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16. Abstract

Glauconite is an abundant aggregate in east central Texas. However, it is rather soft and thus subject to crushing and abrasion under normal construction processes. The purpose of this research study is to evaluate the quality of glauconite and determine its suitability for use on TxDOT pavement construction projects and if it is suitable, how to optimize its utility. Laboratory tests on chemically stabilized glauconite were conducted.

This work was conducted in two phases. Phase I evaluated two unstabilized glauconites: soft and hard. Results of Phase I showed that neither glauconite product was suitable for routine use on TxDOT pavements as a flexible base (Specification Item 247) without some type of stabilization or other strength/durability enhancing strategy. Phase II was conducted to determine selected performance-related properties of stabilized glauconite. The stabilizers included cement, hydrated lime, and lime + fly ash. Unstabilized and stabilized glauconite were compared with unstabilized and stabilized iron ore gravel (which has been used as pavement base materials in East Texas for many years).

Glauconite will absorb and hold relatively high quantities of water. Glauconite will not likely pass the wet ball mill test. This further has a negative impact on linear shrinkage which will also not consistently meet specifications. However, the plasticity index is acceptable. Glauconite will not consistently pass the triaxial test. Stabilization with portland cement yielded the best strength enhancements and resistance to moisture suction when compared to stabilization with lime + fly ash and hydrated lime. Hydrated lime provided the least stabilization for glauconite. Wide variability in glauconite properties manifests potential construction and performance problems related to quality control. This study recommends that the routine use of glauconite on TxDOT roadways be avoided.

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EVALUATION OF GLAUCONITE AGGREGATE FOR PAVEMENT CONSTRUCTION

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Report 3901-S
Research Project Number 7-3901
Research Project Title: Possible Use of Locally Available Glauconite (Blue Rock) in Construction and/or Maintenance Projects for the Lufkin District

Sponsored by the
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November 1997

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IMPLEMENTATION RECOMMENDATIONS

The purpose of this study is to evaluate the quality of glauconite and determine its suitability for use on TxDOT pavement construction projects and, if it is suitable, how to optimize its utility. This report documents the results and findings of this study.

The findings of this study show that glauconite is a variable aggregate and will not consistently pass strength and durability test requirements. This wide variability may lead to significant construction and performance problems related to quality control. The researchers recommend that glauconite not be routinely used on TxDOT roadways.

The implementation of the findings of this study will be to avoid the routine use of glauconite.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation. This report does not constitute a standard, specification or regulation.

ACKNOWLEDGMENT

The authors wish to express their appreciation to the Texas State Department of Highways and Public Transportation personnel in the Lufkin District for their time and effort.

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INTRODUCTION

Locally available pavement base materials historically used in the Lufkin District have become increasingly difficult to locate and, consequently, have increased in cost as the district's sources have become depleted. Iron ore gravel was used as pavement base in East Texas for many years. Although iron ore gravel has served satisfactorily on farm-to-market roads, it does not meet the TxDOT triaxial strength requirements for bases on major roads.

A number of commercial quarries producing glauconite have been opened in San Augustine and Sabine counties. This material has provided satisfactory performance as reported by other public agencies. However, except for a small test in a rural area, it has not been used on TxDOT highway projects.

Glauconite is often called "Blue Rock" because of its distinctive bluish-green color. The color offers a definitive clue to its geological history as well as to the fact that it was produced in a reduced environment. It has the potential to be susceptible to oxidative weathering and perhaps to experience significant property changes in certain uses and under certain conditions. However, previous testing (1) has shown reasonably good strength properties with some glauconites and the potential to overcome some of the limitations through blending with locally available sands or through chemical stabilization.

The purpose of this research study is to evaluate the quality of glauconite and determine its suitability for use on TxDOT pavement construction projects and, if it is suitable, how to optimize its utility.

This work was conducted in two phases. Phase I evaluated two unstabilized glauconites, each from a different quarry. At that time, one of the sources produced a relatively harder glauconite than the other source. Results of Phase I showed that neither glauconite product was suitable for routine use on TxDOT pavements as a flexible base (Specification Item 247) without some type of stabilization or other strength/durability enhancing strategy. Therefore, Phase II was conducted to determine the performance-related properties of stabilized glauconite. The stabilizers included cement, hydrated lime, and lime + fly ash. Unstabilized and stabilized glauconite were compared with unstabilized and stabilized iron ore gravel (which has been used as pavement base materials in East Texas for many years).

EXPERIMENTAL PROGRAM

From two selected quarries, representing generally harder and softer stones, several hundred kilograms of representative samples were obtained. These two quarries were termed Welch's Pit, which was producing a relatively soft material, and Welch's Ford's Corner Pit, which was producing a comparatively hard material. These two products were used in Phases I and II of the study to assess the properties of unstabilized and stabilized glauconite.

Testing Plans

The Phase I experimental program for unstabilized glauconite consisted of the procedures listed in Tables 1 and 2. These tables include tests routinely used to characterize aggregate materials for use in flexible bases and pavement surface courses, respectively. The Phase II program which was performed on both unstabilized and stabilized glauconite and iron ore gravel is shown in Table 3.

Since electrical conductance and dielectric value are not standard tests, the procedures and significance of the results are discussed below.

Dielectric Value

The dielectric constant is a measure of a material's insulating capabilities and is equal to the ratio of the electrostatic capacity of condenser plates separated by the given material to that of the same condenser with a perfect vacuum between the plates. Typical dielectric constant values for highway materials are tabulated in Table 4 (2):

It is interesting to note that water, in the stable crystalline ice form, has a low dielectric; whereas, in liquid form, its value is 81. The presence of non-frozen (non-absorbed) water within any pavement material, whether asphalt concrete, Portland cement concrete, or flexible base, will have a major impact on the material's composite dielectric. Clearly, the higher the "free" or unbound water content, the higher will be the material's dielectric value.

Table 1. Tests Often Used to Characterize Flexible Base Materials - Phase I.

Test Name or TxDOT Designation	Brief Description of Test
Tex-103-E	Moisture Content
Tex-104-E	Liquid Limit
Tex-106-E	Plasticity Index
Tex-107-E, Part II	Bar Linear Shrinkage
Tex-110-E	Sieve Analysis
Tex-113-E	Moisture-Density Determination
Tex-116-E	Wet Ball Mill
Tex-117-E	Triaxial Tests
Electrical Conductance	Related to material's propensity to attract and hold moisture and to the concentration of soluble salts
Dielectric Value	Related to material's propensity to attract and hold moisture and to the concentration of soluble salts

Table 2. Typical TxDOT Tests for Aggregates Used in Surface Courses - Phase I.

TxDOT Test	Brief Description
Tex-217-F, Part I & II	Deleterious Material & Decantation for Coarse Aggregate
Tex-224-F	Flakiness Index
Tex-410-A	Los Angeles Abrasion
Tex-411-A	Sulfate Soundness Test
Tex-460-A	Crushed Face Particle Count

Table 3. Summary of Test Program for Stabilized Glauconite and Iron Ore Gravel - Phase II.

Test*	Purpose	Additive Type and %
Electrical Conductivity	Durability	No Additive Cement - 3% Lime - 3% Lime + Fly Ash - 2%/2%
Dielectric Value	Durability	No Additive Cement - 3% Lime - 3% Lime + Fly Ash - 2%/2%
TxDOT Triaxial Tex-117-E	Strength	No Additive Cement - 3% Lime - 3% Lime + Fly Ash - 2%/2%
Petrographic thin-section analysis	Durability-presence of deleterious reactions	No Additive Cement - 3% Lime - 3% Lime + Fly Ash - 2%/2%

* All tests were performed on unstabilized and stabilized glauconite from Welch's Pit, Welch's Ford's Corner Pit, and iron ore gravel.

Table 4. Typical Dielectric Constant Values.

Material	Dielectric Constant
Vacuum	1.0
Air	1.0
Asphalt	2.1
Dry Aggregates	4-6
Asphaltic Concrete	5-7
Portland Cement Concrete	7-9
Flexible Base	6-20 (depends on moisture content)
Subgrades	10-25 (depends on moisture content)
Water	81
Ice	3-4

FINDINGS

Phase I - Unstabilized Glauconite

Representative samples of aggregates weighing several hundred kilograms were collected at Welch's Pit and Welch's Ford's Corner quarries representing relatively soft and hard materials. Researchers performed several tests to characterize the materials. The findings are presented in Tables 5 and 6 and Figures 1 through 3.

Gradations of the materials obtained were measured in accordance with Tex-110-E. The harder Welch's Ford's Corner material is shown to have the finer gradation (Figure 1). However, considerable variation in gradation is inherent since these are not sized materials.

Results of several laboratory tests performed on the aggregate are summarized in Table 5 along with values specified by TxDOT. The liquid limit of these materials exceeds the specified value for Item 247, Grade 1 flexible base but meets the criteria for Grade 2 flexible base. However, the plasticity index of the minus 425 μm is quite low for both the hard and soft materials.

The in situ moisture contents in the stockpiles were quite high. This is because these bulk materials and individual particles are permeable and capable of absorbing fairly large amounts of water. It should be noted that rainfall had occurred daily for several days immediately prior to the researcher's visit to the sites. In fact, some rain occurred on the day the aggregates were sampled.

Table 5. Test Results on Unstabilized Glauconite - Phase I.

Test	Quarry Source		Values Specified by TxDOT	
	Welch's Pit	Welch's Fords Corner	Grade 1 Flex Base	Grade 2 Flex Base
Liquid Limit	36	35	35 max	40 max
Plastic Index	4	2	10 max	12 max
Stockpile Moisture Content, %	21	22	---	---
Linear Shrinkage, %	2.5	1.5	2 min	2 min
Wet Ball, %	56	45	40 max	45 max
Flakiness Index, %	6	8	17 max	17 max
Los Angles Abrasion, % Loss	78	72	35 max	35 max
Sulfate Soundness, % Loss	24.3	10.8	25 max	25 max
Crushed Particle Count, %	100	100	---	---
Sulfate Content, ppm (saturated paste)	250	214	---	---
Sulphur Content, ppm	120	160	---	---
Dielectric Value after >300 hours	30	25	---	---

Table 6. Results of Triaxial Tests (Tex-117-E) on Glauconite Materials - Phase I.

Sample Type	Confining Pressure, kPa	Failure Stress, kPa	Failure Strain, %
Welch's Pit	0	191	0.9
		203	0.79
		191	1.03
		Avg. 195**	**Avg. 0.91**
	103	846	1.99
		775	2.04
		852	2.39
		Avg. 824**	**Avg. 2.14**
Welch's Ford's Corner	0	259	1.72
		248	1.43
		257	1.60
		Avg. 255*	**Avg. 1.58**
	103	894	2.66
		906	2.68
		1059	2.71
		Avg. 953**	**Avg. 2.68**
TxDOT Specifications for Flexible Base - Item 247	Grade 1 @ 0 kPa	310 minimum	---
	Grade 1 @ 103 kPa	1206 minimum	---
	Grade 2 @ 0 kPa	241 minimum	---
	Grade 2 @ 103 kPa	1206 minimum	---
	Grade 3	Unspecified	---

* An asterisk following the failure strength indicates the product did not meet the individual TxDOT Item 247 Specification for Grade 1 flexible base. Two asterisks mean the product did not meet the specification for Grade 1 or 2.

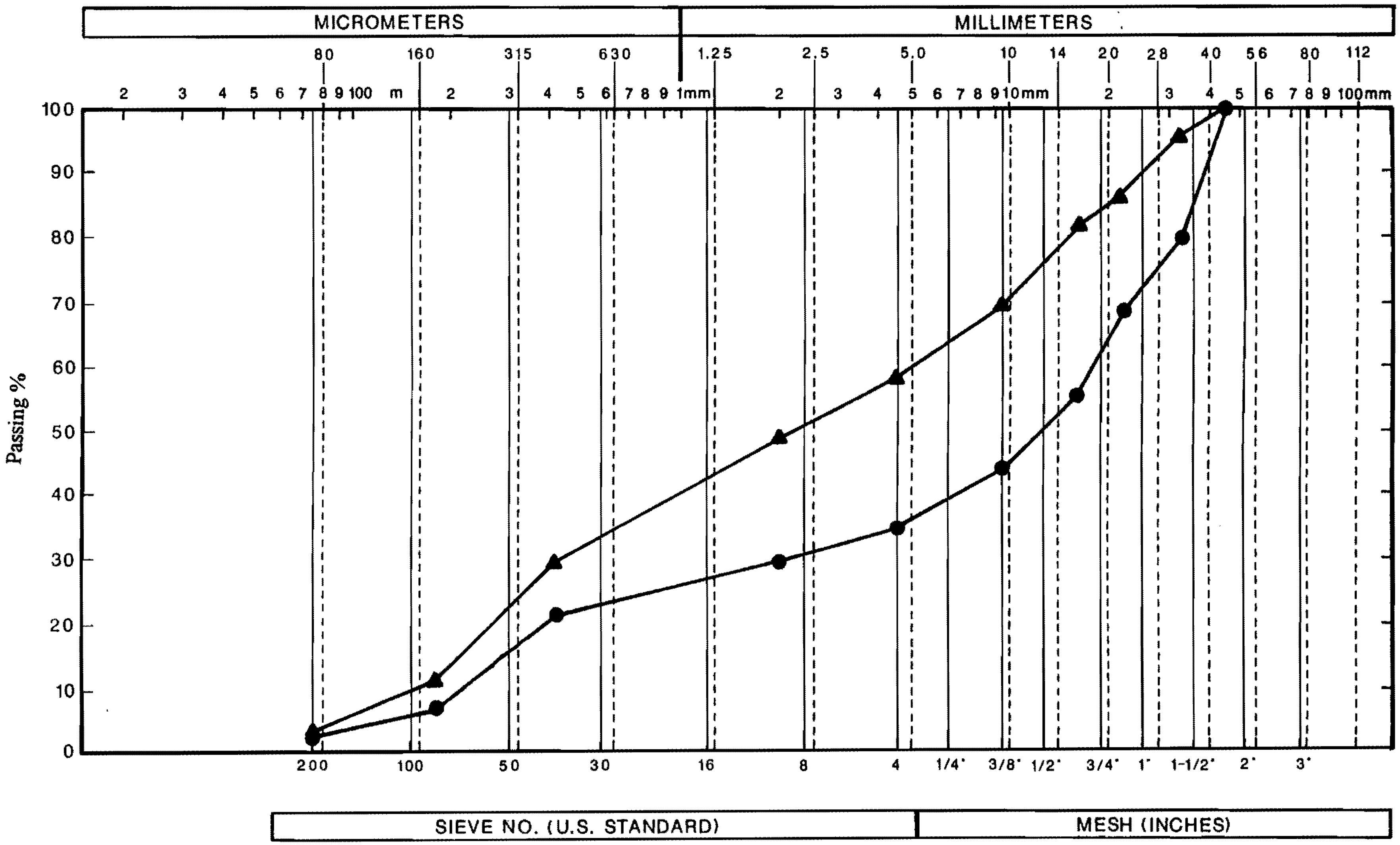

Figure 1. Gradation of Welch Pit Materials as Obtained at the Quarry.

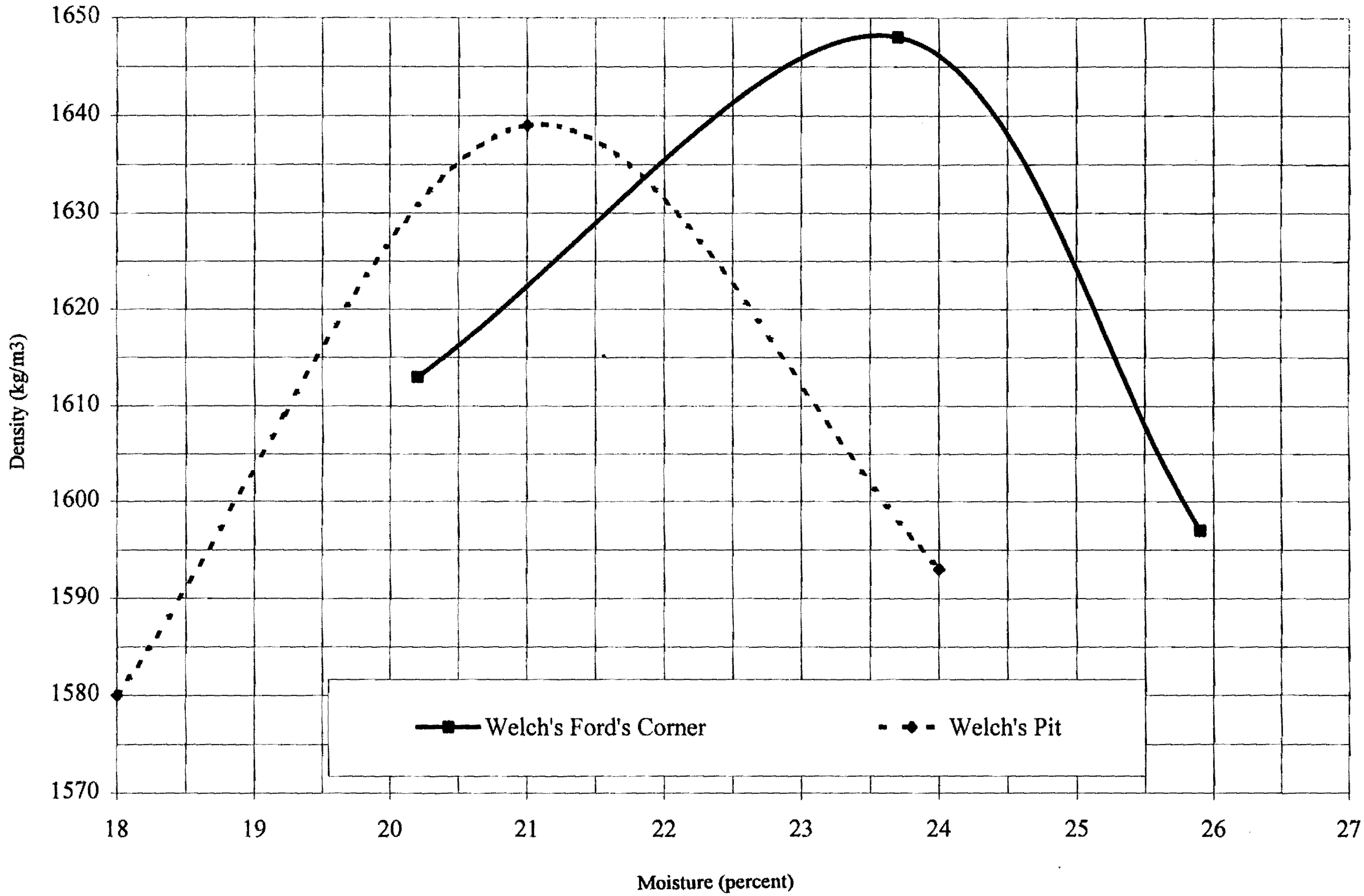

Figure 2. Moisture-Density Curve for Welch's Pit and Welch's Ford's Corner Material.

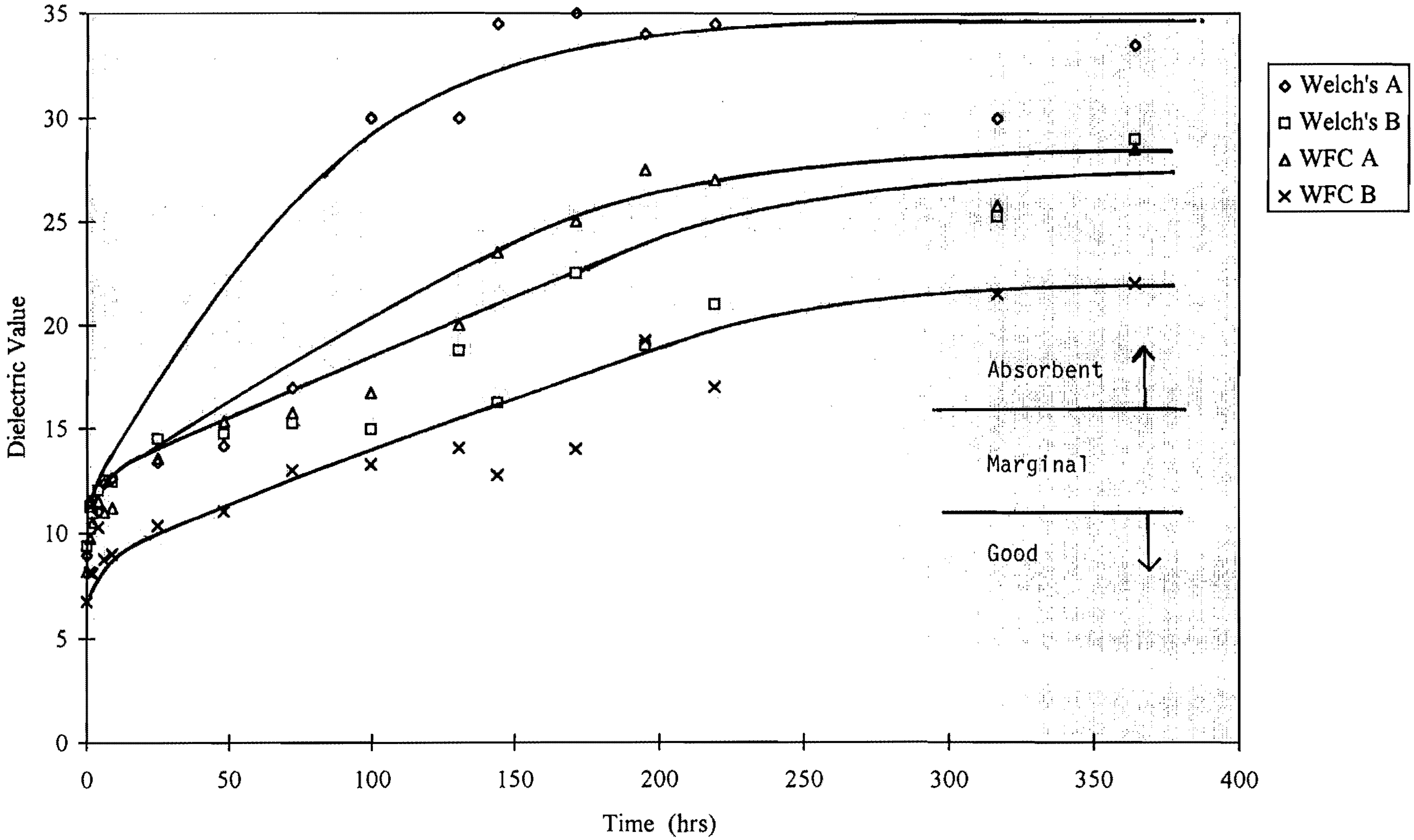

Figure 3. Dielectric Values Versus Time for Replicate Samples of Soft and Hard Glauconite Materials.

The high porosity and absorption of these materials is also evinced by the relatively high optimum moisture contents for compaction and the relatively low compacted densities (Figure 2). These properties are usually indicative of low strengths and poor durability.

The wet ball mill values and the Los Angeles abrasion values show that glauconite exhibits very poor resistance to abrasion. In fact, it does not conform to typical specified values for these tests (Table 5).

Flakiness Index testing indicated that both glauconite products tested passed the specifications required by TxDOT for flexible base (Table 5).

Sulfate Soundness of the softer Welch's Pit material scarcely meets the value specified by TxDOT for base materials. However, the Welch's Ford's Corner pit material easily passed the specifications.

Sulfur content and sulfate content of both glauconite materials were measured using chemical methods. Sulfur and sulfate contents are quite low and, as a result, should not present any swelling problems when stabilizing these materials with hydrated lime or Portland cement. Some soils and aggregate sources in the Lufkin District and in this region of east Texas, in general, have relatively high concentrations of total sulfur or pyritic sulfur. The presence of pyritic sulfur can lead to the formation of acidic conditions during the oxidation process and to the formation of sulfate. Acidic conditions can inhibit the development of strength through pozzolonic reactions (lime and lime+fly ash) or through cementation reactions (Portland cement). Furthermore, high sulfate contents can lead to an attack on the stabilization product which can not only lead to strength loss and stabilization reversals but also to significant swell.

Average dielectric values for replicate tests on the soft and hard glauconites were 30 and 25, respectively, after 300+ hours of exposure (Table 5 and Figure 3). Based on past experience, a value above 16 indicates the material will readily absorb water and is thus quite susceptible to freeze-thaw damage, and a value below 10 is indicative of a high quality, nonabsorptive material. Therefore, these glauconite products should not be used in pavement layers where freezing and thawing is probable. Further, these high dielectric values indicate that glauconite should be chemically stabilized to reduce the probability of moisture-related problems when used in roadway bases.

Results from triaxial testing indicate the harder Welch's Ford's Corner material always yielded

Summary of Experience of Glauconite Users

Several users of glauconite were interviewed by telephone. Most of these individuals used glauconite for unpaved county roads or for unpaved roads to oil well sites and pads for oil well equipment. Only one county commissioner stated he paved (using a bituminous surface treatment) over glauconite. A few have stabilized glauconite with cement. The primary reason stated for using glauconite is that iron ore gravel is no longer available and hauling in limestone is quite expensive.

Some specific problems associated with glauconite by the individuals interviewed include the following:

- Glauconite exhibits much variability within a quarry and between quarries;
- Glauconite requires large amounts of water for optimum working and compaction;
- When saturated, glauconite becomes soft and does not support loads of vehicular traffic and construction equipment;
- Glauconite is so soft that a road grader readily cuts up the larger aggregate particles, thus reducing its effectiveness;
- Glauconite cannot support tracked vehicle construction traffic without crushing and grinding;
- In service, glauconite will eventually be ground up by traffic and wash or blow away; and
- Glauconite does not bridge a soft subgrade as well as limestone.

Phase II - Stabilized Glauconite and Iron Ore Gravel

Samples of aggregates from the Welch's quarry and the Welch's Ford's Corner quarry similar to those used in Phase I were used in Phase II study. The findings are summarized in Figures 4 through 7 and Table 7.

Average dielectric values after 300+ hours of exposure for replicate tests on the unstabilized and stabilized glauconite and iron ore gravel are shown in Figure 4. Stabilization of either glauconite product is shown to improve the dielectric value. As expected, Portland cement consistently lowered the dielectric value better than lime or lime+fly ash; however, none of the stabilizers at the concentrations used lowered the dielectric value below 17. As mentioned earlier, a dielectric value above 16 indicates the material will readily absorb water, and a value below 10 is indicative of a high quality, low absorption concentrations used lowered the dielectric value below 17. As mentioned earlier, a dielectric value above 16 indicates the material will readily absorb water, and a value below 10 is indicative of a high quality, low absorption capacity material. It appears that more than 3% cement is required to lower the absorption capacity of glauconite to an acceptable value. However, higher cement contents might lead to excessive shrinkage and thus reflective cracking in the overlying pavement.

Figure 4 also shows dielectric values for iron ore gravel. The dielectric value for unstabilized iron ore gravel is well below the value of 10 which indicates a low absorption material. All of the stabilizers further lower this value. By comparison, glauconite is much more likely than iron ore gravel to absorb water, and thus to lose shear strength and/or to sustain damage by freezing and thawing.

Electrical conductivity values after 300+ hours of exposure, which were measured to compute dielectric value, are presented in Figure 5. These values show a large difference between unstabilized and stabilized glauconite and between glauconite and iron ore gravel. Electrical conductivity for all three stabilized iron ore materials was zero. One might assume that the reason for these large differences between glauconite and iron ore gravel is more dissolved salts in the glauconite. However, examination of Figure 6 shows that the glauconite specimens absorbed much more water than the iron ore gravel. The mere presence of the water is the major contributor of the higher values of electrical conductivity and dielectric.

Results of triaxial tests on the unstabilized (control) and stabilized materials at zero confining pressure and 25°C indicate that all three unstabilized materials met TxDOT's strength requirements for a Grade 2 flexible base but not those for a Grade 1 flexible base (Table 6 and Figure 7). Stabilization of all three materials with 3% Portland cement yielded marked increases in failure stress above those for the unstabilized aggregates. Lime+fly ash offered some increase with all three materials. Hydrated lime alone provided almost no increase in strength for the glauconite but provided a significant increase for the iron ore gravel. This indicates the glauconite contains very little clay; whereas, the iron ore gravel probably contains some clay.

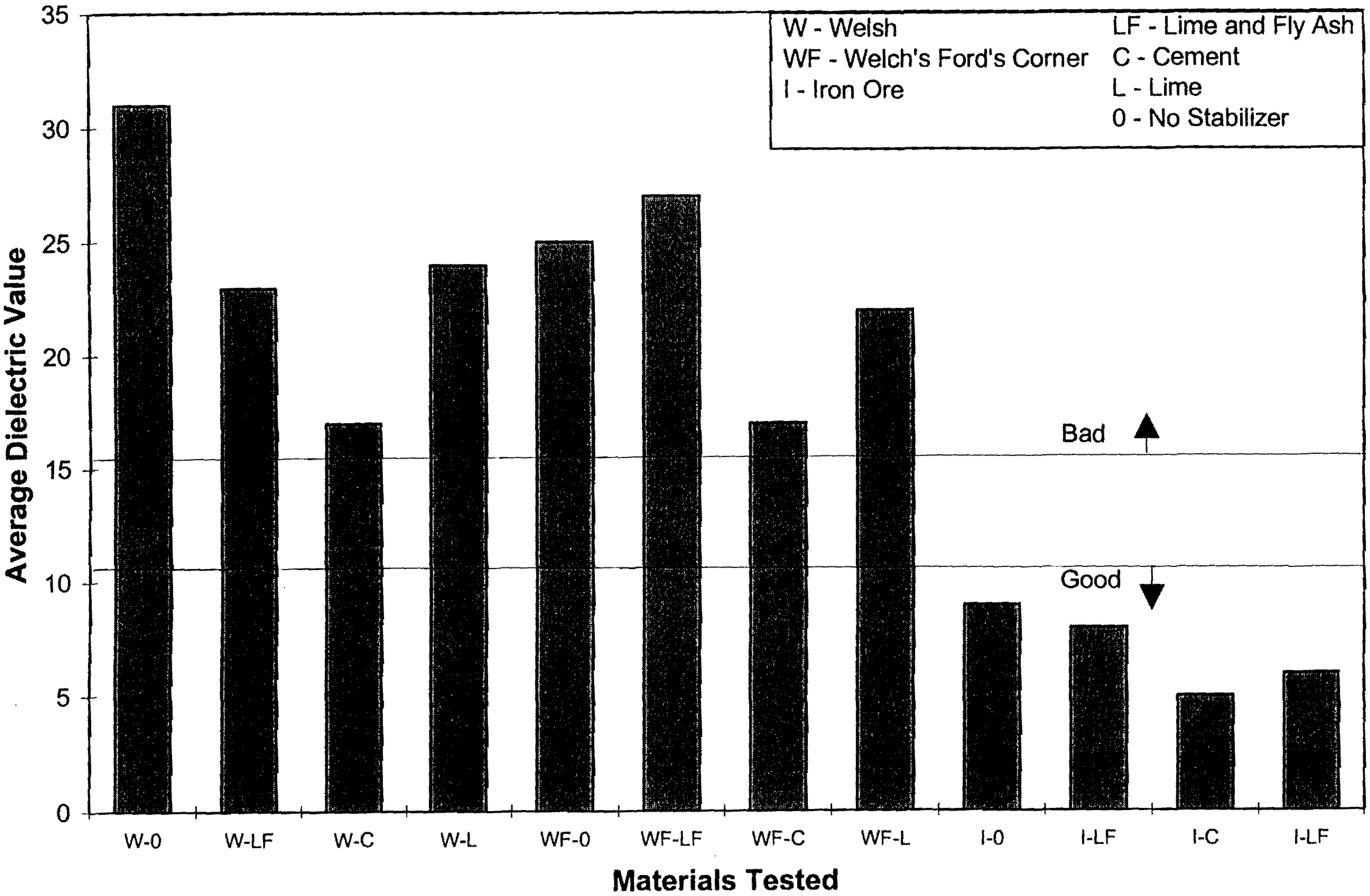

Figure 4. Average Dielectric Values After 345 Hours of Sitting in Water.

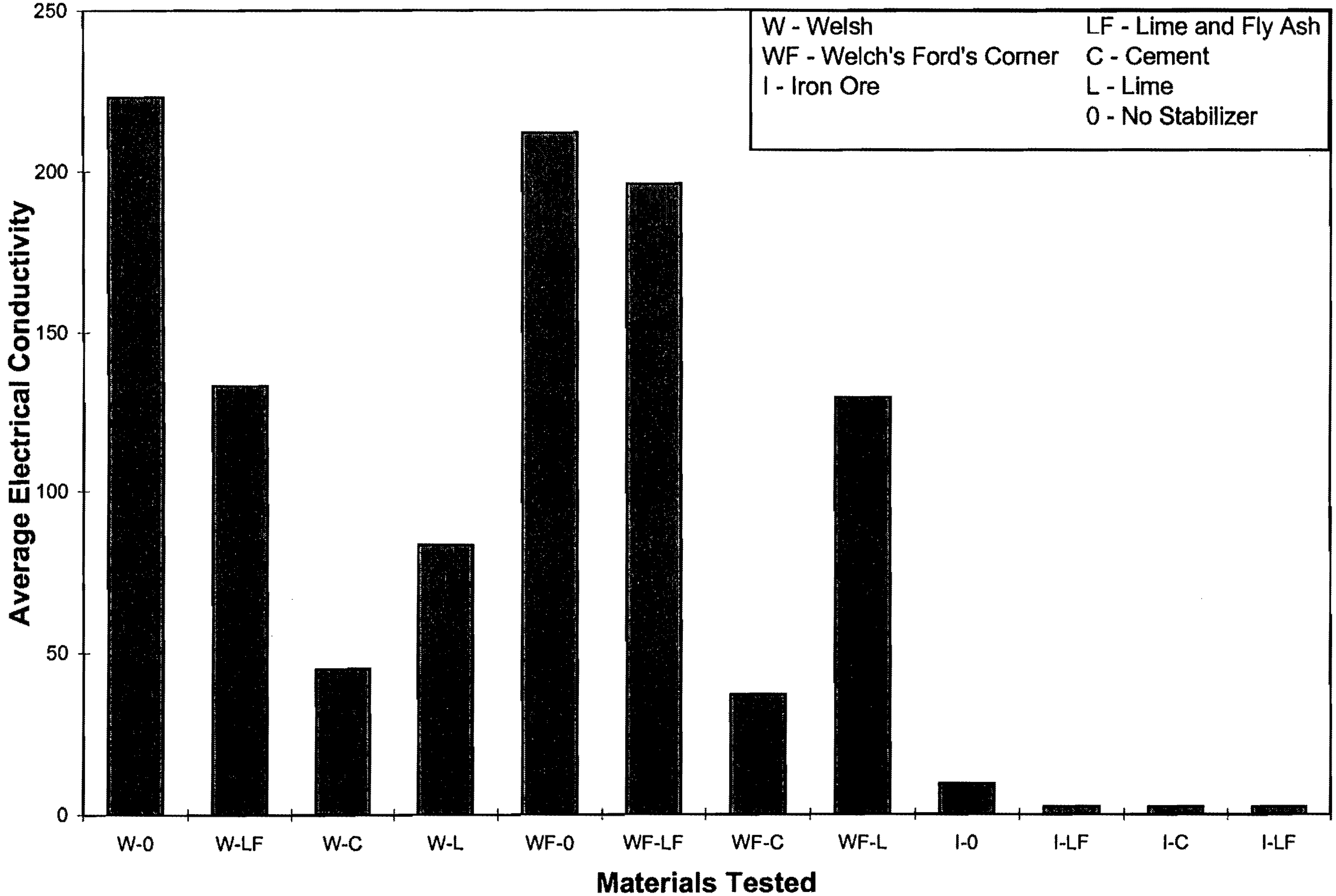

Figure 5. Average Electrical Conductivity Values After 345 Hours of Sitting in Water.

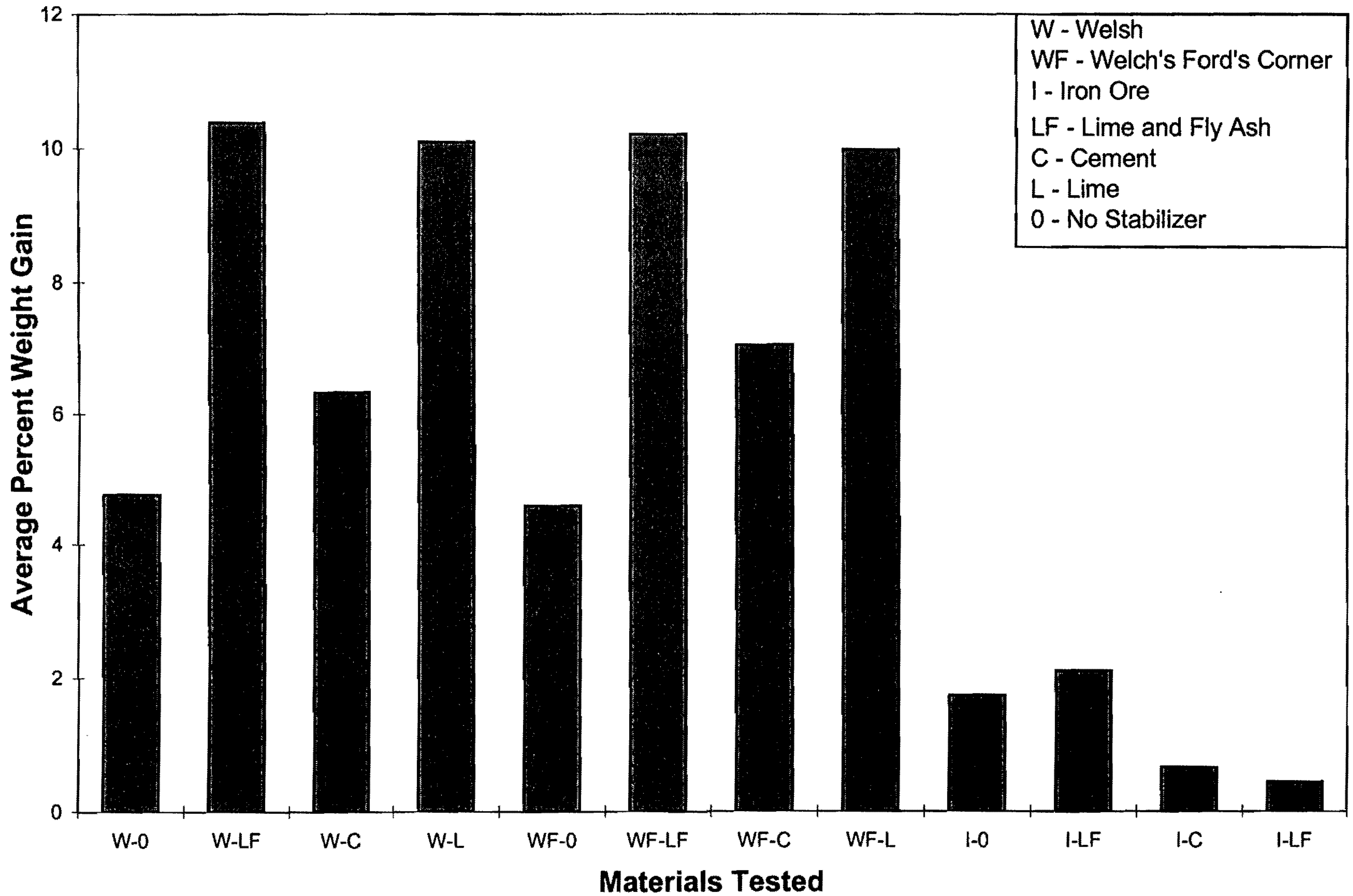

Figure 6. Average Weight Gain Due to Water Absorption After 345 Hours of Sitting in Water.

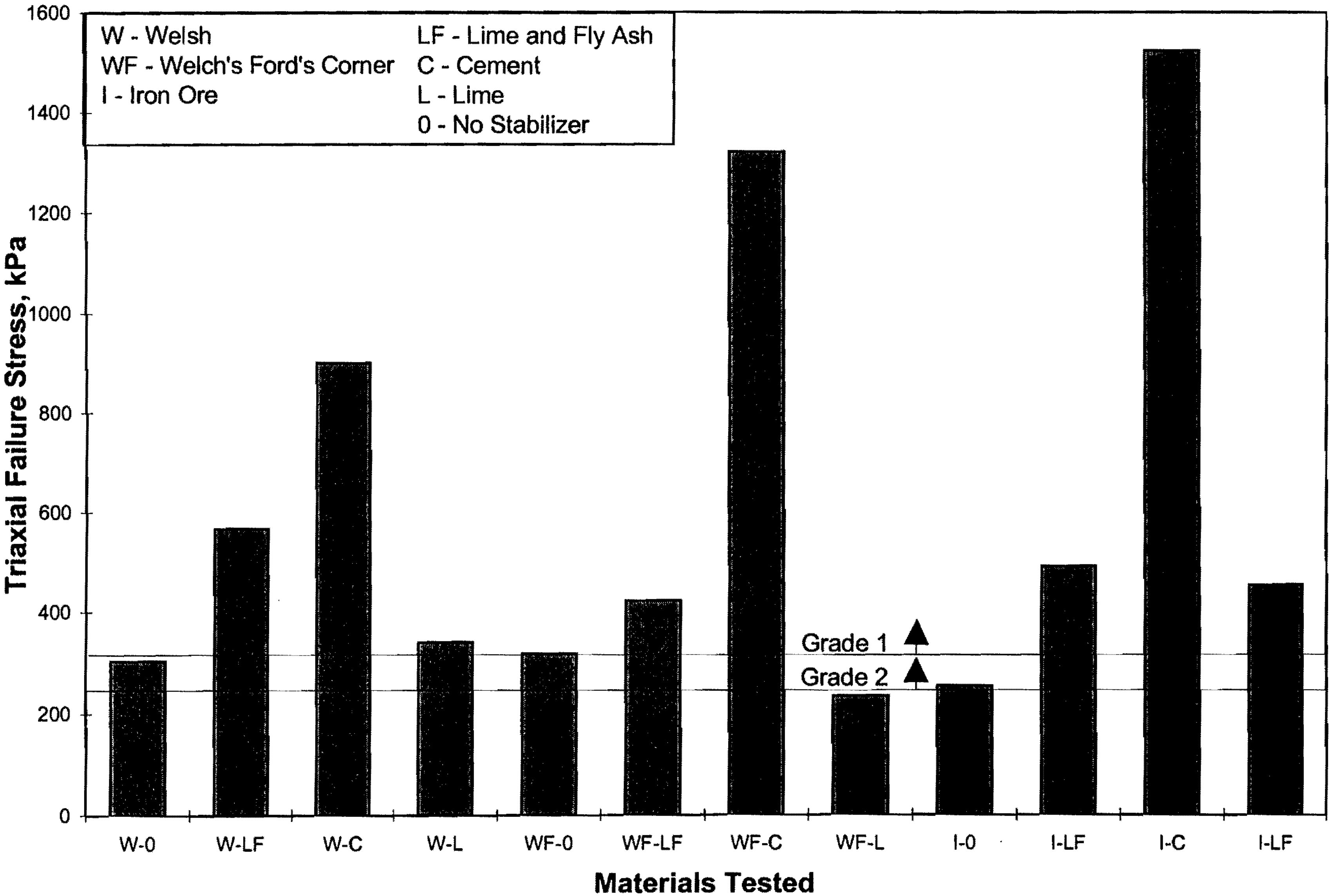

Figure 7. Average Triaxial Failure Stress for Unstabilized and Stabilized Materials.

Table 7. Results of Triaxial Tests (Tex-117-E) at Zero Confining Pressure on the Stabilized Materials - Phase II.

Sample Type	Failure Stress, kPa	Failure Strain, %
Welch's Control	321	2.51
	291	1.58
	Avg. 306*	**Avg. 2.04**
Welch's + Lime	341	1.18
	335	1.34
	Avg. 338	**Avg. 1.26**
Welch's + Lime+Fly Ash	394	1.16
	739	0.69
	Avg. 567	**Avg. 0.93**
Welch's + Cement	874	0.87
	931	1.06
	Avg. 903	**Avg. 0.97**
Welch' Fords Corner Control	297	331
	0.87	0.93
	Avg. 314	**Avg. 0.90**
Welch' Fords Corner + Lime	191	0.86
	278	0.87
	Avg. 235**	**Avg. 0.87**
Welch' Fords Corner + Lime+Fly Ash	429	1.24
	423	0.89
	Avg. 426	**Avg. 1.07**
Welch' Fords Corner + Cement	1416	0.85
	1238	0.84
	Avg. 1327	**Avg. 0.85**

Table 7. Results of Triaxial Tests (Tex-117-E) at Zero Confining Pressure on the Stabilized Materials - Phase II.

Sample Type	Failure Stress, kPa	Failure Strain, %
Iron Ore Gravel Control	230	1.36
	282	1.28
	Avg. 256*	**Avg. 1.32**
Iron Ore Gravel + Lime	474	0.82
	427	0.93
	Avg. 451	**Avg. 0.88**
Iron Ore Gravel + Lime+Fly Ash	542	0.96
	440	0.88
	Avg. 491	**Avg. 0.92**
Iron Ore Gravel + Cement	1552	0.57
	1515	1.70
	Avg. 1530	**Avg. 1.14**

* An asterisk following the failure strength indicates the product did not meet the individual TxDOT Item 247 Specification for Grade 1 flexible base. Two asterisks mean the product did not meet the specification for Grade 1 or 2.

CONCLUSIONS & RECOMMENDATIONS

Conclusions

Unstabilized and stabilized glauconite aggregates were tested using standard TxDOT procedures as well as non-standard procedures. The results were compared to specified values for flexible base (Item 247) and to results of similar tests on unstabilized and stabilized iron or gravel. Based on results of testing relatively soft and hard samples of glauconite in controlled laboratory experiments, the following conclusions are tendered:

1. Glauconite is likely to absorb and hold relatively high quantities of water. This will likely be detrimental to the ability of a pavement base to support heavy, repeated traffic loads particularly where frost penetration is probable. Although sulfate soundness tests exhibited passing values, the softer material was very near the specified maximum value.
2. Glauconite is soft and probably will not consistently meet TxDOT's requirements for the wet ball mill for Grade 2 flexible base.
3. The liquid limit of glauconite fines is relatively high and will not consistently pass specifications for flexible base. This further has a negative impact on linear shrinkage which also will not consistently meet specifications. However, the plasticity index is acceptable.
4. Neither the soft nor the hard glauconite products met the Item 247 requirements for triaxial testing.
5. Stabilization with portland cement yielded the best strength enhancements and resistance to moisture suction when compared to stabilization with lime+fly ash and hydrated lime.
6. Hydrated lime provided the least stabilization for glauconite. This is probably because glauconite contains little clay for pozzolonic activity.
7. Wide variability in glauconite properties manifests potential construction and performance problems related to quality control.
8. The low sulfur and sulfate contents indicate that lime or cement stabilization of glauconite should not result in heaving problems.

Recommendations

It is recommended that the routine use of glauconite on TxDOT roadways be avoided.

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