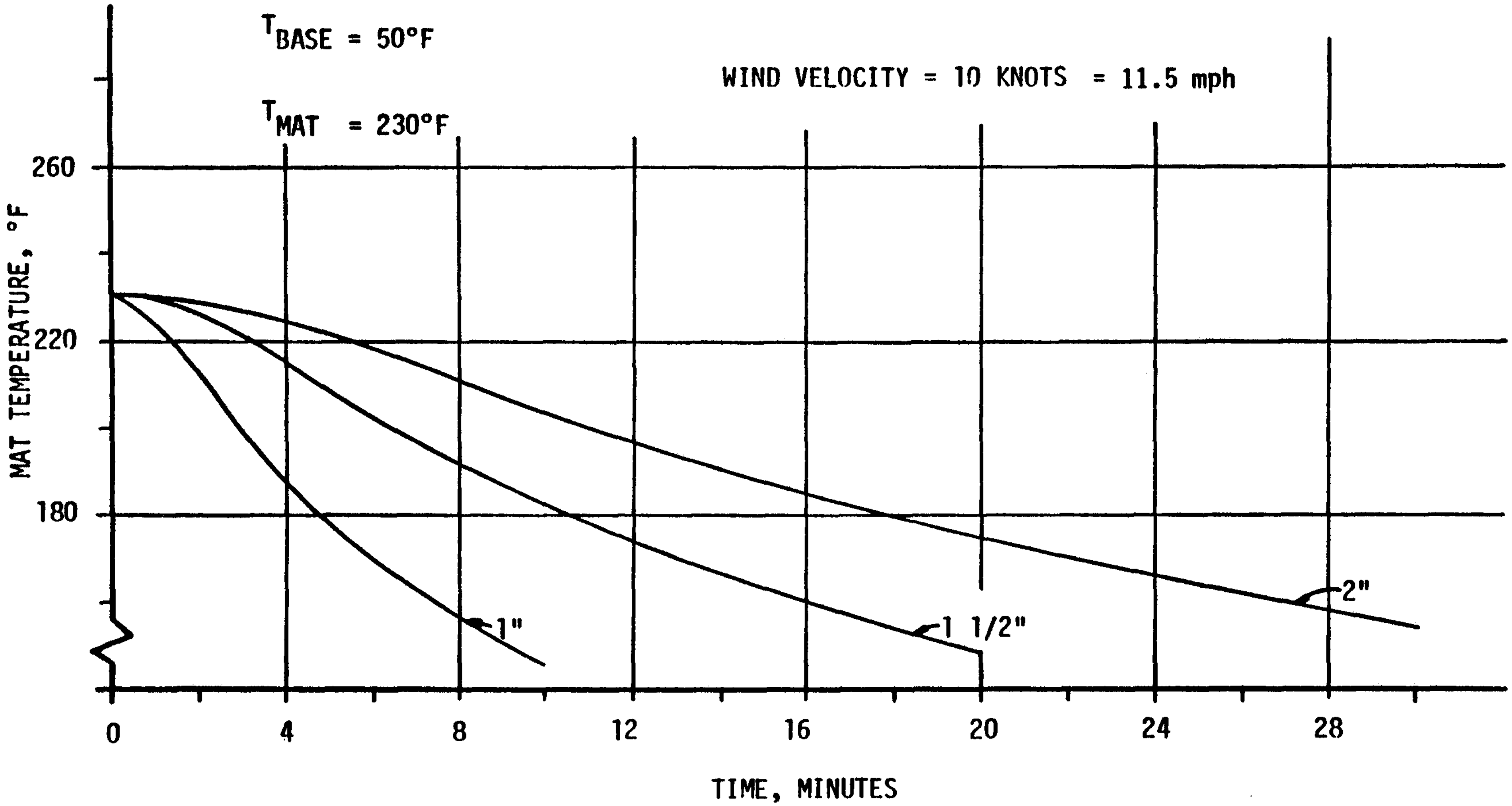


Figure 9. Cooling Curves for Lightweight Aggregate Hot Mix (T_{mat} = 230°F).

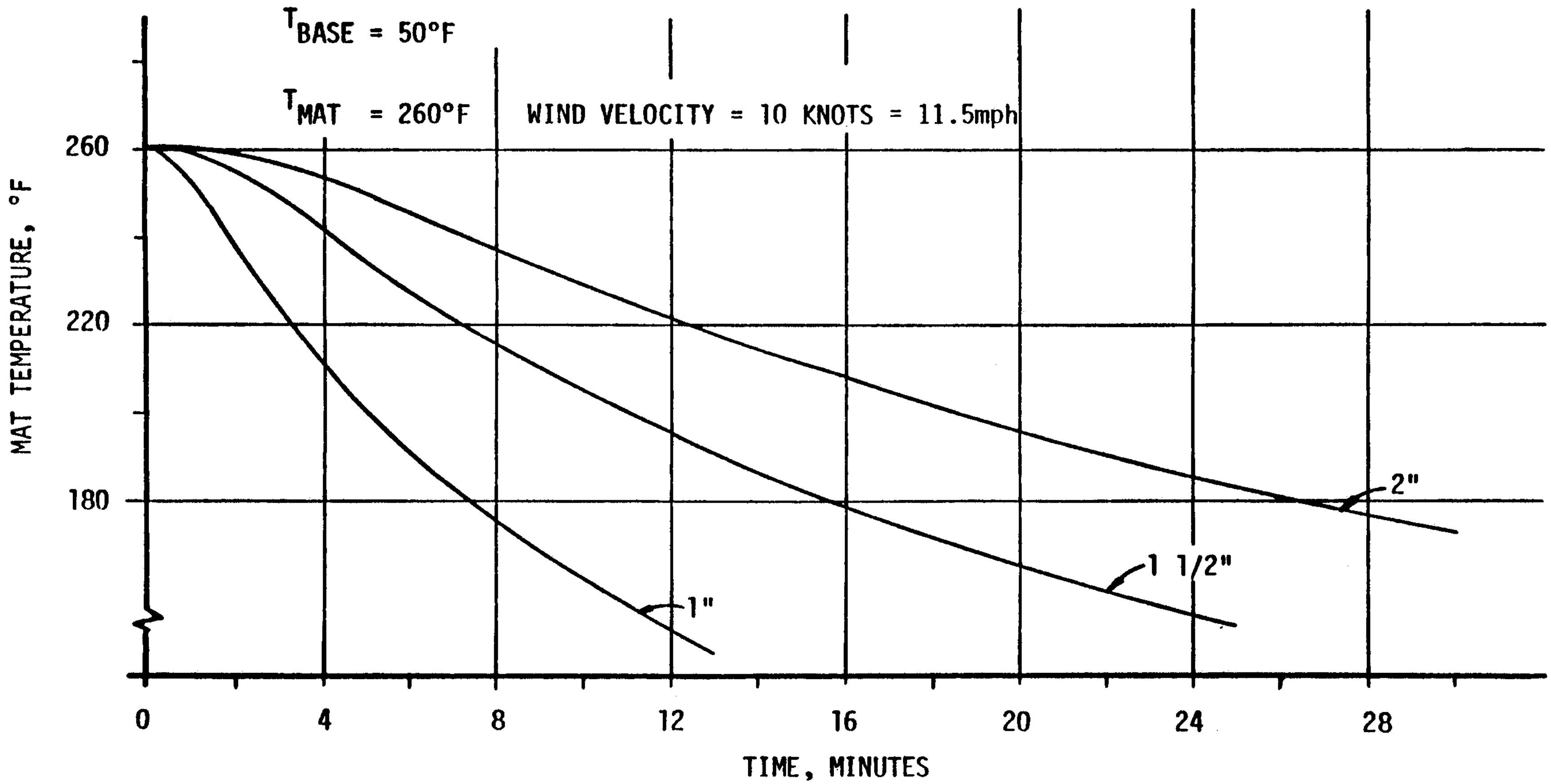


Figure 10. Cooling Curves for Lightweight Aggregate Hot Mix (T_{mat} = 260°F).

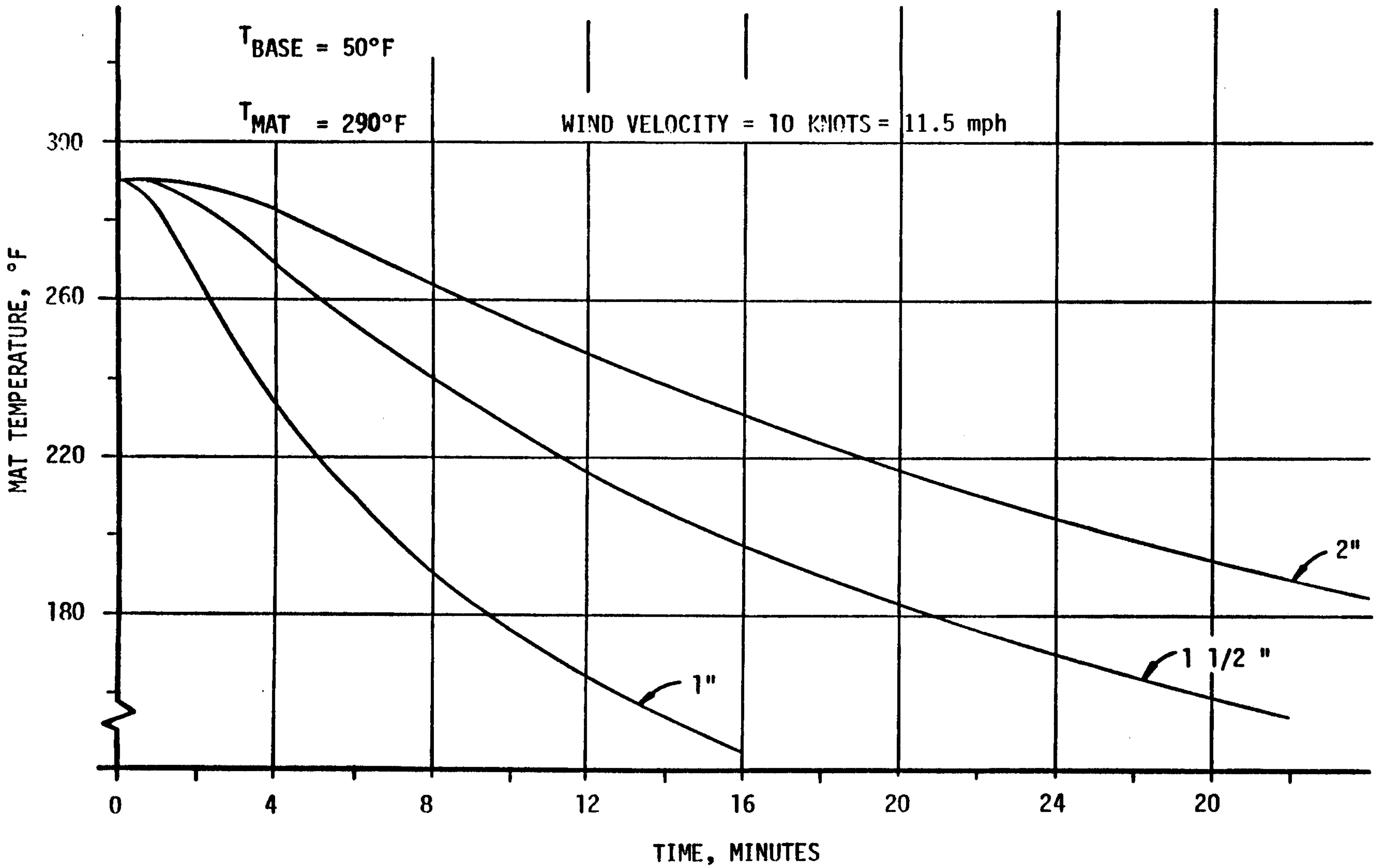


Figure 11. Cooling Curves for Lightweight Aggregate Hot Mix (T_{mat} = 290°F).

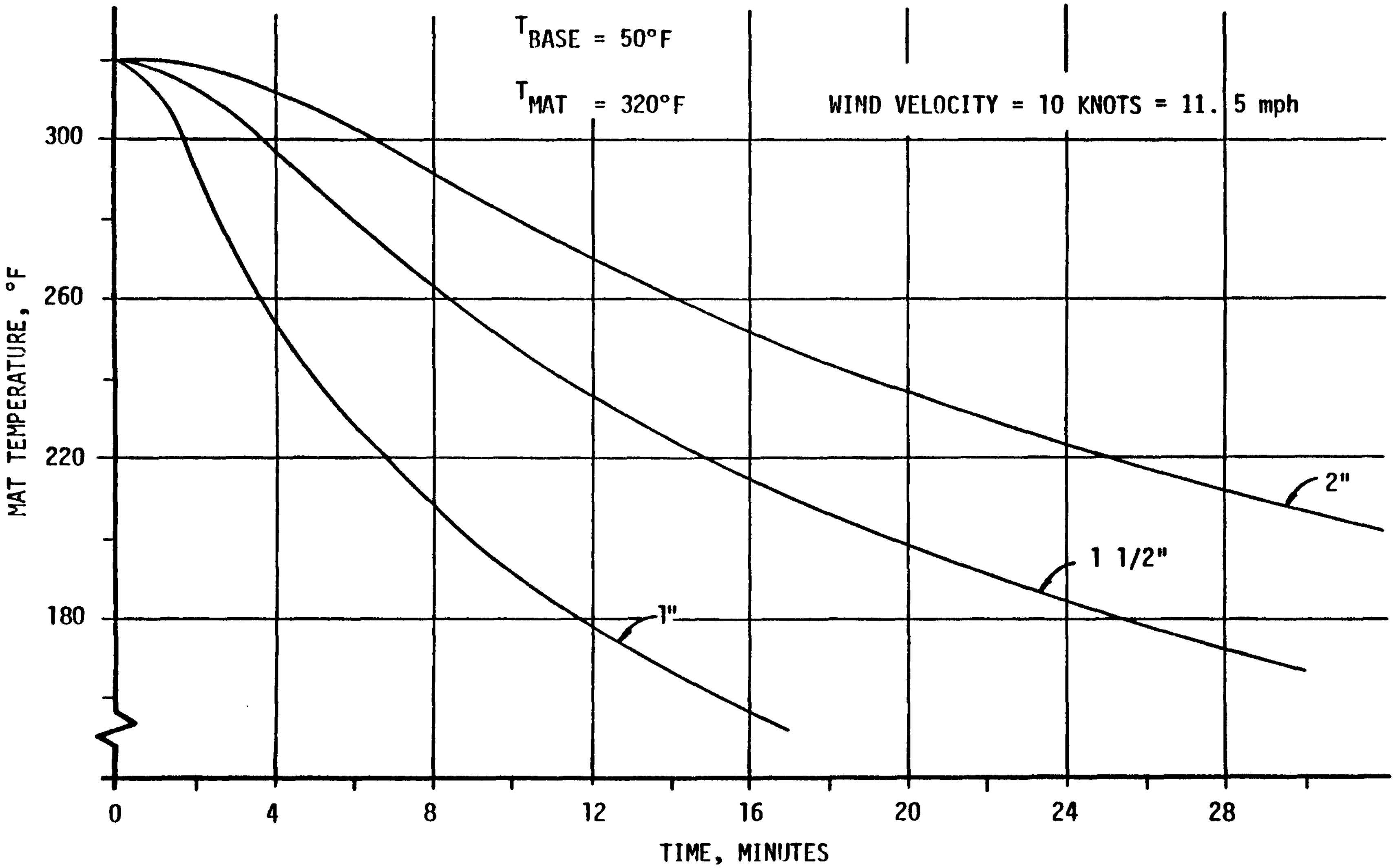


Figure 12. Cooling Curves for Lightweight Aggregate Hot Mix (Tmat = 320°F).

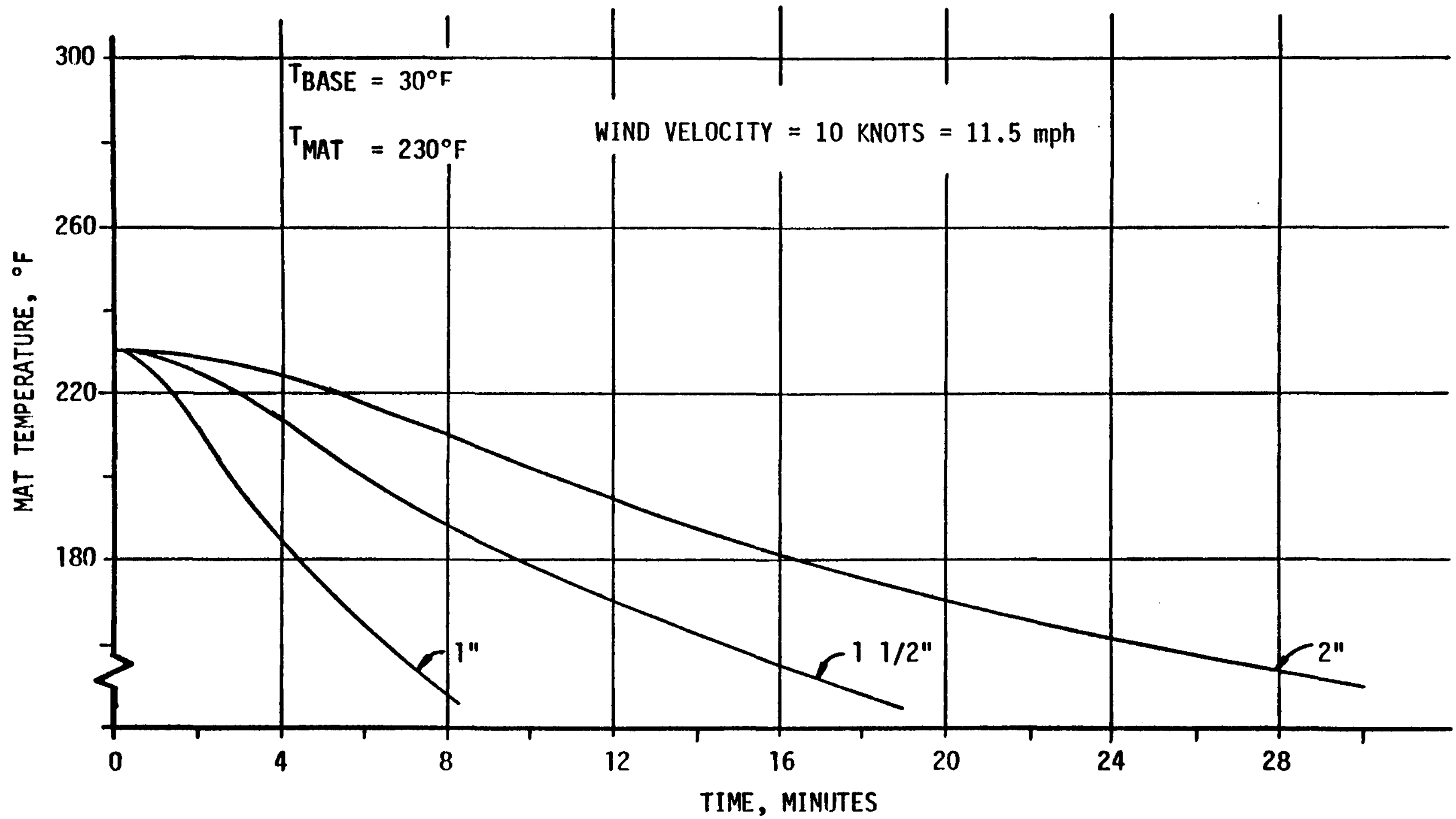


Figure 13. Cooling Curves for Lightweight Aggregate Hot Mix (T_{mat} = 230°F).

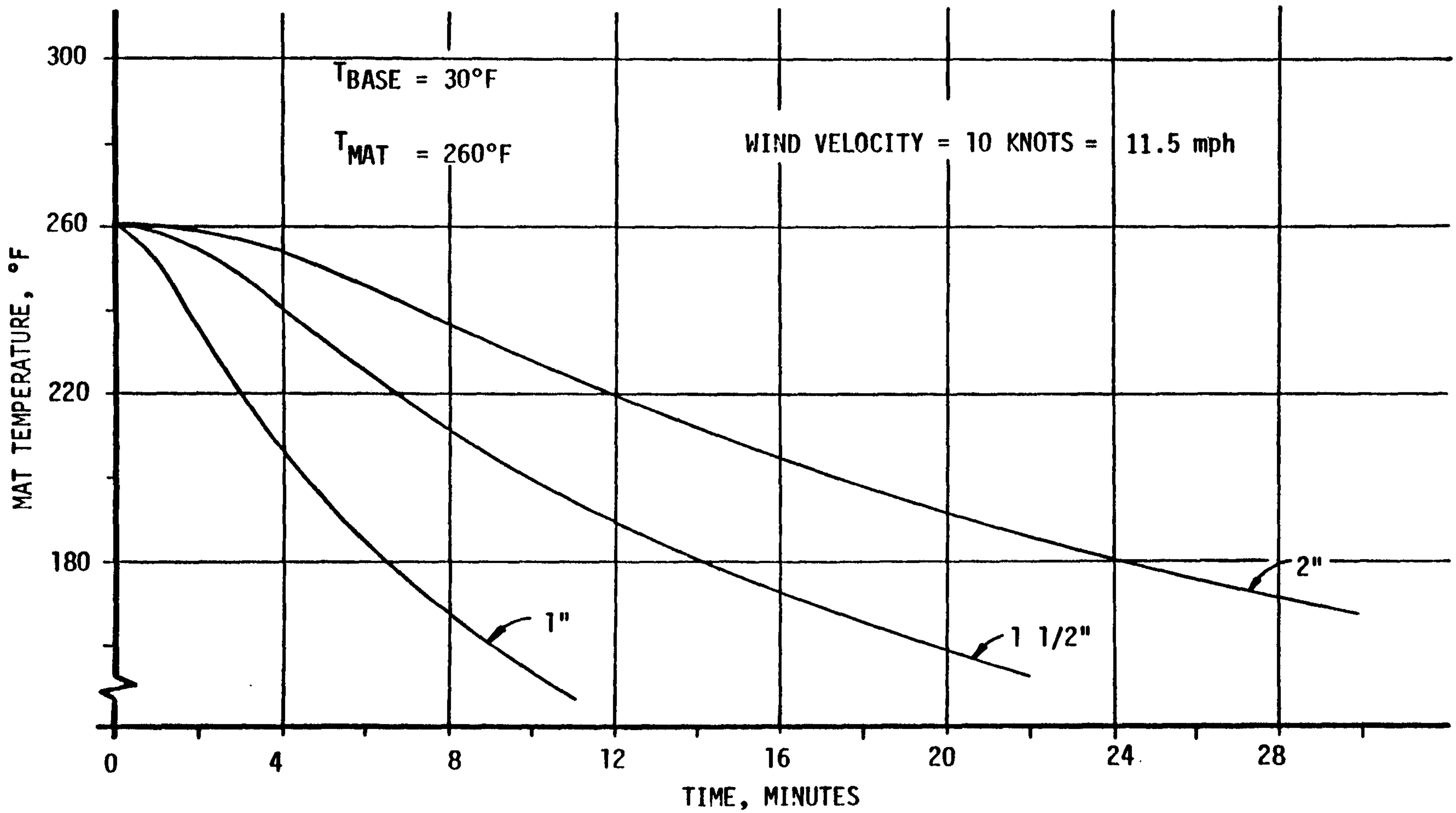


Figure 14. Cooling Curves for Lightweight Aggregate Hot Mix (T_{mat} = 260°F)

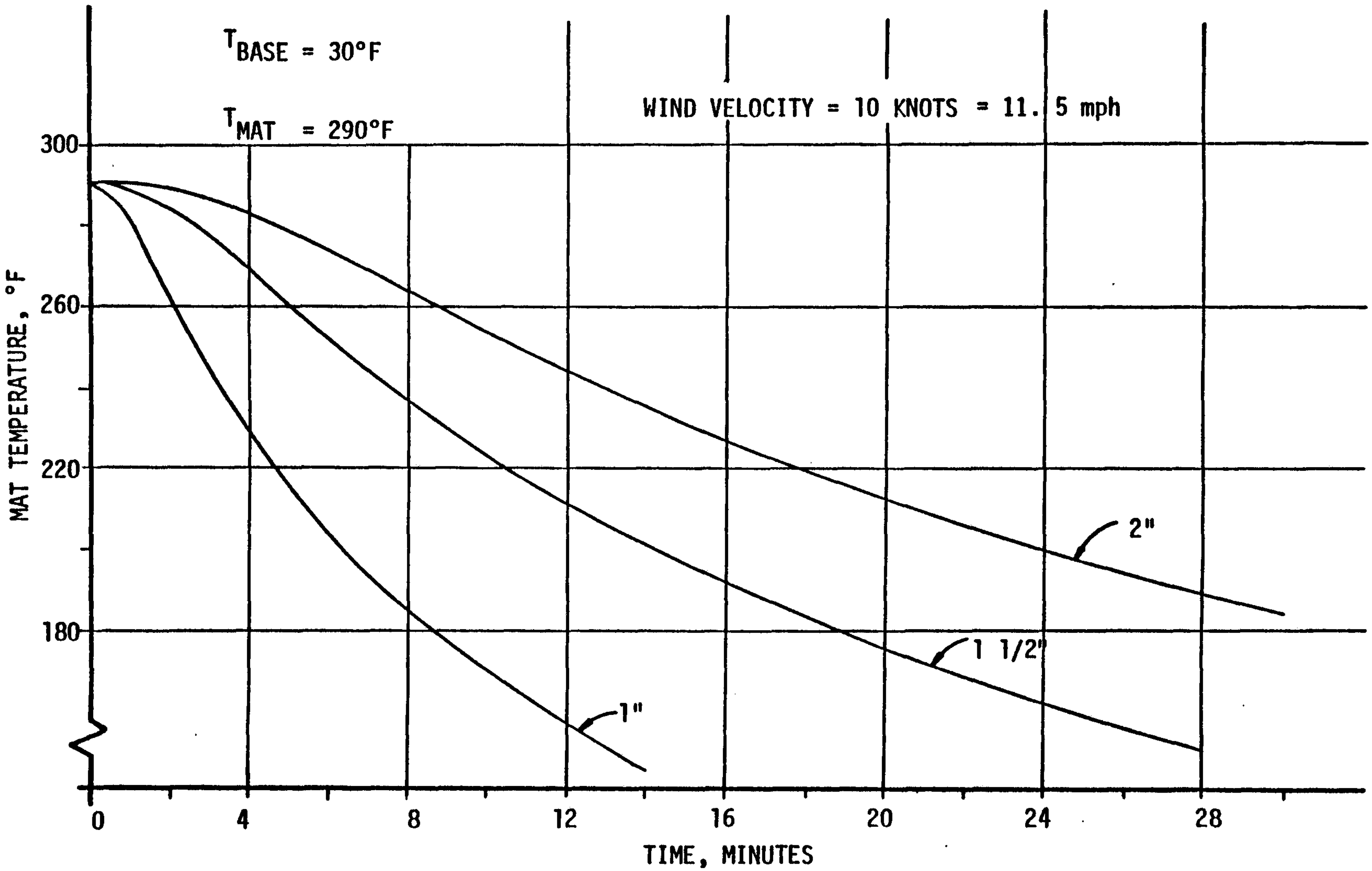


Figure 15. Cooling Curves for Lightweight Aggregate Hot Mix (T_{mat} = 290°F).

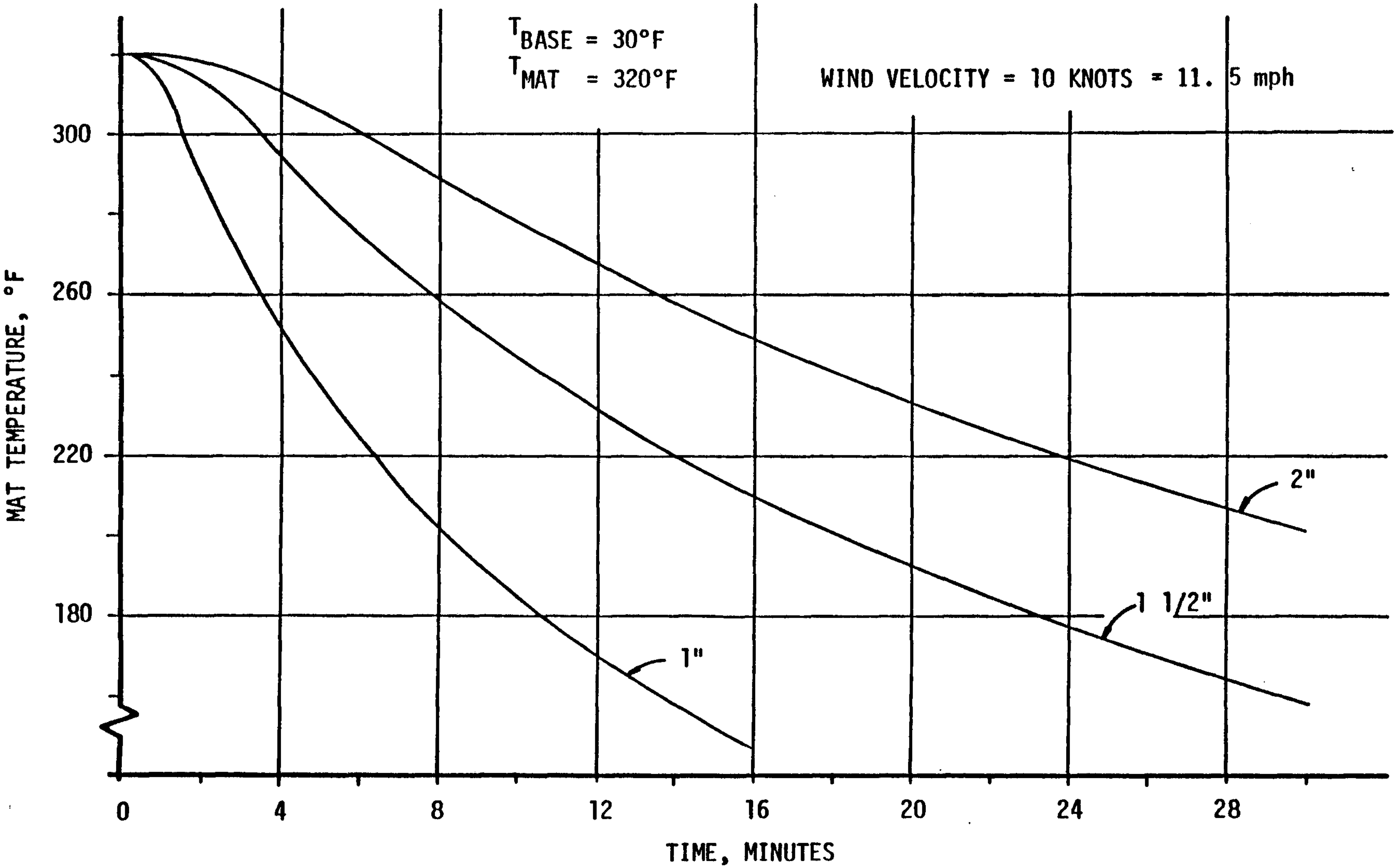


Figure 16. Cooling Curves for Lightweight Aggregate Hot Mix (T_{mat} = 320°F).

knots* and an elevation of approximately 500 feet were selected for all solutions. Air temperature and solar flux were selected in reference 1. Thermal properties for lightweight aggregate hot mixes are listed below.

	Lightweight Hot Mixes	Normal Weight Hot Mixes
Thermal conductivity Btu, hr^{-1}, ft^{-1}, F^{-1}	0.35	0.70
Thermal diffusivity ft^2, hr^{-1}	0.0227	0.0138
Specific heat, Btu, lb^{-1}, ft^{-1}	0.22	0.22

A wind velocity change of plus or minus 10 knots can alter the mat cooling time plus or minus about 2 minutes. The temperature noted on these figures represents that expected at the center of the placed mat.

Figure 17 summarizes the data presented in Figures 4 to 16 by showing the time to cool 175^{O}F for mat thicknesses of 1, 1 1/2, and 2 inches, base temperatures of 30°, 50°, and 70°F and a range of laydown temperatures. The relative importance of mat thickness, base temperature and laydown temperatures can be illustrated by use of these figures. For example, a change of laydown temperature of a 1 1/2-inch mat from 260 to 290^{O}F placed on a 50^{O}F base will change the cooling time from 17 minutes to 22 minutes while a change in base temperatures from 30 to 70^{O}F for 1 1/2-inch mat placed at 260^{O}F will change the cooling time from 15 minutes to 20 minutes.

The importance of mat thickness on cooling time is the single most important factor as illustrated in the following example. Assuming a laydown temperature of 220°F and a 50°F base temperature, the cooling time for a 1-inch mat is about 4.5 minutes, for a 1 1/2-inch mat 10 minutes and a 2-inch mat 17.5 minutes.

It should be emphasized that the treatment of rate at which these mats cool assumes that the hot mix is essentially dry when it is placed and that cooling is caused principally by conduction and radiation. The importance of water evaporation to the cooling rate is separately discussed in the following paragraphs.

*Knot (nautical miles per hour) is the unit commonly used for wind velocity. 1 nautical mile - 1.15 statute miles.

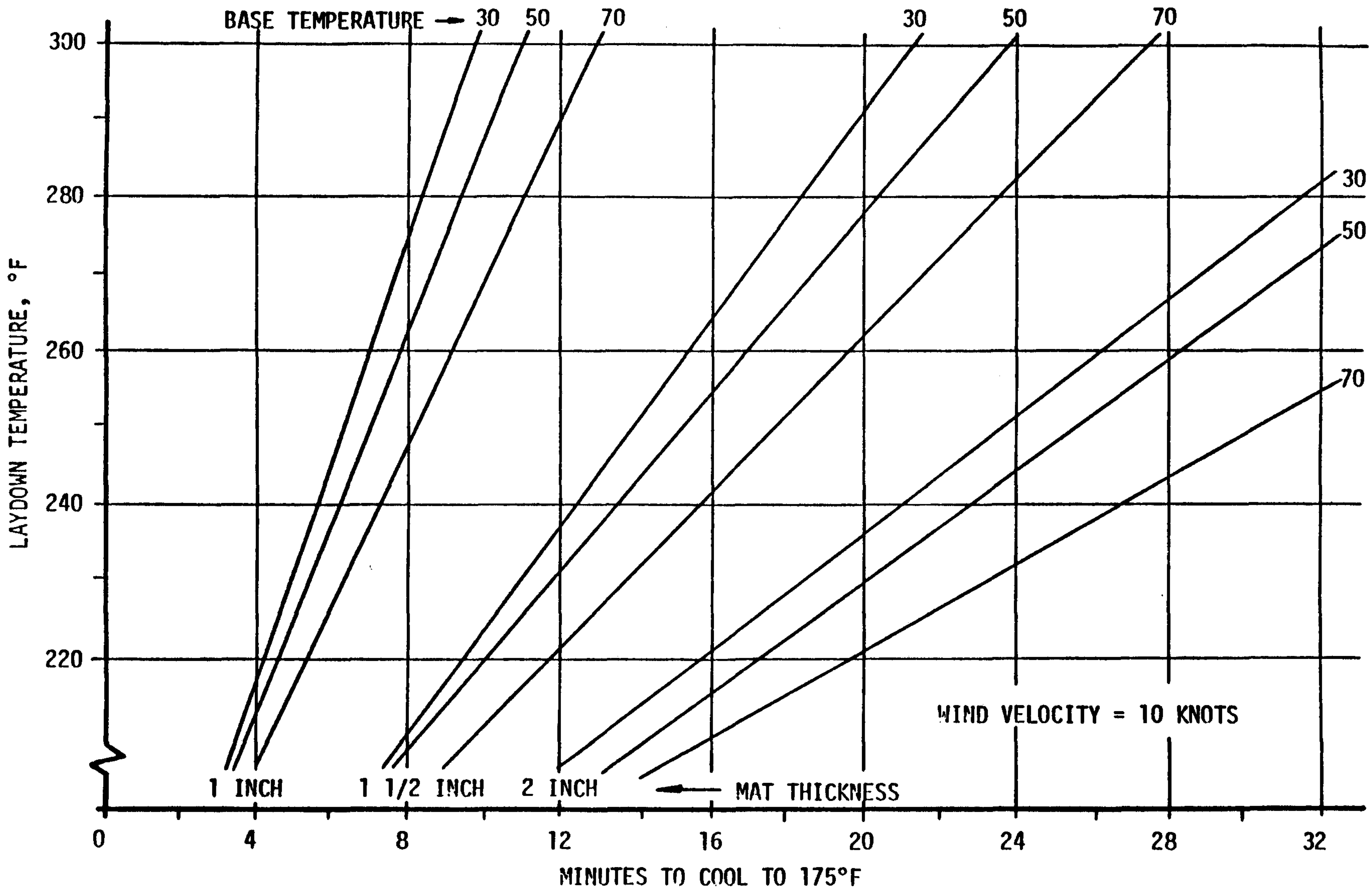


Figure 17. Effect of Base Temperature on Cooling Rate for Lightweight Aggregate Hot Mix.

Cessation Requirements - To this point it has been assumed that the lightweight aggregate mixes in question were essentially water free (less than one percent moisture) when they were dropped into the haul units. And this may very well be the case in the hot summer time when the stockpile moisture contents of all aggregates are low and the drying conditions are good.

Such is not usually the case in late fall, during winter, and in early spring. Stockpiles are usually wet and drying conditions are generally poor.

The paving mixture may contain 3 to 6 percent moisture as it is dropped into the haul unit and the mix temperature may not be above 250°F in spite of a much higher dryer exit temperature, possibly as high as 375°F. Delayed evaporation of water is the cause of this problem. As discussed previously, the dryer is capable of removing most of the free water on the aggregate, but some of the absorbed water is left in the lightweight aggregate to be driven off by the heat (sometimes referred to as "heat capacity") carried out of the dryer by both the coarse and the fine aggregates.

The actual amount of water that a mix will release in a given situation is difficult to estimate. Nevertheless, any evaporation which takes place after the aggregate leaves the dryer and before the mix is finally compacted in the field lowers the temperature and increases the mass viscosity of the mixture. At the same time a limited amount of moisture in the mat may act as a compaction aid! However, an excess of moisture in the finished mat is undesirable, since experience has shown that excess moisture may contribute to early structural distress in the form of tenderness, spot-to-spot mat distortion, or disintegration.

Field experiences with the dryer drum mixing process appear to indicate a need, under adverse environmental conditions, for a minimum temperature of about 230°F in the mat as it is laid on the road surface. This applies to dense graded mixtures which contain roughly 60 percent by volume of 1/2-inch to No. 4 lightweight aggregates. Open graded mixtures permit a somewhat lower minimum temperature.

Construction Effects of Moisture - From the above discussion it is apparent that some moisture will be lost from the aggregate after "drying" and prior to mixing and after mixing and prior to completion of breakdown rolling. Thus, the influence of moisture on cooling should be included in cessation requirements. The amount of moisture, however, has not been established by field work. Under wet cool conditions, a first estimate would be, for mixes with 2 to 4 percent moisture at the time the mix is dropped in the truck, to lose about half of this moisture. Thus, the temperature loss of asphalt concrete during transport, laydown and compaction operations could amount to 80° to 90°F due to evaporative cooling.

In most cases of high moisture contents and poor drying conditions, considerable evaporative cooling of the aggregate and some cooling of the mix will have occurred between the dryer and the discharge to the haul unit--this in addition to the evaporative cooling under discussion. However, thermal monitoring of the mix as it is discharged into the haul unit is standard practice--hence the treatment of heat losses from this point through breakdown rolling.

With these data in mind cessation requirements or the conditions under which mixtures can have a reasonable degree of being successfully placed and adequately densified in the field have been established. Figures 18 through 23 graphically present these requirements. Figures 18, 19, and 20 were established for 15 minutes of available compaction time which allows paver speeds to 30 feet per minute if one breakdown roller is used and 60 feet per minute if two breakdown rollers are used. Figures 21, 22, and 23 were established for 8 minutes of available compaction time, the minimum time required for breakdown with one roller. This requirement of 8-minute roller time will limit the paver speed to 30 and 55 feet per minute for one and two rollers, respectively.

A specific example will illustrate the usefulness of Figures 18 to 23. Assuming 8-minute cooling time and a 1 1/2-inch mat thickness as typical of many paving operations utilizing dense graded lightweight aggregate hot mixes, Figure 22 would be selected. Assuming no moisture is lost from the time the aggregate leaves the dryer to a point in time after breakdown compaction begins, a 210°F temperature is required

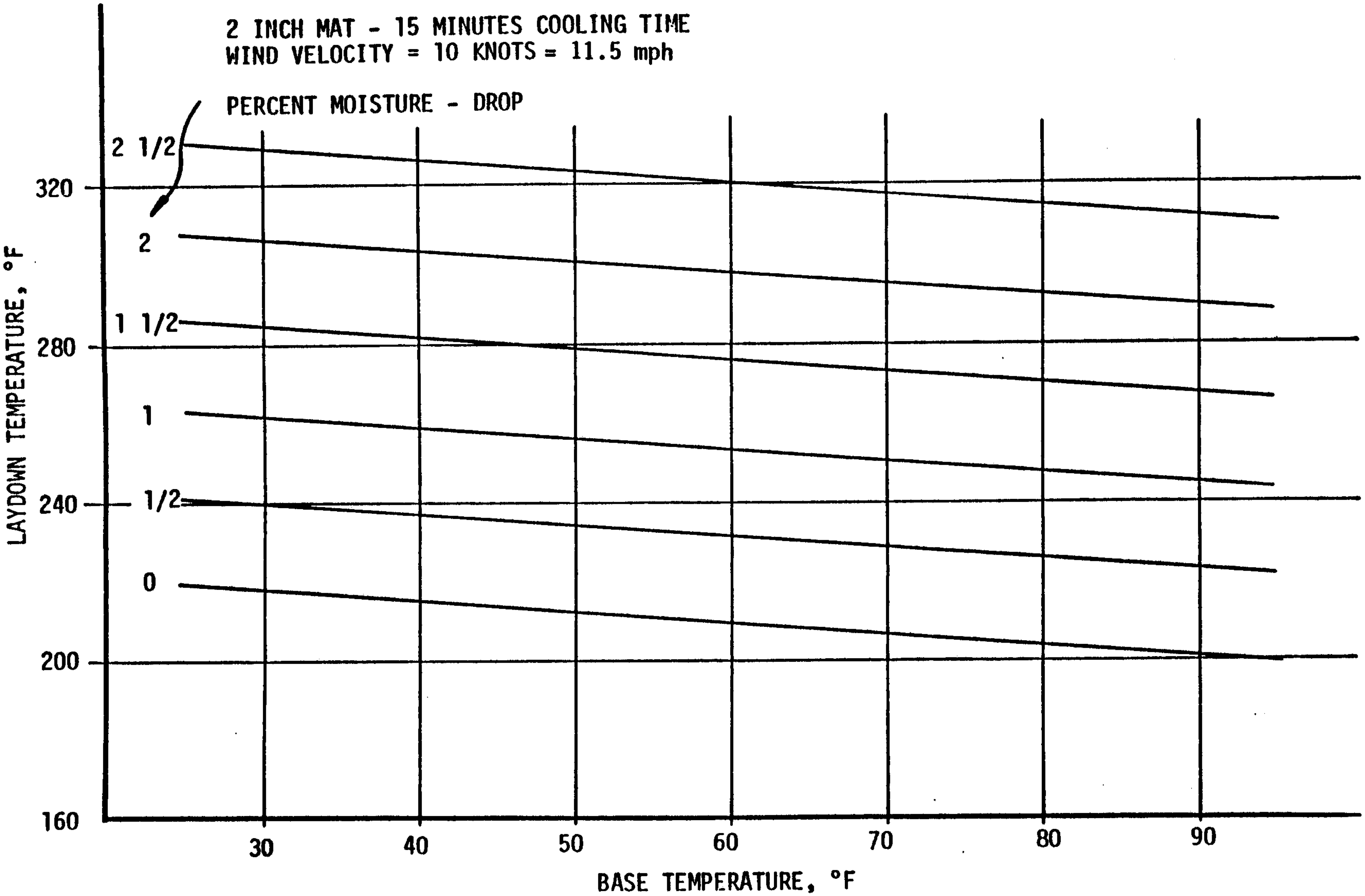


Figure 18. Cessation Requirements, 2-INCH MAT, 15-MINUTES COOLING TIME.

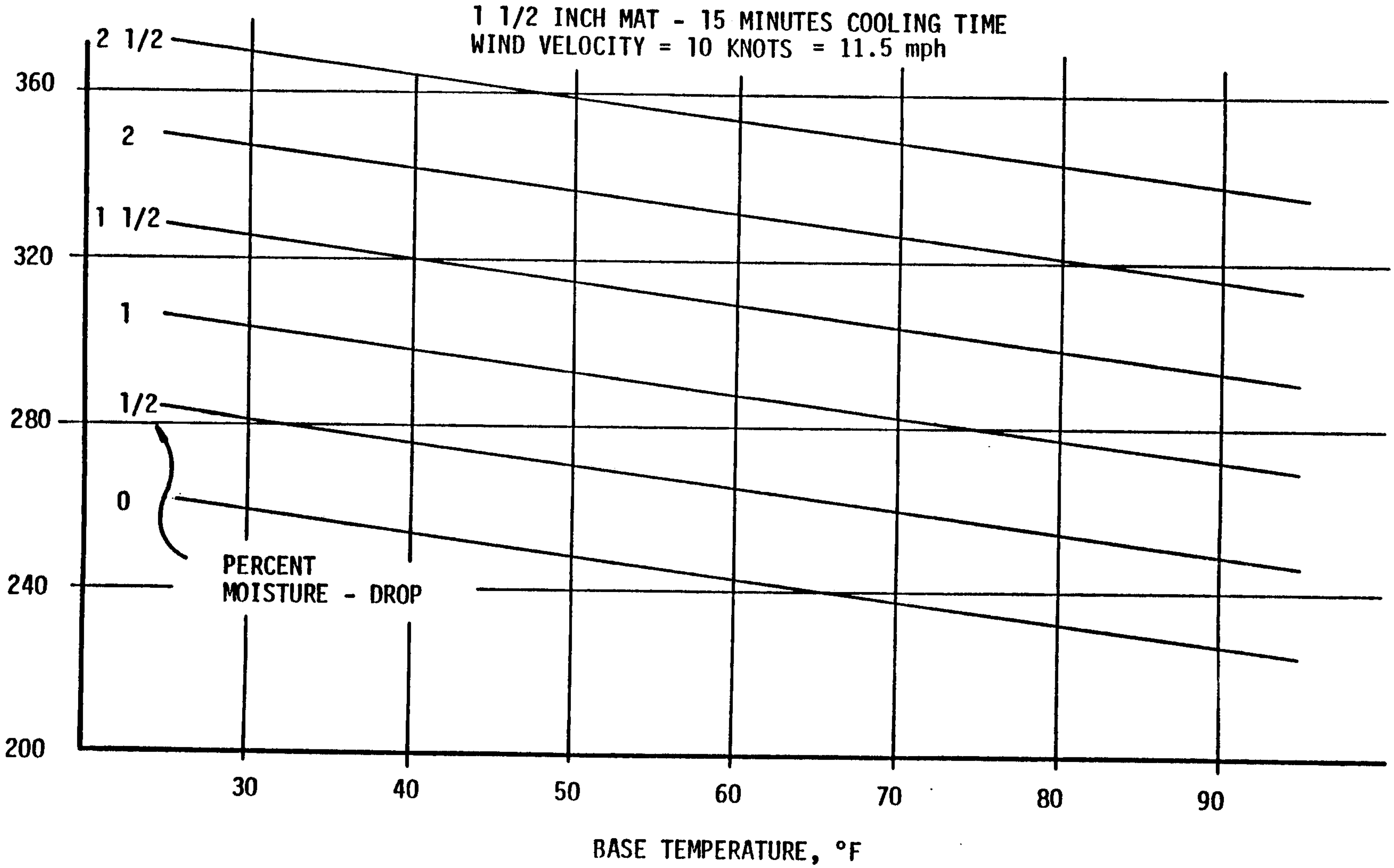


Figure 19. Cessation Requirements, 5 1½=INCH MAT, 15-MINUTE COOLING TIME.

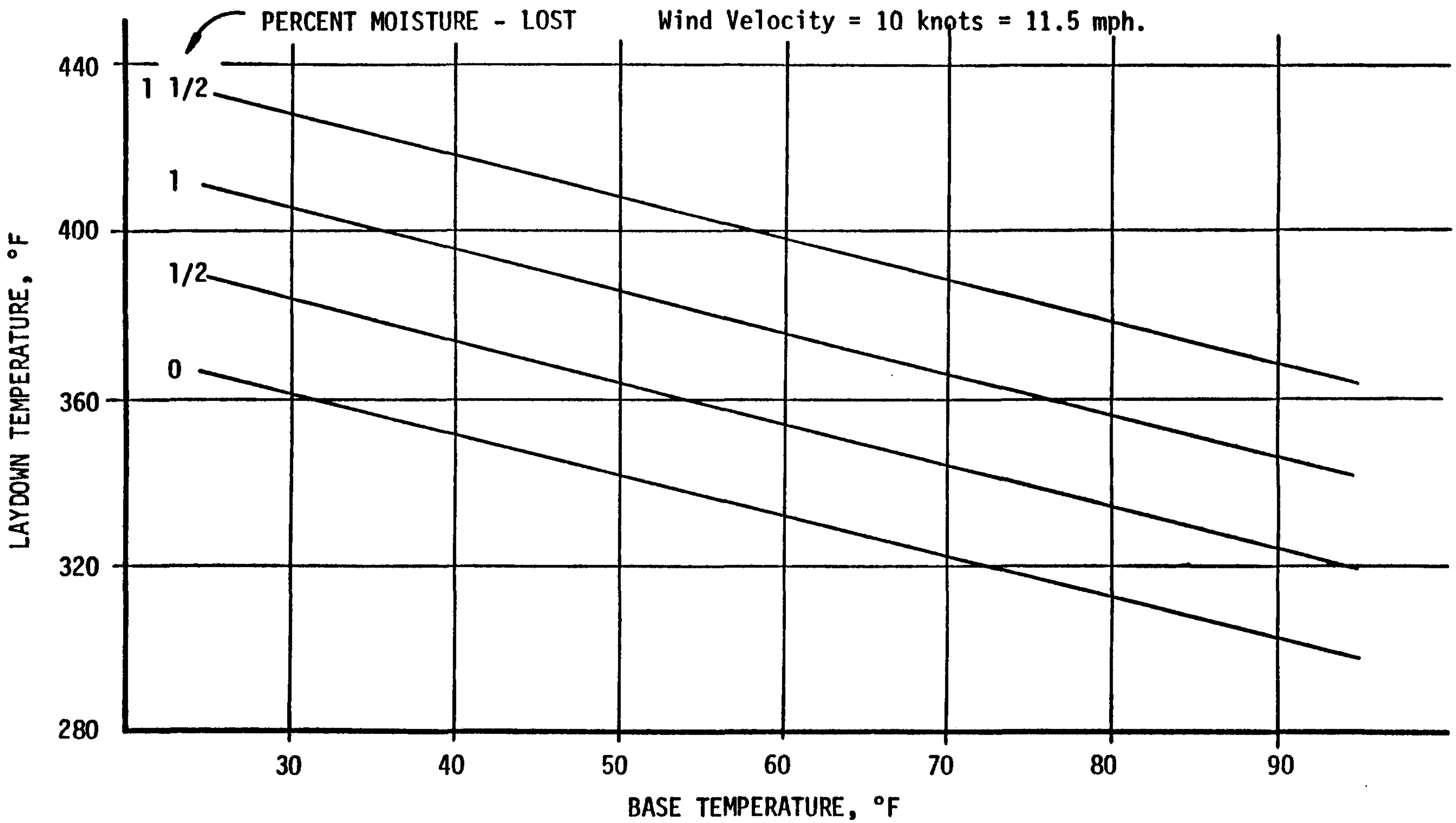


Figure 20. Cessation Requirements, 1-INCH MAT, 15-MINUTE COOLING TIME.

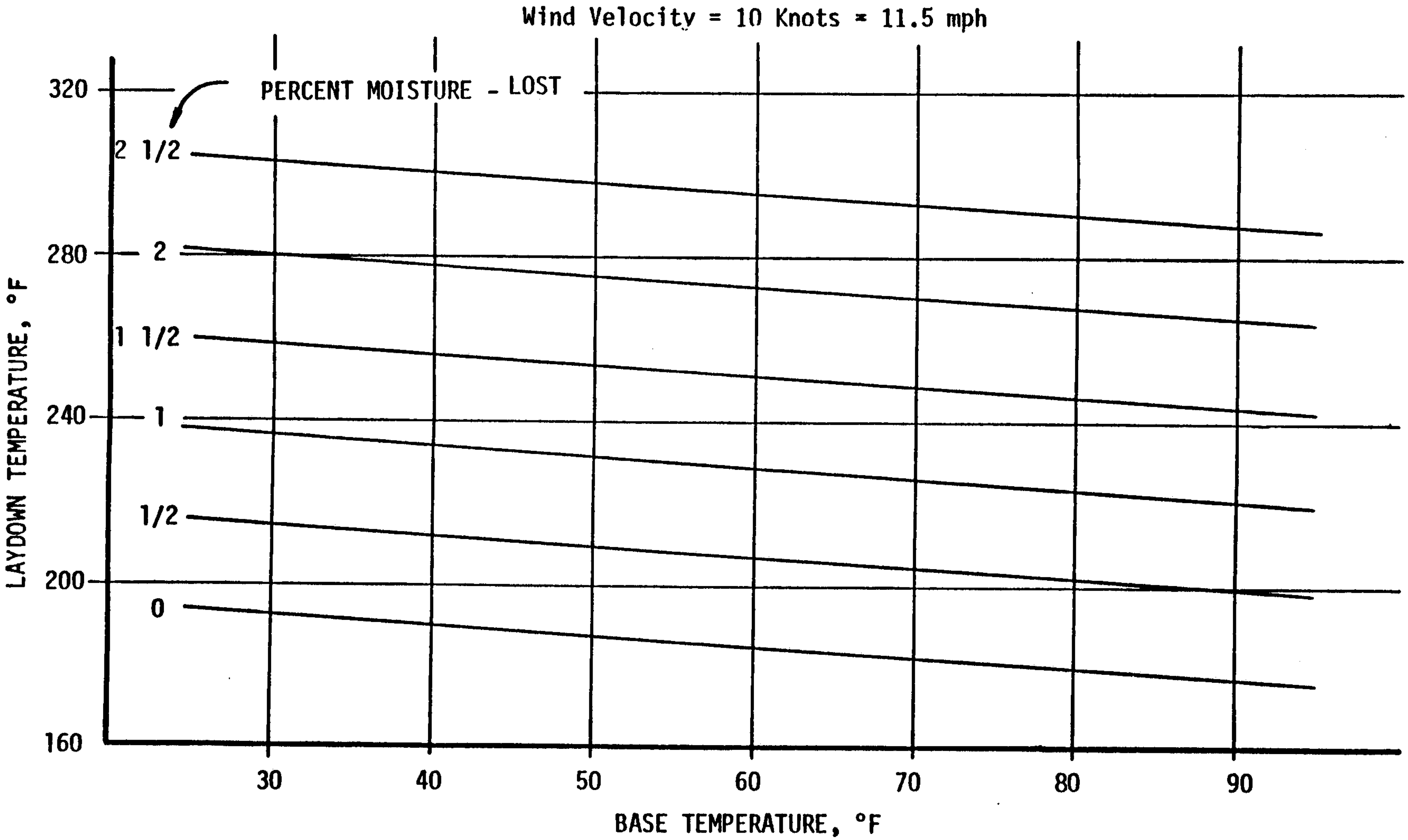


Figure 21. Cessation Requirements, 2-INCH MAT, 8-MINUTE COOLING TIME.

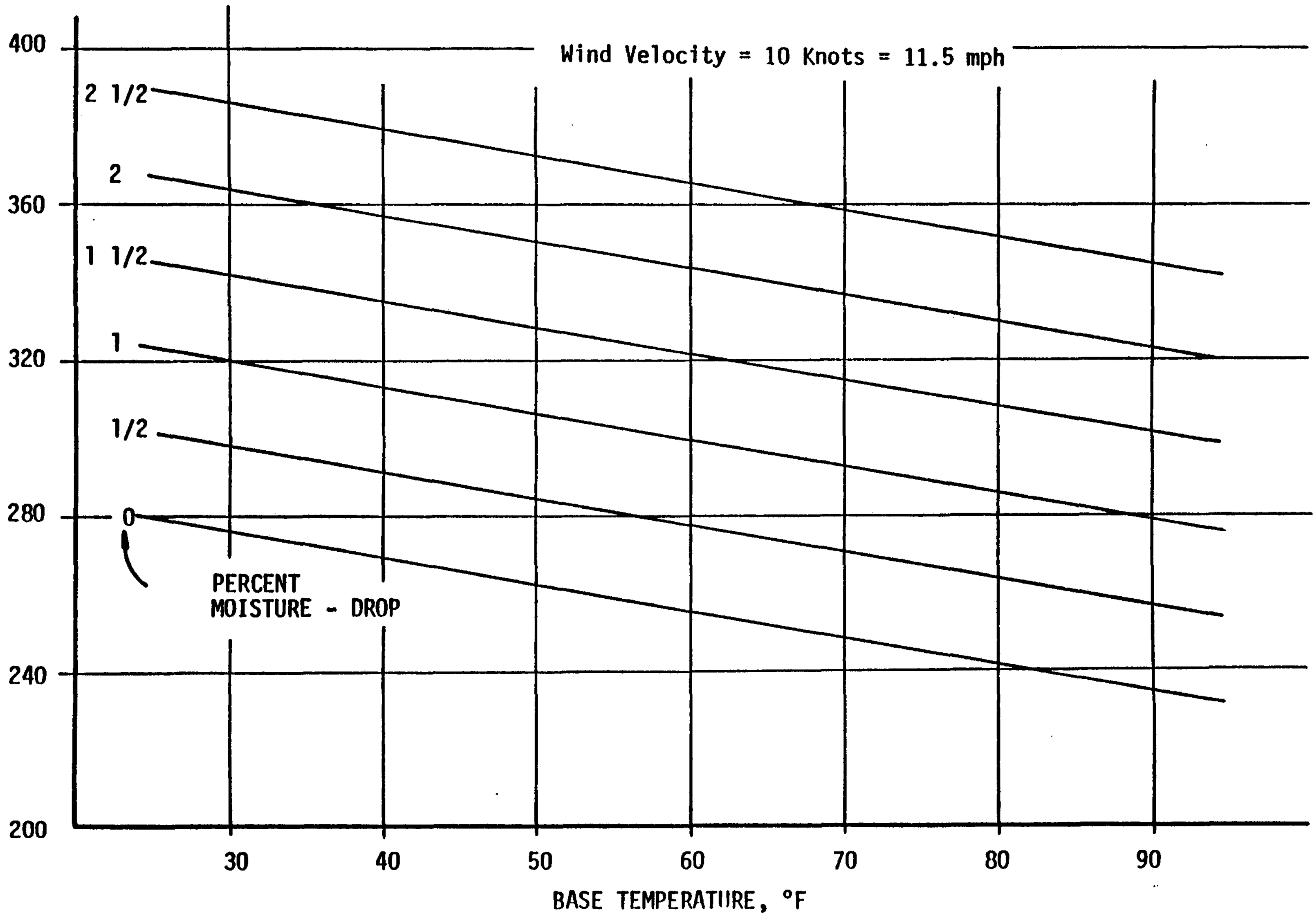


Figure 22. Cessation Requirements, 1½ INCH MAT, 8-MINUTE COLLING TIME.

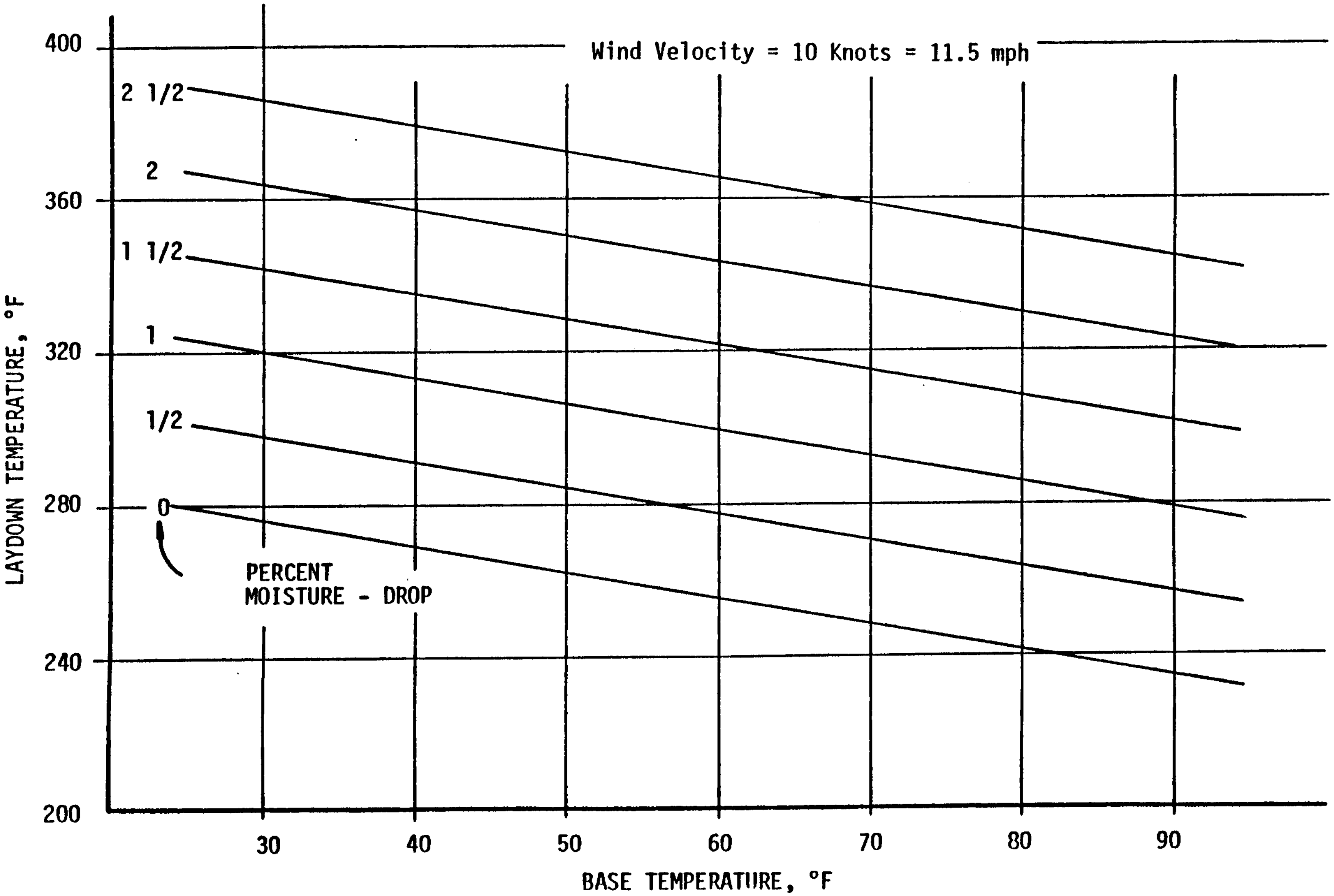


Figure 23. Cessation Requirements, 1-INCH MAT, 8-MINUTE COOLING TIME.

on a 50^{O}F base. Similarly, if the moisture content of this mix dropped one percentage point during this same period, a temperature of 250^{O}F would be required, and for 2 percentage points moisture loss, a temperature of 290°F would be required, both referenced at the exit of the pugmill. As previously discussed for high moisture content aggregates, it would be difficult to reach this required 295^{O}F temperature due to evaporative cooling during hot aggregate handling operations and the normal 10 to 15^{O}F temperature loss experienced during transportation and laydown. Both of these factors may require the 295^{O}F temperature to be achieved by supplying a hot aggregate as it leaves the dryer at a temperature in the neighborhood of 400^{O}F which may be considered impractical from an economic standpoint.

Use of Silicone - Extensive use of silicone in asphalt cement for eliminating foaming is well documented. Within the past about 20 years, silicone has been widely used to reduce tearing or pulling of the mat behind the laydown machine. Silicone has also been found useful in improving the release of moisture from hot mix. It is in this area of use that contractors may wish to explore the advantages of using silicone in asphalt cement programed for lightweight aggregate mixtures.

According to NAPA (11) (Information Series 16) the most widely used silicone is Dow Corning 200 Fluid (DC-200) which technically is a dimethyl siloxane polymer.

The effect of moisture release from the aggregate in a hot asphalt concrete mixture is to create steam which forms asphalt bubbles as the water vapor leaves the asphalt coated aggregate. These bubbles are trapped in the mix and the load of paving mixture may become fluid. The addition of 2 parts per million of the silicone fluid (about 2 ounces per 5,000 gallons of asphalt cement) will depress the formation of these bubbles and the mix will not slump (become fluid) in the haul unit, nor will the mix tear or snag behind the laydown machine. Additionally, it has been found that silicone treatment of asphalt cement reduces the rate of hardening during hot storage. Hot storage or the use of surge tanks is widely practiced, particularly at fixed plants in urban areas.

The use of more than about 2 ounces of DC-200 in 5,000 gallons of asphalt cement appears to serve no useful purpose and in fact under certain circumstances in a large dose (10 ounces in 5,000 gallons) has been found to cause some mixes to appear tender when compacted, all other factors fixed.

The cost of treating asphalt with DC-200 at the above specified rate is minimal, amounting to less than one-half cent per ton of mix.

Numerous studies on the effect of low level DC-200 treatment of asphalt cement have shown no measurable detrimental effects on the properties of the cement or the mixtures in which the treated cements were used. The beneficial effects have been outstanding. It is therefore recommended that DC-200 or other suitable material be used at all times in lightweight aggregate mixtures where moisture in the mix is expected to be a problem.

SERVICEABILITY AND RELATED CONSIDERATIONS - FIELD FEEDBACK

Based on conversations with the SDPHT Austin office and District personnel, materials suppliers and personal observations in the field, problems have developed on certain jobs where lightweight aggregates have been used in plant mixes. Some of these have been quite costly. In contrast, problems have not developed in other jobs of similar design which utilized aggregates from the same source. It would be quite difficult to determine the magnitude of factors that may have contributed to the success or the failure of these different jobs. Furthermore, it is not the purpose of this discussion to point an accusing finger at anyone. But rather, it is hoped that a discussion covering several of the possible reasons for pavement distress will be useful to the Materials Supplier, Design Engineer, the State Inspector, and the Contractor and will assist in improving the success ratio of similar jobs now under contract or planned for the future. The potential for improved cost-benefit ratio is great.

THE CHANGING TRAFFIC PICTURE AND WHY THIN OVERLAYS SLIP

The structural design of Texas highways is normally based on equivalent 18-kip axle loads for an estimated life of say, 15 years. On the other hand, design for the surface properties of Texas pavements is usually based on average daily traffic on a given facility independent of number of lanes or percent of trucks. A more realistic estimate of traffic effects on the surface properties of each lane of the highway should involve a correction for added wear and increased rate of polishing caused by trucks. The author is not aware of any published data which give the needed equivalency. Estimates vary from about 25 to 50; that is, one 18-wheeler is equivalent to 25 to 50 passenger vehicles. Even at an equivalency of 25 and an assumed 10 percent trucks, the corrected ADT per lane expressed in terms of passenger vehicles only would be increased three-fold! In addition, selected segments of some Interstate Highways carry 40 percent or more trucks in a given lane.

As a general rule, surface layers with a polish value requirement, placed as part of new construction or for friction improvement on an existing highway, are quite thin ranging from 3/4 inch to 1½ inches in thickness.

The magnitude of the traffic-induced horizontal shear force at the interface between the surface layer and the substrate or underlying pavement is a function of external shear force and the depth of the interface below the pavement surface. All other factors considered constant, the force transmitted at the interface between the overlay and the substrate is related directly to frictional properties of the overlay. One might then say that for an overlay of given thickness, as the pavement friction increases, so must the bond strength at the interface. (Aside from high friction plant mixes used on our highways for safety improvement, this same reasoning applies to seal coats wherein high friction aggregates are used as coverstone.)

Possibly, there should be special provisions in specifications and construction procedures to assure adequate bond of thin high friction overlays. The need for such a requirement is not as critical for dense mixes as it is for OGFC. Just as there are few points of contact within the mat of an OGFC, there are even fewer at the interface with the substrate. Asphalt drain down, if it occurs, will serve to improve this bond but in many cases this drain down is minimal or nonexistent. The result is a thin harsh mix resting on a relatively smooth substrate and subjected to very large horizontal shear forces. It is not at all surprising that there are reported instances of debonding, with some of these taking place at an alarming rate!

One answer is a rough textured substrate that will provide a mechanical interlock between the layers and enhance adhesion via increased area of contact between the asphalt coated aggregate particles of the OGFC and the substrate. A flush seal with cover aggregate in the form of crusher fines might offer a solution, and in certain cases a heavy tack coat could be expected to serve adequately. Weather conditions permitting, emulsified asphalt should be used for interlayer bonding; HVRS-90 or CRS-2h is suggested. The usual practice is to dilute the emulsion with an equal volume of water and apply the mixture at a rate of about 0.1 gals/sq yd. Road surface conditions and weather may create a need to apply the tack in more than one shot. Surface conditions may dictate higher or lower rate of application.

WATER SUSCEPTIBLE PAVEMENT INTERLAYERS

Another problem that may occur and one which has been observed on different jobs across the State deals with water susceptibility of the pavement layer immediately below the thin lightweight surfacing. The distress-contributing layer may be thick or thin. One example would be a thin level-up course on portland cement concrete preparatory to placing a high friction surface course. Another situation might be an asphalt stabilized hot mixed base of considerable thickness placed in new construction with this base surfaced with a thin lightweight aggregate hot mix.

If the base in the latter example is only mildly water susceptible, trouble is a strong possibility when the facility is opened to traffic immediately, particularly in the fall of the year and/or in inclement weather.

Where this condition exists it would be advisable, if at all practical, to delay placing the surface layer for 6 to 12 months to take advantage of traffic compaction and thorough "curing" of the susceptible base material before application of the lightweight aggregate overlay mixture.

The normal two percent cross slope and the low level of surface macro-texture of this dense base material promote quick removal of surface water, thus minimizing water intrusion and possible associated damage. Conversely, immediate placement of an OGFC on this base would create a water holding device allowing time for damage to take place. Water is known to be held in the OGFC surface for hours to days after a rain depending on weather conditions, and unless the substrate is adequately compacted, positively sealed and/or composed of materials that are not water susceptible, trouble is a definite probability.

USE OF ANTI-STRIP AGENTS IMPROVES ASPHALT PERFORMANCE

Improved resistance to the action of water on asphalt-aggregate mixtures is obtained by use of the optimum amount of good quality asphalt cement with well graded hydrophobic aggregates of acceptable quality. When properly mixed and placed, this optimized paving material should be adequately compacted before service begins. Even these optimized materials and technically sound construction procedures do not always assure good service because not all economically available aggregates are hydrophobic; indeed, in Texas where extensive use is made of locally available river gravel and native sands, the reverse is more often the case. Historically, Texas has utilized local materials to minimize construction, maintenance and reconstruction costs. In most cases these materials have served our highway needs adequately; however, with the continued increase in traffic volume and weight, weakness in the form of water susceptibility are evident on many jobs.

Just as it has been in the past, asphalt quality is controlled largely by source of crude and method of manufacture. In the past two decades this country has developed a very large petrochemical industry, and as a consequence, the typical barrel of oil serves a much wider variety of more profitable markets than ever before. One may then ask, "Has the quality of asphalt cement that goes into paving suffered because of these new markets?" Technically speaking, there are two acceptably correct answers to this question. While examining these answers one must keep in mind the above listed primary factor of crude source and method of manufacture. Either or both of these may change while the refiner moves into a new market that requires the production of selected feed stocks to supply his or some other refiner or petrochemical manufacturer raw charge from which resins, plastics, rubber, etc. are made.

Therefore, the residuals which constitute 4 to 5 percent of the crude oil barrel and from which asphalt is usually made, may or may not be altered in composition as a result of the birth of this relatively new industry. And again, technically speaking, the quality of the paving grade asphalt cement could be enhanced or degraded as a result.

Whether or not today's asphalt meeting current specification is better or worse than it was ten or twenty years ago is debatable. What we do know is that we continue to be pressed for economically available supplies of good quality aggregates, and further, that the traffic picture has changed. These are hard facts and for these reasons alone we need a better "glue" for our paving materials.

Let us now return to the subject of this segment of the discussion -- anti-strip agents. Effective anti-strip agents are available for treating the asphalt cement and/or the aggregate going into a paving mixture. A proven performer for treating aggregates is hydrated lime. The proper use of lime requires that the aggregate be pretreated in the wet condition before it goes to the dryer. One to two percent by weight of the fraction of aggregate needing treatment is sufficient. Only a short time delay is required between treatment and use of the treated material, say, approximately two to four minutes. This lime treatment may even serve double duty. Lime treatment may very well convert an aggregate supply from noncompliance to compliance to selected specification requirements, thus making an otherwise unacceptable local material quite acceptable.

There are several heat stable anti-strip agents on the market today, any one of which, when properly used, will minimize water damage. Such additives are generally used in amounts of one to three percent by weight of the asphalt cement and may be added at the refinery or at the plant site. To minimize possible damage, add the agent at the plant, if at all practical.

Are lightweight aggregates "per se" more water susceptible than the average Texas river gravel or field sand? The answer is "No!" for materials in current production; indeed, they are less susceptible. As a matter of fact, one Texas source of lightweight aggregate is pretreated with quicklime as an inescapable part of the manufacturing procedure! The other two sources contain modest amounts of quicklime.

Then, do we need to treat lightweight aggregates for use in paving mixtures to minimize water damage? Usually pretreating of the asphalt or part of the aggregate is in order because both OGFC and dense graded lightweight aggregate paving mixtures may contain water susceptible intermediate and/or fine fractions. In cases where the fraction requiring treatment is small, the economical approach would be to treat this fraction only.

In the mix design phase, laboratory tests should be run to measure water susceptibility and construction guides should emphasize the necessary steps required to reduce the intrusion of water, namely, in-place density control for dense mixtures and adequately thick films of asphalt for OGFC overlays.

BETTER ASPHALT BASED BINDING MATERIALS

Today's asphalt producers are entirely capable of providing better binders for use in paving operations. Such binders will consist of asphalt as the base with some added material selected to meet special specification requirements. Such binders will, if supplied, cost more then asphalt made to meet current specifications. One should not expect otherwise; however, the extra cost may make vast improvements in the cost-benefit ratio.

A knowledge of materials properties, key mixture design parameters, construction procedures, and climate and service demands coupled with good engineering judgements effected systematically can be made to produce functionally sound pavements at reasonable cost; of this there is little question. Attesting to this are thousands of miles of Texas highways, outstanding examples of the well planned accomplishments of materials producers, paving contractors, and Texas highway personnel.

Of course there are other pavement binders* that are being field tested and still others on the horizon that will contain little or no petroleum products. These will not be discussed here.

STRIPPING AND RAVELLING

Water susceptible asphalt-aggregate mixtures may show distress in the field in the form of stripping or ravelling. These two forms of distress may be initiated by entirely different factors; yet, in selected cases the causative factors may be essentially the same. Visual differences of the two are striking. Ravelling begins at the pavement surface; whereas, stripping begins within the pavement mat. A primary factor contributing to both ravelling and stripping can be inadequate binder. Generally, however, ravelling does not occur in OGFC because most designs of this material utilize comparatively thick films of asphalt. Dense paving mixtures made with lightweight aggregate may be subject to stripping in the intermediate and/or fines fraction simply because insufficient binder was used or because the finer fractions are water sensitive.

An additive is not a cure for stripping in those cases where insufficient binder is used; so, let us deal with the possible benefits of selected additives for minimizing stripping wherein optimum binder contents are used. As a point of beginning, stripping of asphalt from an aggregate surface involves a complex array of interacting variables, the net effects of which create considerable frustrations. For example, mixtures of given aggregates from selected sources may produce paving

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*Current research including field trails is presenting strong evidence that elemental sulphur will enter the pavement binder market within the next decade. Sulphur will be used to extend the supply of asphalt and/or it will constitute the major portion of the binder. In this latter case sulphur will serve as a structuring agent, or it will be plasticized with selected additives produced from animal or vegetable matter, shale oil, coal or lignite to form a binder with properties somewhat similar to asphalt. The direction of this discussion is such that further coverage of sulphur binder systems seems inappropriate.

materials that show no stripping in laboratory tests or field service when utilizing a doped or anti-strip treated asphalt cement from, say, Source A. However, paving mixtures which use the same aggregates and an asphalt cement from Source B and treated with the same anti-strip agent as that used with Source A asphalt may show severe stripping under similiar conditions of traffic environment. Stated another way, anti-strip additives must, in many instances, be customized to be effective.

The establishment of the asphalt-to-aggregate bond takes time and is further affected by interruptive mechanisms during the bonding process. Rain coupled with traffic on a surface soon after construction may cause either ravelling or stripping; whereas, rain on the same surface two or three days after construction would cause no distress.

The interruption of the establishment of a secure bond will usually cause no long term problem if traffic is eliminated temporarily while the asphalt-to-aggregate bond becomes secure. Stated another way, the damaging effects of an unexpected rain may be minimized or eliminated by temporarily taking the facility out of service or imposing strict speed control.

Some anti-strip additives, when used on certain water sensitive aggregates, are effective for indifinite time periods; whereas, a particular additive may have a short life span when used on other aggregates, even though commonly used laboratory tests indicated good protection from water when the additive was utilized in the laboratory.

PREVENTATIVE MEASURES

A program of preventative measures to minimize stripping is the recommended approach, mainly because once stripping advances much beyond the initial phases, reconstruction is the only technically sound approach available for solving the problem.

A number of cases of severe stripping have been observed in Texas. And although some of the affected pavement structures contain lightweight aggregate in the surface layer, actual proof of asphalt stripping from the lightweight particles themselves has not been documented.

Also, it has not been conclusively shown that large water absorption capacities per se contribute to stripping. Time of exposure is a more critical factor.

Heat stable cationic adhesion additives with amine bases are absorbed out of the treated asphalt onto aggregate surfaces and the effectiveness of such an additive is a function of asphalt compaction, aggregate mineralogy, and aggregate-to-asphalt interfacial condition. Such additives have been found effective but they do not always accomplish the desired end result. The use of a good wetting agent under proper conditions of mixing or the addition of hydrated lime on the prewetted aggregate surface offers the best practical protection from loss of bond to water susceptible aggregates. In the case of dense mixes, this assumes adequate compaction (low air voids) before the pavement is released to traffic.

MAINTENANCE OF PLANT MIXED PAVEMENTS MADE WITH LIGHTWEIGHT AGGREGATES

Thin overlays of the type being discussed usually require maintenance of some type during their service life. In any case, preventive maintenance scores well in a cost-benefit analysis. Experience has shown, however, that distress may go undetected and progress to severe proportions before action is taken. Two modes of flexible pavement distress that may progress unnoticed to create serious problems are a) delamination and b) stripping.

A general review of mixture design, batching, placing and service related problems of OGFC was reported by Gallaway and Epps in 1974 (13).

Delamination is a bond failure at the interface between the substrate and the overlay. Stripping is a bond failure at the aggregate-to-asphalt interface. These will be discussed separately as they apply to maintenance operations.

Delamination may be attributed to inadequate construction guides and/or improper preparation of the surface receiving the overlay. There is no known method that is both economical and practical for correcting a debonded surface, short of removing and replacing delaminated areas. Depending on the extent of the area affected, the decision may be to do spot repairs or to remove and replace the entire road surface.

Raveling of either OGFC or dense graded hot mix may be prevented or stopped when it first appears by light applications of diluted asphalt emulsion. The actual amount of residual asphalt required may be quite small, say, in the order of 0.02 to 0.06 gallons per square yard. As a general rule, a dense mixture will require less asphalt than an open overlay. Slow-setting cationic asphalt emulsions with a low pen ($90^{\pm}$) residue are recommended for dense surfaces; whereas, a medium-setting material may be more suitable for OGFC. A very light application of sharp sand may be required following the application of the emulsion to avoid a slick surface in the early life of the repair job.

When entire segments of an OGFC have been lost--extending completely through the surface layer--patching* or resurfacing is advised. Skin patches restricted to the wheel paths may serve to extend the life and/or the ride quality of the pavement, but such maintenance techniques may block the lateral internal drainage of water and impair one of the functions of the OGFC.

If the decision is made to skin patch and reduce lateral drainage within the OGFC mat, care should be exercised to duplicate as nearly as is practical the existing surface macrotexture using an aggregate of the same polish value as that of the existing surface.

Cold-laid patching materials may also be used but such materials must meet the surface design requirements of the facility. The usual cold-patch material when used to repair an OGFC, will block lateral internal drainage; nevertheless, these repair modes should suffice on a temporary basis.

The repair of "pot holes" in free-draining open graded surface courses is difficult at best, but such repairs are often an inescapable alternative and must therefore be made. One of two technically feasible

---

*If such distress is extensive and it is indicated that progressive spot failure will continue, reconstruction should be considered.

solutions are offered. Standard procedures should be used to prepare the area to be patched. Then one may fill and level and compact the hole with rock of the same type and grading as that of the surface being repaired. A cationic quick-setting emulsion with a hard residue (EA-CRS-2h) is then poured into the stone void area to a depth sufficient to almost submerge the topmost layer of stone. The emulsion is allowed to break and the patch is further compacted by light rolling.

Under average environmental conditions, patches formed by the above procedures may be opened to 45 mph free rolling traffic in one to two hours.

A suggested alternate procedure is to patch with hot open graded paving material in conjunction with an ongoing job which utilizes an acceptable OGFC mixture design. Haul distance and/or environmental conditions may require the use of an insulated and heated "transfer box" designed for easy attachment to a standard haul unit. Patch material must be transferred quickly from hot "storage" and raked as little as possible to form the patch. Immediate compaction is essential.

Summary and Recommendations

The material that has been presented offers avenues of approach that may be found useful in improving the success ratio of paving jobs which utilize lightweight aggregates on pavement surface layers. The discussions cover the properties of lightweight aggregates as these affect the design, production and handling of dense graded hot mix and open graded friction courses. Also enclosed are suggestions for modifying plant operations to offset adverse environmental conditions.

The use of volumetric design of paving mixtures containing lightweight aggregates is strongly recommended for dense mixtures as well as OGFC designs.

Cooling curves have been developed for paving mixtures that contain appreciable quantities of lightweight aggregate. The curves permit one to estimate available time for breakdown rolling, given the base temperature, mat temperature, lift thickness, and wind velocity.

Also included is a series of curves from which estimates of the magnitude of the effect of evaporative cooling may be made.

Procedures for maintenance of hot mix paving mixtures made with lightweight aggregates are discussed. Necessary precautions peculiar to these materials are emphasized.

Limited discussions cover the suggested use of silicone for minimizing the effects of moisture and reducing placing problems.

Causes for debonding or slippage are suggested along with preventive as well as corrective measures. The effect of moisture is magnified on jobs where lightweight aggregates are used. Precautions are given to minimize these effects including the use of anti-strip agents added to the asphalt cement and/or the aggregates.

Field problems of stripping and raveling are described and discussed including preventive measures. Recommendations are presented for handling the maintenance associated with stripping and/or raveling.

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APPENDIX A

State Department of Highways and Public Transportation

Materials and Tests Division

DESIGN OF BITUMINOUS MIXTURES

Scope

This procedure provides a means to determine the proper proportions of approved aggregates and asphalt which, when combined, will produce a mixture that will satisfy the specification requirements. Examples of typical procedures for design by weight or design by volume are included in this test method.

Procedure

1. Obtain and identify representative samples consisting of approximately 50 pounds of each type of material or each size aggregate proposed for use, and dry to constant weight at a temperature of 200°F minimum.

2. Secure laboratory size samples of each aggregate by carefully reducing the amount of material by quartering as outlined in Test Method Tex-200-F. (Figure 1)

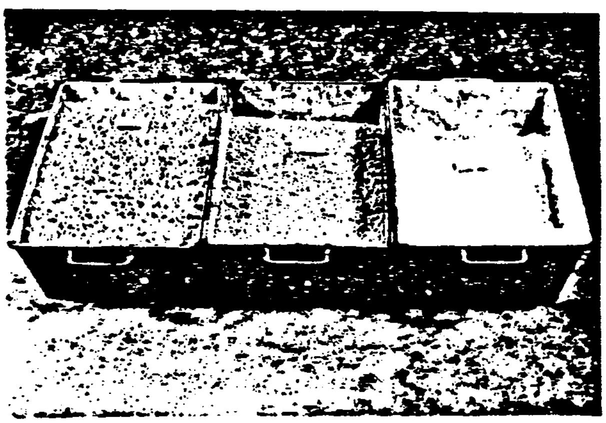

Figure 1

3. Determine the sieve analysis as outlined in Test Method Tex-200-F using the sieve sizes as set forth in the specifications for the type mix desired, and the bulk specific gravity of each size aggregate in accordance with Test Methods Tex-201-F or Tex-202-F.

4. The proper design technique requires that the aggregate proposed for use be combined in such a manner as to approach the average or mid-point of the allowable range set forth in the specifications. However, economy and ratio of production of the aggregate are factors which should be kept in mind in selecting the initial combination to be tested. Only after combinations utilizing the most economical proportions have been determined to be unsatisfactory will other less desirable combinations be tried.

5. After determining the required data in Step 3, assume, on the basis of the aggregate alone, the most satisfactory combination of the available materials which meets the requirements set forth in Step 4. Calculate the combined sieve analysis on Form D-9-F 24 (Table 2). In the event this assumed combination is at any point outside the specified grading limitations or, in the opinion of the Engineer, too close to these limits for consistent acceptable plant production, other combinations will be tried.

6. After the design gradation has been selected, the necessary asphalt content must be determined which will enable the mixture to satisfy the density (percent compaction), stability values specified and other requirements of the governing specification. Unless previous experience with these aggregates justifies the use of a smaller asphalt range, the method for selecting the proper asphalt content is to prepare five mixtures containing five different asphalt contents which cover the allowable range of the specifications. The percentages of asphalt to be tried are each end-point, the mid-point, and the two quarter-points of the allowable range shown in the specification. A trial specimen should be molded so that any necessary corrections can be made in the amount of material necessary to obtain a standard specimen height of 2.0 ± 0.06 inches. The asphalt content of the trial specimen should be at the mid-point of the specification range. After calculating the correct weight to produce the trial specimen of standard height, the total weights for specimens containing other percentages of asphalt can be closely approximated in most instances by using the corrected weight of the trial specimen as a base value and for every one percent by weight change in percentage by weight of asphalt, change the total weight by 5 grams.

7. Combine materials, mix and mold specimens 4 inches in diameter and 2.0 ± 0.06 inches in height as described in Test Method Tex-205-F and Tex-206-F.

8. When the quality tests include the sand equivalent value, perform this test on the combined materials prior to the addition of asphalt as set forth in Test Method Tex-203-F.

9. Determine the density or percent compaction of the specimen according to Test Method Tex-207-F.

10. Determine the stabilometer value or percent stability of the specimens as described in Test Method Tex-208-F.

11. Plot the test values obtained from the density and stability determinations versus the percent asphalt as illustrated in Figure 2. From this curve the percent asphalt which will provide a mixture that will satisfy the density and stability requirements of the specifications can be determined. If there is not an asphalt content within the allowable range which will provide such a mixture, it will be necessary to assume another combination of aggregates, or, possibly, even obtain new materials and perform a new design as outlined herein.

PART I

TYPICAL EXAMPLE OF DESIGN BY WEIGHT

Conditions

1. The processed materials consist of crushed limestone for the coarse aggregate, Aggregate "A" (1/2-inch maximum size) and medium size aggregate, Aggregate "B" (1/4-inch maximum size) and a fine siliceous sand obtained from a local pit.

2. It is desired to combine the three aggregates and penetration grade asphalt in such proportions to meet the requirements of grading, density and stability of Specification Item 340, Type D for Asphaltic Concrete.

Solution

1. Obtain representative laboratory samples of the aggregates as set forth in the Procedure of this Test Method. The results of the sieve analysis of each type material are shown in Table I.

2. After considering all factors relating to the production, etc., of the available materials, assume that the most economical combination of the aggregates will consist of 35% by weight coarse aggregate (Aggregate "A"), 22% by weight medium aggregate (Aggregate "B") and 43% by weight of field sand.

Table II on Form D-9-F-24 shows the resulting bin sieve analysis and the combined grading along with the specification grading for Item 340, Type "D".

3. The test mixtures are designed on the basis of the combined weight of the aggregate and asphalt, e.g., the total weight of the asphaltic mixtures. The combined grading of the aggregates is changed to include the asphalt as shown in Table III. The asphalt content allowed for Type D is 4.0% to 8.0% by weight and as previously stated, the suggested asphalt contents for the test mixes are the end points, the mid-point and the two quarter-points of the allowable asphalt spread. In this example these will be: 4.0, 5.0, 6.0, 7.0 and 8.0 percent by weight. Therefore, the corresponding percentages by weight of the aggregate in the mixtures will be 96.0, 95.0, 94.0, 93.0 and 92.0.

4. A total weight of 1000 grams for any mixture will usually produce a standard specimen approximately 2.00 inches in height and is an easy, convenient figure to work with in calculating the design mixes. After the mixes have been calculated on the basis of 1000 grams total weight, a trial mixture should be mixed and molded at the mid-point of the asphalt range specified to obtain the actual specimen height this total weight will produce. The total weight for this trial mixture can then be corrected by direct proportion as shown in Table III for the proper total weight for a 2.00 inch high specimen. After this correct weight has been determined for the trial mixture, the corrected weights for all the remaining design mixtures can be calculated to a close approximation by adding to or subtracting from the total weight of the trial mixture 5 grams for every one percent increase or decrease in the asphalt content. For the example in Table III, 8.0% by weight asphalt content was used to show this correction from a trial mixture containing 6.0% by weight of asphalt.

5. After correcting the weights for the design mixes, combine the materials, mix and mold the test specimens and obtain the percent density and stability values as described in Test Methods Tex-205-F, 206-F, 207-F and 208-F.

6. The following table shows the average values obtained from the above tests.

Percent Asphalt	Average Percent Density	Average Percent Stability
4.0	92.0	44
5.0	93.9	45
6.0	96.1	40
7.0	97.5	29
8.0	98.3	16

7. To obtain the optimum asphalt content for the design, the above test values are plotted on a sheet of graph paper with specimen density and stability on the vertical axis and percent asphalt on the horizontal axis. The density and stability curves are drawn by connecting the respective plotted values (Figure 2). Since the standard specifications specify an optimum density of 97%, a line is drawn vertically down the sheet from the point at which the density curve intersects the 97% density line. This vertical line intersects both the stability curve and the horizontal axis.

The optimum asphalt content, as read from the graph, is 6.7% by weight and the expected laboratory stability of this mixture would be 33%. The above procedure has established a bituminous mixture design based on either stockpile or cold bin aggregates. The design indicates the material should be fed to the plant in the following proportions:

Fine Sand	= 43.0%
Medium Aggregate "B"	= 22.0%
Coarse Aggregate "A"	= 35.0%

If the materials are carefully proportioned in this manner and the screens of the plant are properly choseh and operate efficiently, the resulting combined hot bin aggregate should closely approximate the design gradation. Experience has proven, however, that this ideal situation rarely exists.

In order to provide the producer with batch weights for plant production, a complete sieve analysis of each hot bin is necessary. Then a combined grading of these hot bin materials is developed in exactly the same manner as described previously for the cold bin or stockpile aggregates. (This constitutes a new design based on hot bin sieve analyses.) This new combined grading should be as nearly identical to the original grading as possible so that the resulting mixture will have characteristics similar to the laboratory designed mixture.

As an example, assume that the second design has been made based upon the hot bin sieve analysis, and that this design resulted in Bin No. 1 (Fine Aggregate) providing 40% of the aggregate, Bin No. 2 (Medium Aggregate) providing 25% of the aggregate, and Bin No. 3 (Coarse Aggregate) providing the remaining 35% of the aggregate. This combination of aggregates would result in a new combined grading that closely approximates the original design.

The batch weights needed by the producer to produce the mixture would include the weight of aggregate from each bin and the weight of asphalt. The original design established an optimum asphalt content of 6.7% by weight. Therefore, the aggregate would constitute 93.3% by weight of the mixture. The proper proportion of each material in the final mixture would result as follows:

Bin No. 1 (Fine)	40% x 93.3% = 37.3%
Bin No. 2 (Medium)	25% x 93.3% = 23.3%
Bin No. 3 (Coarse)	35% x 93.3% = 32.7%
	Asphalt = 6.7%

Assuming that the plant will produce a 4000 pound batch, the batch weights are as follows:

Bin No. 1	= 37.3% x 4000 = 1492 lbs.
Bin No. 2	= 23.3% x 4000 = 932 lbs.
Bin No. 3	= 32.7% x 4000 = 1308 lbs.
Asphalt	= 6.7% x 4000 = 268 lbs.
	Total = 4000 lbs.

Notes:

1. Keep the various sizes of aggregate, as shown in Table III, separate and recombine to make the three test specimens for each percent asphalt uniform and as near identical as possible.

2. In calculating design quantities, keep in mind that the sum of the combined aggregates must equal 100 percent, and that the sum of the total mixture of aggregate and asphalt will also be 100%.

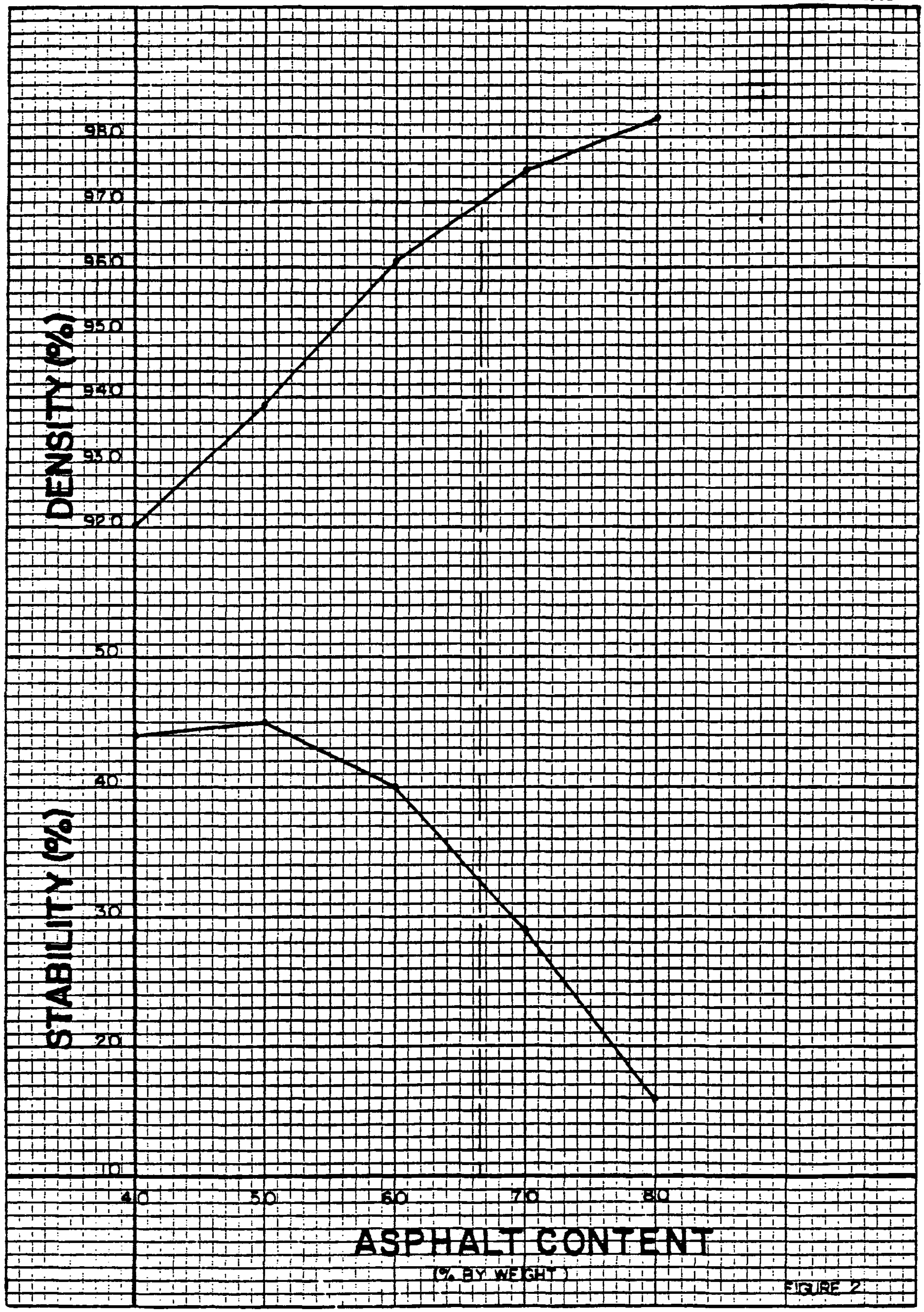
98.0
97.0
96.0
95.0
94.0
93.0
92.0
DENSITY (%)
50
40
30
20
10
STABILITY (%)
4.0
5.0
6.0
7.0
8.0
ASPHALT CONTENT
(% BY WEIGHT)
FIGURE 2

Table 1

MATERIALS AND TESTS DIVISION
BITUMINOUS SECTION
SIEVE ANALYSIS

Date 1-2-61	District No. M & T Laboratory
Time	Req. No. Hot-Mix Plant Stockpiles
Spec. Item No. 340	Project No.
Type D	Design No. D-1

SIEVE ANALYSIS, % BY WEIGHT

Sieve Size	~~Car No.~~ Fine Sand	~~Car No.~~ Aggregate "B" Medium Agg.	~~Car No.~~ Aggregate "A" Coarse Agg.	Car No.	Car No.	Car No.	Car No.	Car No.	Car No.	Car No.	T.H.D. Specs.
Retained ~~Pass~~ 1/2"			0.0								
Retained ~~Pass~~ 3/8"			3.0								
1 3/4" - 7/8"											
7/8" - 3/8"											
5/8" - 3/8"											
3/8" - No.4		0.2	89.1								
1/4" - No.4											
1/4" - No.10											
No.4 - No.10		94.1	7.5								
Ret. No.10											
No.10 - No.40	40.2										
No.40 - No.80	39.2										
No.80 - No.200	14.4										
Pass No.200	6.2	5.7	0.4								
Total	100.0	100.0	100.0								
Asphalt Added											

Inspector

Form No. D-9-F23

Table 2

MATERIALS AND TESTS DIVISION
BITUMINOUS SECTION
MIX DESIGN SHEET

Date	1-2-61	District No.	M&T Laboratory
Spec. Item No.	340	Material Ident.	Hot Mix Plant Stockpiles
Type	D	Design No.	D-1

Sieve Size	Fine Sand		Aggregate "B" Medium		Aggregate "A" Coarse						Comb. Grad.	T.H.D. Specs.
	Sieve Analysis	43%	Sieve Analysis	22%	Sieve Analysis	35%	Sieve Analysis		Sieve Analysis			
Retained ~~Pass~~ 1/2"					0.0						0.0	0.0
Retained ~~Pass~~ 3/8"					3.0	1.1					1.1	0-5
1 3/4"–7/8"												
7/8"–3/8"												
5/8"–3/8"												
3/8"–No.4			0.2	0.0	89.1	31.2					31.2	20-50
1/4"–No.4												
1/4"–No.10												
No.4–No.10			94.1	20.7	7.5	2.6					23.3	10-30
Ret. No.10											55.6	50-70
No.10–No.40	40.2	17.3									17.3	0-30
No.40–No.80	39.2	16.8									16.8	4-25
No.80–No.200	14.4	6.2									6.2	3-25
Pass No.200	6.2	2.7	5.7	1.3	0.4	0.1					4.1	0-8
Total	100.0	43.0	100.0	22.0	100.0	35.0					100.0	

Inspector

Form No. D-9-F24

TABLE III

DESIGN OF LABORATORY MIXES

			Mix No. 1, 6.0% Asphalt 94.0% Aggregate				Mix No. 2, 8.0% Asphalt 92.0% Aggregate			
Material	Size	Agg. %	Mix (%)	Wt. (Gms.)	Cumul. Wt. (Gms.)	Corrected Cumul. Wt. (Gms.)	Mix (%)	Wt. (Gms.)	Cumul. Wt. (Gms.)	Corrected Cumul., Wt. (Gms.)
Bin No. 3 (Coarse)	3/8 - No. 4	35.0	32.9	329.0	329.0	316.3	32.2	322.0	322.0	312.8
Bin No. 2 (Medium)	No. 4 - No. 10	22.0	20.7	207.0	536.0	515.4	20.2	202.0	524.0	509.1
Bin No. 1 (Fine)	Minus No. 10	43.0	40.4	404.0	940.0	903.8	39.6	396.0	920.0	893.8
Asphalt			6.0	60.0	1000.0	961.5	8.0	80.0	1000.0	971.5
		100.0	100.0	1000.0			100.0	1000.0		

TRIAL SPECIMEN HEIGHT = 2.08 INCHES

Correct Weight for 2.00 inch specimen = $\frac{2.00}{2.08}(1000) = 961.5$ gms.

Corrected total weight for 2.00 inch specimen with
8.0% asphalt = $961.5 + (8.0 - 6.0)\ (5) = 971.5$ gms.

Corrected cumulative weights for 8.0% asphalt = (Cumul. Wt.) $\left(\frac{971.5}{1000}\right)$

PART II

TYPICAL EXAMPLE OF DESIGN BY VOLUME

The Volumetric Design Method may be beneficial to use when designing bituminous mixtures using aggregates of widely differing specific gravities.

1. The processed materials consist of the following:

Coarse Aggregate-Aggregate, 1/2 inch maximum size.

Medium Aggregate-Aggregate, 3/8 inch maximum size.

Fine Aggregate-Aggregate, the majority of which passes the No. 10 sieve.

2. It is desired to combine the three aggregates and asphalt cement in such proportions to meet the requirements of grading, density, and stability of the specifications.

3. Obtain representative laboratory samples of the aggregates as set forth in the "Procedure" of this Test Method.

4. After drying to constant weight, perform sieve analysis on each individual material according to Test Method Tex-200-F. Test results are recorded on the accompanying Mix Design Sheet, No. 1.

5. Separate each individual aggregate into sizes corresponding to specification and type grade fractions. Determine the Bulk Specific Gravity, Test Method Tex-201-F, on each size fraction of the materials retained on the 80 mesh sieve and the Apparent Specific Gravity, Test Method Tex-202-F, on material passing the 80 mesh sieve.

6. Determine the Average Bulk Specific Gravity of each individual aggregate, fine, medium, and coarse, according to Test Method Tex-201-F.

Note: Assume the specific Gravity of each size fraction of each individual aggregate is equal to the Average Bulk Specific Gravity of each individual aggregate, then the percentages obtained in the sieve analysis, Test Method Tex-200-F, can be considered percentages by volume or percentages by weight.

7. Beginning with the coarse aggregate, assume percentages of each individual aggregate (totaling 100 percent) which by trial and error will produce a combined grading which satisfies the specifications item gradation. Referring to the Mix Design Sheet, No. 1, the individual aggregate percentages by volume are 43% fine, 22% medium, and 35% coarse.

8. Referring to the bottom of the Mix Design Sheet No. 1, multiply the percentages of each individual aggregate by its Average Bulk Specific Gravity to obtain the calculated weights of each aggregate. Total the individual weights. Then divide the individual aggregate weights by the total weight x 100 to obtain the percentages by weight of each individual aggregate.

9. Record the sieve analyses and percentages by weight of the individual aggregates on Mix Design Sheet, No. 2. Keeping in mind that the original sieve analyses are both percentage volumes and percentage weight, use the calculated percentage by weight and the sieve analyses to obtain a combined by weight gradation.

10. Determine the average Bulk Specific Gravity for the combined by weight gradation using the percentages by weight and the Average Bulk Specific Gravity of the individual aggregates according to Test Method Tex-201-F. In the accompanying example, the Average Bulk Specific Gravity for the combined by weight gradation is:

$$GB - \frac{100}{\frac{50.9}{2.632} + \frac{25.2}{2.546} + \frac{23.9}{1.520}} = 2.224$$

11. The asphalt content range specified for this mixture is 10.0% to 19.0% by volume; the suggested asphalt contents for the laboratory mixes are the end points, the mid-point, and the two quarter points. Table I depicts a method of converting the suggested asphalt and aggregate combinations from percentages by volume to percentages by weight for laboratory batching.

12. Use the mid-point asphalt content to produce a trial specimen. A total sample weight of 1000 grams is a convenient starting weight. In the example, Table II, the mid-point asphalt content of 7.2 percent by weight is used. Multiply the percentage aggregate in the total sample (92.8%) by the percent fractions of the individual aggregates in the first column of Table II to obtain the percentage of each aggregate fraction in the mixture containing asphalt. These percentages are used to determine the cumulative batch weights as shown in the Cum. Wt. column. The mixture thus contains 72 grams asphalt and 928 grams aggregate.

The trial sample is then mixed and molded according to Test Methods Tex-205-F and Tex-206-F, respectively. The batch weight of the 1000-gram trial sample is corrected by proportion, as shown in Table II to obtain a 2.00-inch high specimen. After this corrected weight has been determined for the trial mixture, the individual cumulative weights of each aggregate size are determined by direct proportion

(Example: $\frac{\text{Corr. Wt.}}{6} = \frac{952.4}{1000}$; Corr. Wt. = 5.7 gms.)

and recorded in the Corr. Wt. column.

The corrected weights for the remaining design mixtures can be approximated by adding or subtracting from the total weight of the trial mixture 5 grams for every one percent by weight increase or decrease in asphalt content.

(Example: 9.6 - 7.2 = 2.4; 2.4 x 5.0 = 12.0; 952.4 + 12.0 = 964.4 gms. for 9.6% by weight asphalt content mixture.)

Determine the individual aggregate and asphalt weights for each of the five asphalt content mixtures. Mix and mold three Hveem specimens for each of the five mixtures. Determine the average density of each set of specimens as described in Test Method Tex-207-F. Determine the average Hveem stability for each set of specimens according to Test Method Tex-208-F.

Using the average density and stability data for each asphalt content mixture, construct the "design curves" as illustrated in Figure 2. Draw a line representing the "optimum density" (97.0% for this mixture) horizontally until it intersects the design density curve. Then draw a vertical line from this intersection to the horizontal axis. The intersection of this vertical line with the horizontal axis provides the "optimum asphalt content" for the design. (In the example, Figure 2, a mixture of the chosen aggregate gradation with 6.7% asphalt should yield a specimen density of approximately 97.0% with a Hveem stability value of approximately 33%.)

Should the resulting Hveem stability value be near or below the minimum required, a slightly lower asphalt content may be chosen or a new design may be required with different aggregates or combination of aggregates that will produce the specified characteristics.

13. This procedure has produced a bituminous mixture design based on either stockpiled or cold bin aggregates. The design indicates that the aggregates should be fed to the plant in the following proportions:

Coarse = 23.9% by weight

Medium = 25.2% by weight

Fine = 50.9% by weight

If the materials are carefully proportioned in this manner and the screens of the plant are properly chosen and operate efficiently, the resulting combined hot bin aggregate should closely approximate the design gradation. Experience has proved, however, that this ideal situation rarely exists.

14. After the plant has been running for a sufficient period of time to be producing a consistent mixture gradation, samples must be taken from the hot bins to the laboratory. The specific gravities of these hot bin aggregates must be determined and a complete redesign by volume must be made in the same manner as that previously described for the cold bin or stockpiled aggregates.

Following the steps of this procedure, the percentage by weight of aggregate from each hot bin and the optimum asphalt content for the hot bin design can be determined that will satisfy the specifications.

15. As an example, assume that the special design has been made based upon the hot bin aggregate samples, and that this design resulted in Bin No. 1 (Fine Aggregate) providing 40.0% by weight of the aggregate, Bin No. 2 (Medium Aggregate) providing 25.0% by weight of the aggregate, and Bin No. 3 (Coarse Aggregate) providing the remaining 35.0% by weight of the aggregate. This combination of aggregates should result in a combined grading that approximates the original design.

Assuming that the optimum asphalt content of the second design results in the same as the original design, 6.7% by weight, the aggregate would constitute 93.3% by weight of the mixture. The proper proportion of each material in the final mixture would be as follows:

Bin No. 1 40.0% x 93.3% = 37.3% by weight

Bin No. 2 25.0% x 93.3% = 23.3% by weight

Bin No. 3 35.0% x 93.3% = 32.7% by weight

Total = 93.3% by weight

Asphalt = 6.7% by weight

Total = 100.0% by weight

16. Assuming that the plant will produce a 4000-pound batch, the batch weights are as follows:

Bin No. 1 = 37.3% x 4,000 = 1,492 lbs.

Bin No. 2 = 23.3% x 4,000 = 932 lbs.

Bin No. 3 = 32.7% x 4,000 = 1,308 lbs.

Asphalt = 6.7% x 4,000 = 268 lbs.

Total = 4,000 lbs.

Notes: For the volumetric design method, it must be realized that plant control is based upon the percent by weight combined grading resulting from the hot bin design. The periodic hot bin sieve analyses and extraction sieve analyses and residual bitumen contents must meet this combined grading and the specified tolerances.

If the grading of the mixture exceeds the tolerances in any part and it requires cold feed adjustments to correct the gradation (or should it be desirable to substitute another aggregate for one or more being used), a complete redesign by volume must be made.

The volumetric sieve analysis may be used for gradation control. In this instance both the tolerances and the standard gradation specifications will apply.

MATERIALS AND TESTS DIVISION
BITUMINOUS SECTION
MIX DESIGN SHEET
NO. 1

Date	District No.
Spec. Item No.	Material Ident.
Type	Design No.

Sieve Size	Fine		Medium		Coarse						Comb.	T.H.D.
	Sieve Analysis	43.0%	Sieve Analysis	22.0%	Sieve Analysis	35.0%	Sieve Analysis		Sieve Analysis		Grad. (% by	Specs. Vol)
+ 1/2"					0	0					0	0
+ 3/8"			0	0	3.0	1.1					1.1	0-5
1 3/4" - 7/8"												
7/8" - 3/8"												
5/8" - 3/8"												
3/8" - No.4			2.2	0.5	89.1	31.2					31.7	20-50
1/4" - No.4												
1/4" - No.10												
No.4 - No.10	0	0	94.1	20.7	7.5	2.6					23.3	10-30
Ret. No.10											56.1	50-70
No.10 - No.40	40.2	17.3									17.3	0-30
No.40 - No.80	39.2	16.8									16.8	4-25
No.80 - No.200	14.4	6.2									6.2	3-25
Pass No.200	6.2	2.7	3.7	0.8	0.4	0.1					3.6	0-8
Total	100.0	43.0	100.0	22.0	100.0	35.0					100.0	

	Vol.		Avg. Bulk Sp. Gravity		Wt.	% By Wt.
Coarse—	35.0	x	1.520	=	53.200	23.9
Medium—	22.0	x	2.546	=	56.012	25.2
Fine—	43.0	x	2.632	=	113.176	50.9
	100.0				222.388	100.0

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The corrected weights for the remaining design mixtures can be approximated by adding or subtracting from the total weight of the trial mixture 5 grams for every one percent by weight increase or decrease in asphalt content.

(Example: 9.6 - 7.2 = 2.4; 2.4 x 5.0 = 12.0; 952.4 + 12.0 = 964.4 gms. for 9.6% by weight asphalt content mixture.)

Determine the individual aggregate and asphalt weights for each of the five asphalt content mixtures. Mix and mold three Hveem specimens for each of the five mixtures. Determine the average density of each set of specimens as described in Test Method Tex-207-F. Determine the average Hveem stability for each set of specimens according to Test Method Tex-208-F.

Using the average density and stability data for each asphalt content mixture, construct the "design curves" as illustrated in Figure 2. Draw a line representing the "optimum density" (97.0% for this mixture) horizontally until it intersects the design density curve. Then draw a vertical line from this intersection to the horizontal axis. The intersection of this vertical line with the horizontal axis provides the "optimum asphalt content" for the design. (In the example, Figure 2, a mixture of the chosen aggregate gradation with 6.7% asphalt should yield a specimen density of approximately 97.0% with a Hveem stability value of approximately 33%.)

Should the resulting Hveem stability value be near or below the minimum required, a slightly lower asphalt content may be chosen or a new design may be required with different aggregates or combined of aggregates that will produce the specified characteristics.

13. This procedure has produced a bituminous mixture design based on either stockpiled or cold bin aggregates. The design indicates that the aggregates should be fed to the plant in the following proportions:

Coarse = 23.9% by weight

Medium = 25.2% by weight

Fine = 50.9% by weight

If the materials are carefully proportioned in this manner and the screens of the plant are properly chosen and operate efficiently, the resulting combined hot bin aggregate should closely approximate the design gradation. Experience has proven, however, that this ideal situation rarely exists.

14. After the plant has been running for a sufficient period of time to be producing a consistent mixture gradation, samples must be taken from the hot bins to the laboratory. The specific gravities of these hot bin aggregates must be determined and a complete redesign by volume must be made in the same manner as that previously described for the cold bin or stockpiled aggregates.

Following the steps on this procedure, the percentage by weight of aggregate from each hot bin and the optimum asphalt content for the hot bin design can be determined that will satisfy the specifications.

15. As an example, assume that the special design has been made based upon the hot bin aggregate samples, and that this design resulted in Bin No. 1 (Fine Aggregate) providing 40.0% by weight of the aggregate, Bin No. 2 (Medium Aggregate) providing 25.0% by weight of the aggregate, and Bin No. 3 (Coarse Aggregate) providing the remaining 35.0% by weight of the aggregate. This combination of aggregates should result in a combined grading that approximates the original design.

Assuming that the optimum asphalt content of the second design results in the same as the original design, 6.7% by weight, the aggregate would constitute 93.3% by weight of the mixture. The proper proportion if each material in the final mixture would be as follows:

Bin No. 1 40.0% x 93.3% = 37.3% by weight

Bin No. 2 25.0% x 93.3% = 23.3% by weight

Bin No. 3 35.0% x 93.3% = 32.7% by weight

Total = 93.3% by weight

Asphalt = 6.7% by weight

Total = 100.0% by weight

16. Assuming that the plant will produce a 4000 pound batch, the batch weights are as follows:

Bin No. 1 = 37.3% x 4,000 = 1,492 lbs.

Bin No. 2 = 23.3% x 4,000 = 932 lbs.

Bin No. 3 = 32.7% x 4,000 = 1,308 lbs.

Asphalt = 6.7% x 4,000 = 268 lbs.

Total = 4,000 lbs.

Notes

For the volumetric design method, it must be realized that plant control is based upon the percent by weight combined grading resulting from the hot bin design. The periodic hot bin sieve analyses and extraction sieve analyses and residual bitumen contents must meet this combined grading and the specified tolerances.

If and when the grading of the mixture exceeds the tolerances in any part and it requires cold feed adjustments to correct the gradation; or should it be necessary or desirable to substitute another aggregate for one or more being used, a complete redesign by volume must be made.

MATERIALS AND TESTS DIVISION
BITUMINOUS SECTION
MIX DESIGN SHEET

NO. 1

Date	District No.
Spec. Item No.	Material Ident.
Type	Design No.

Sieve Size	Fine		Medium		Coarse						Comb. Grad. (% by	T.H.D. Specs. Vol)
	Sieve Analysis	43.0%	Sieve Analysis	22.0%	Sieve Analysis	35.0%	Sieve Analysis		Sieve Analysis			
+ 1/2"					0	0					0	0
+ 3/8"			0	0	3.0	1.1					1.1	0-5
1 3/4" - 7/8"												
7/8" - 3/8"												
5/8" - 3/8"												
3/8" - No.4			2.2	0.5	89.1	31.2					31.7	20-50
1/4" - No.4												
1/4" - No.10												
No.4 - No.10	0	0	94.1	20.7	7.5	2.6					23.3	10-30
Ret. No.10											56.1	50-70
No.10 - No.40	40.2	17.3									17.3	0-30
No.40 - No.80	39.2	16.8									16.8	4-25
No.80 - No.200	14.4	6.2									6.2	3-25
Pass No.200	6.2	2.7	3.7	0.8	0.4	0.1					3.6	0-8
Total	100.0	43.0	100.0	22.0	100.0	35.0					100.0	

	Vol.		Avg. Bulk Sp. Gravity		Wt.	% By Wt.
Coarse—	35.0	x	1.520	=	53.200	23.9
Medium—	22.0	x	2.546	=	56.012	25.2
Fine—	43.0	x	2.632	=	113.176	50.9
	100.0				222.388	100.0

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MATERIALS AND TESTS DIVISION
BITUMINOUS SECTION
MIX DESIGN SHEET

NO. 2

Date	District No.
Spec. Item No.	Material Ident.
Type	Design No.

Sieve Size	Fine		Medium		Coarse						Comb. Grad. (% by	T.H.D. Specs. Wt.)
	Sieve Analysis	50.9%	Sieve Analysis	25.2%	Sieve Analysis	23.9%	Sieve Analysis		Sieve Analysis			
+ 1/2"					0	0					0	
+ 3/8"			0	0	3.0	0.7					0.7	± 4
1 3/4" – 7/8"												
7/8" – 3/8"												
5/8" – 3/8"												
3/8" – No. 4			2.2	0.6	89.1	21.3					21.9	± 4
1/4" – No. 4												
1/4" – No. 10												
No. 4 – No. 10	0	0	94.1	23.7	7.5	1.8					25.5	± 4
Ret. No. 10											48.1	± 4
No. 10 – No. 40	40.2	20.5									20.5	± 3
No. 40 – No. 80	39.2	19.9									19.9	± 3
No. 80 – No. 200	14.4	7.3									7.3	± 3
Pass No. 200	6.2	3.2	3.7	0.9	0.4	0.1					4.2	± 2
Total	100.0	50.9	100.0	25.2	100.0	23.9					100.0	

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TABLE I

	% By Vol.		Avg. Bulk Sp. Gravity		Wt.	% By Wt.
Combined Aggregate	90.0	x	2.224	=	200.16	95.2
Asphalt Content	10.0	x	1.012	=	10.12	4.8
	100.0				210.28	100.0
Combined Aggregate	87.7	x	2.224	=	195.04	94.0
Asphalt Content	12.3	x	1.012	=	12.45	6.0
	100.0				207.49	100.0
Combined Aggregate	85.5	x	2.224	=	190.15	92.8
Asphalt Content	14.5	x	1.012	=	14.67	7.2
	100.0				204.82	100.0
Combined Aggregate	83.2	x	2.224	=	185.04	91.6
Asphalt Content	16.8	x	1.012	=	17.00	8.4
	100.0				202.04	100.0
Combined Aggregate	81.0	x	2.224	=	180.14	90.4
Asphalt Content	19.0	x	1.012	=	19.23	9.6
	100.0				199.37	100.0

TABLE II

Identification	% By Wt.	7.2% Asphalt % By Wt.	7.2% Asphalt Cum. Wt. (gms.)	7.2% Asphalt Corr. Wt. (gms.)	9.6% Asphalt % By Wt.	9.6% Asphalt Cum. Wt. (gms.)	9.6% Asphalt Corr. Wt. (gms.)
Coarse							
Ret. 3/8"	0.7	0.6	6	5.7	0.6	6	5.8
3/8"-No.4	21.3	19.8	204	194.3	19.3	199	191.9
No.4-No.10	1.8	1.7	221	210.5	1.6	215	207.3
Pass No.10	0.1	0.1	222	211.4	0.1	216	208.3
Medium							
3/8"-No.4	0.6	0.6	228	217.1	0.6	222	214.1
No.4-No.10	23.7	22.0	448	426.7	21.4	436	420.5
Pass No.10	0.9	0.8	456	434.3	0.8	444	428.2
Fine	50.9	47.2	928	883.8	46.0	904	871.8
Asphalt	----	7.2	1000	952.4	9.6	1000	964.4
	100.0	100.0			100.0		

Weight Correction for Specimen Height

$$\frac{\text{Corr. Wt.}}{2.00''} = \frac{1000 \text{ gms.}}{2.10''}$$

$$\text{Corr. Wt.} = \frac{2000}{2.10} = 952.4 \text{ gms.}$$