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# CLASSIFICATION OF ASPHALT EMULSION/AGGREGATE MIXTURE SYSTEMS BY COHESION TESTER MEASUREMENT OF SET AND CURE CHARACTERISTICS

by

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## INTRODUCTION

During construction, the primary concern of all bituminous contractors is the time required between application and trafficking. HMAC is a thermoplastic material whose time of trafficking depends upon the rate of cooling. Cut-back bitumens depend on the rate of solvent evaporation to determine the traffic time. When emulsions are used, however, the rate of cure or traffic time is a more complex phenomena but concerns primarily removal of water or removal of the effects of the presence of water in the mix.

In emulsified asphalt/dense-graded aggregate mixes such as slurry seal, chip mixes and emulsified asphalt stablized base mixes, the companion problems of "mix-time", "set-time", "water resistance", "traffic-time" and "cure-time" have plagued our industry from its beginnings; now, twenty-three years ago. What has been lacking, in my opinion, is an objective, precise definition of these characteristics; i.e., a way to measure and put hard numbers to these characteristics. This paper will be concerned only with measuring of the set-times and traffic-times during the curing process and to classify these characteristics. We will, for the first time, place hard numbers which should be universally understandable to these all important characteristics.

The measurement of mixing characteristics and the cohesive strength of completely cured mixes are very important but are separate studies and will not be discussed here.

We will present the subject by discussing: (a) a historical review of various approaches to the problem, (b) a description of the modified ASTM cohesion tester, (c) the modified cohesion test procedure, (d) information acquired, (e) definitions of system setting and curing characteristics, (f) a new system classification of emulsion-aggregate mixes and finally (g) we will present several examples of the uses of the cohesion tester for optimum emulsion formulation, optimum mix design and design for field variables.

## HISTORICAL REVIEW

At our 1969 Miami, Florida meeting, Charles G. Schmitz et. al. (1) presented in his paper "Practical Quick-Set Slurry Seal Coats" a modified blunt-nosed grease cone penetrometer (figure 1) to measure rate of cure of various slurry systems. Many curves (figure 2) were presented to show the effects of different aggregates, additives, fillers and temperature on the chemical set or relative cohesive strength or resistance to compaction by his penetrometer during the initial set and cure. However, no meaningful numbers were presented.

Les Harkness (2) introduced to us his Armak Dead Weight Power Steering Similator or Cohesion Tester at our El Paso meeting in 1971. He later reported to us at Mexico City in 1974 (3) and in the Armak Highway Chemical Newsletter of fall 1980 (4) (figure 3). His findings were essentially, that, in all the slurry systems tested, maximum cohesion is not reached until the water content of the curing mix reaches between 5 and 6%. He also reports the development of cohesive strength to be linear and proportional to the loss of water (figure 4).

Lee (5) in his extensive research "Laboratory Study of Slurry Seal Coats" shows that after an initial rapid loss of water, then only does the loss of water become linear (figure 5).

At our first World Congress held in Madrid, Spain in 1977, Pedro Ferree Franquet (6) presented in his paper, "The Influence of Bitumen Acidity in Cationic Slurry Seals", a "slurry penetrometer" (figure 6) the use of which generated data points showing the rate of curing or the rate of resistance to penetration. The resulting curves were meaningful demonstrators of the "rate of set or cure" but measure only very thick or atypical samples (figure 7). Note the similarity to Lee's evaporation curves but significant evaporation could not occur in the very thick and confined specimens used by Franquet. Clearly, the effect of water content is overcome by some "chemical" activity.

In ISSA's "Design Technical Bulletins-1978 and -1980" (7) the Schmitz-Chevron blotter method of determining set time and water resistance time is published as Technical Bulletin No. 102-76 "Mixing, Setting and Water Resistance Test to Identify Quick-Set Emulsified Asphalts. ISSA also issued in DTB-78 & 80 Technical Bulletin #116-78 "Specifications for Quick-Set Emulsified Asphalt Slurry Seal Systems" and the formalized Harkness-Armak method as Technical Bulletin #135-80 "Cure Time Measurement by Armak Cohesion Tester".

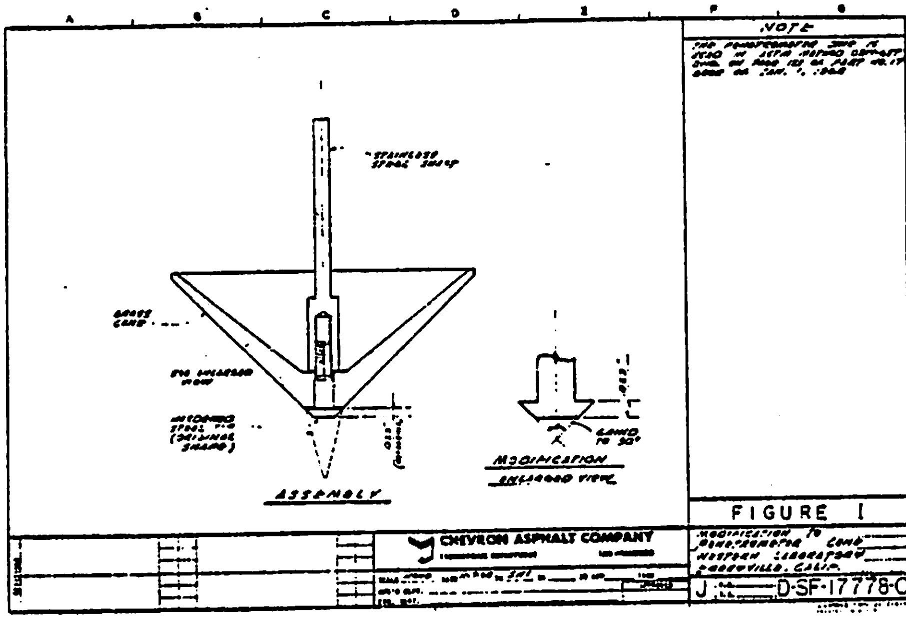



Fig. 1. V. Schmitz/Chevron
Blunt-nosed slurry penetrometer

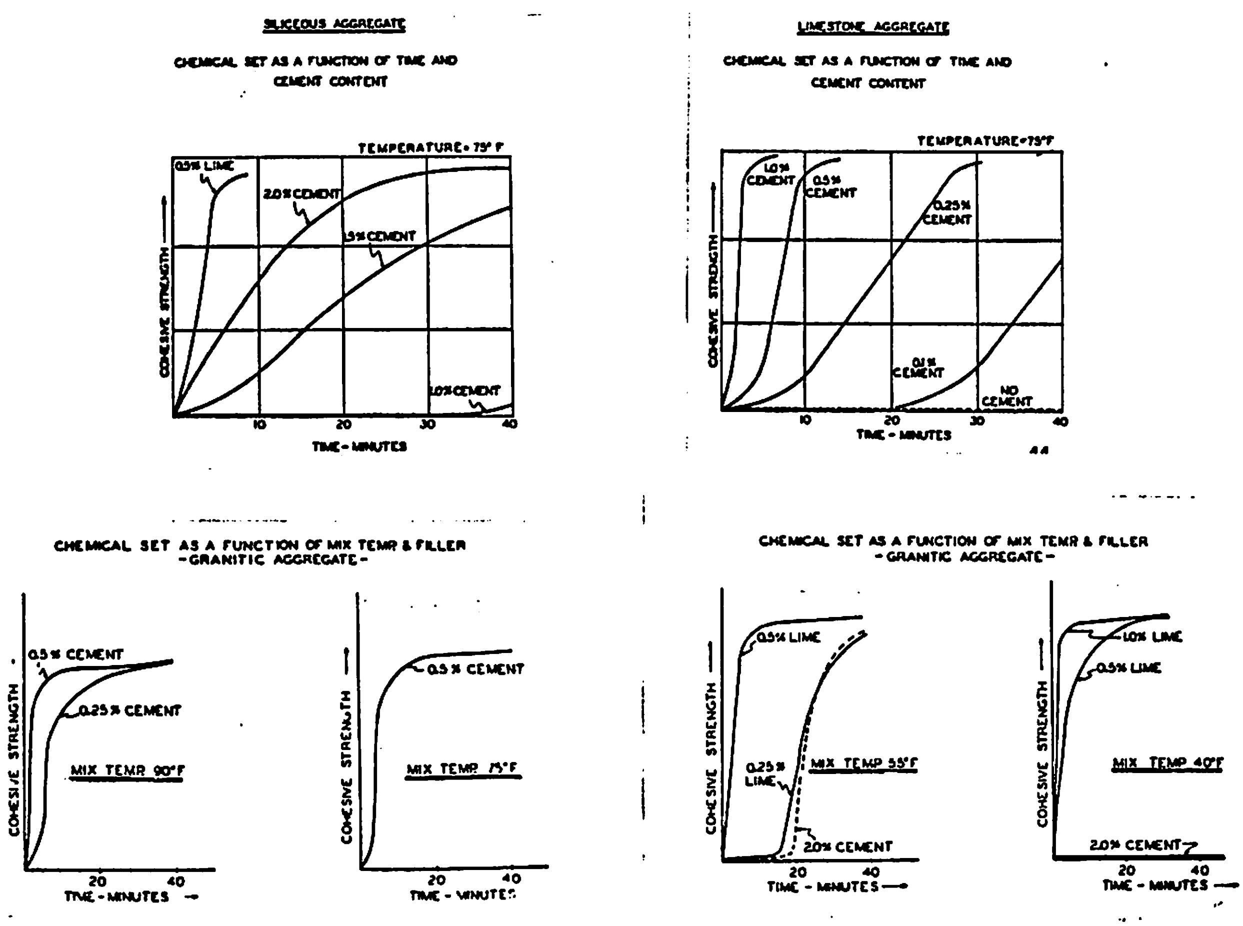



Fig. 2 Generalized slurry set curves (Schmitz 1969)

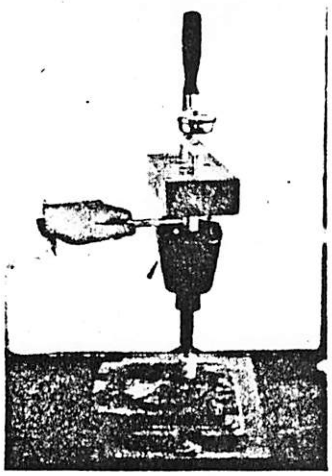



Fig. 3 ARMAK/Harkness Cohesion Tester

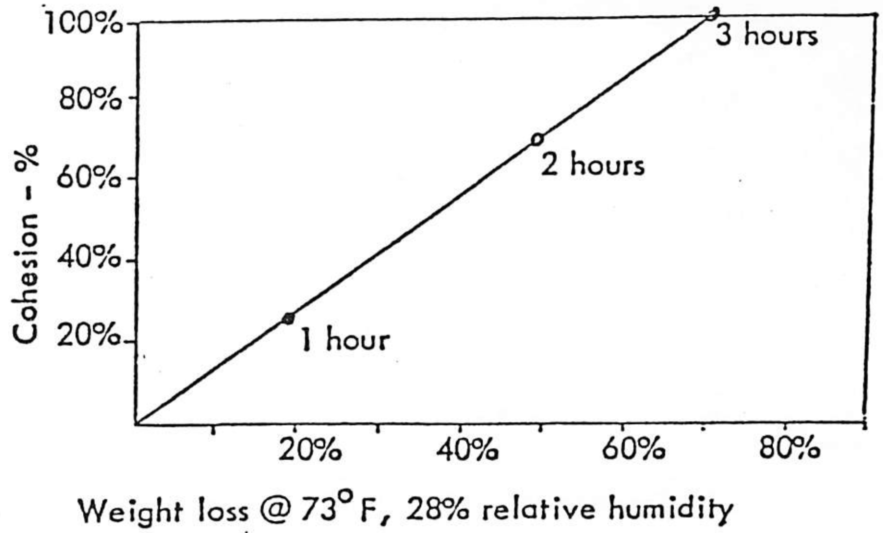



Fig. 4 Relationship between cohesion development and water loss in a typical ARMAK Slurry Formulation with Illinois limestone.

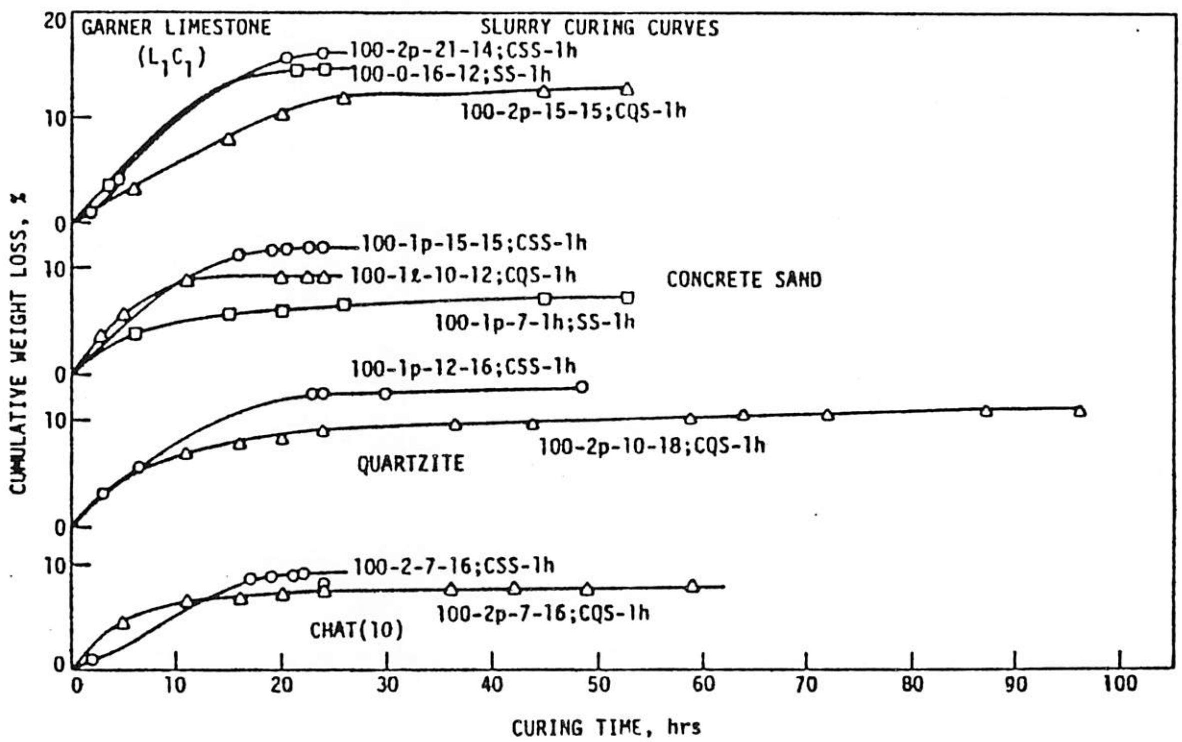



Fig. 5 Typical evaporative slurry curing curves (Lee)

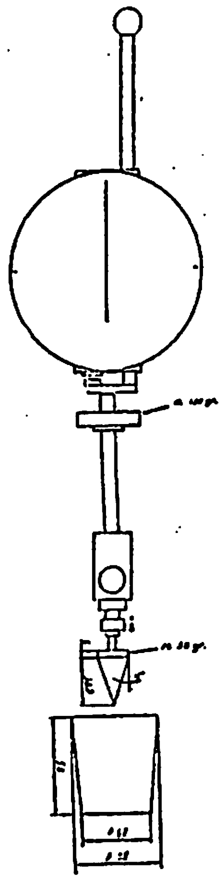


Fig. 6 Deep cup slurry penetrometer
(Feree Franquet 1977)

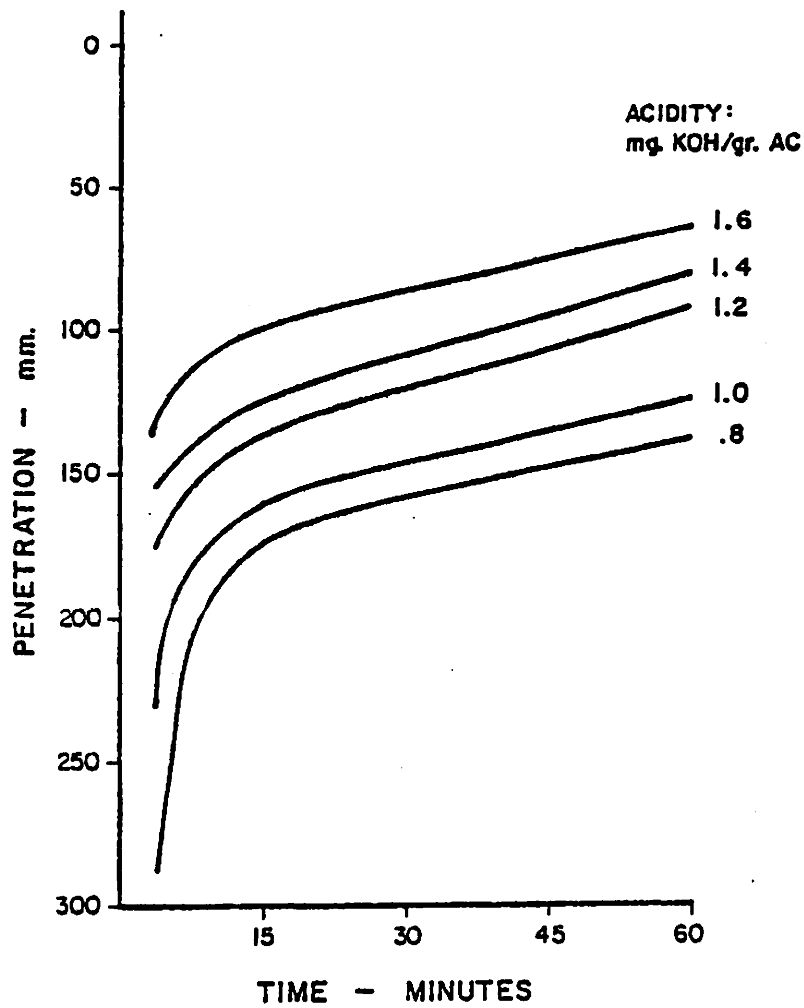



FIGURE 7. RATE OF CONE PENETRATION VS. BITUMEN ACIDITY

(Adapted from Pedro Feree Franquet, 1977)

This latter method has since been incorporated into ASTM D-3910-80a. (8), "Standard Practices for Design, Testing and Construction of Slurry Seal", where "cure-time" is defined as the time required "for the highest torque readings to remain constant".

A discussion of many approaches to the problem of set-time and cure-time titled "Quick-Set, Quick-Cure Slurry Seal Systems---State of the Art", (9) was presented to the 1978 Atlanta ISSA "Symposium QS QC Slurry System". (10) Many other useful references are contained in the symposium proceedings.

THE MODIFIED ASTM D-3910 COHESION TESTER

The modified cohesion tester (figure 8) consists essentially of (1) a frame, (2) instrument panel, (3) pressure gauge, (4) pressure regulator, (5) 4-way air valve and (6) a double-rod air cylinder mounted vertically so that a (7) rubber faced foot when lowered by air pressure against a specimen may be manually twisted to failure by a (8) peak-reading torque wrench.

Specimens are prepared and cast in a 60 mmØ mold. A 6 mm-deep mold is used for aggregates 100% passing the 4.75 mm (#4 or 3/16") sieve and a 10 mm-deep mold is used for aggregates 100% passing the 8 mm (5/16") sieve. The specimens are cast on 10 cm. (4") squares of non-absorbtive 15-pound bitumen saturated roofing felt. This felt has been used for specimen mountings of all the data presented in this paper.

The modified cohesion tester is similar to the Armak ASTM D 3910-80 machine except that it is designed for a constant regulated air supply, convenient 4-way cylinder valve to operate the cylinder at controlled rate of speed. The cylinder is larger and more rugged. The contact foot used here is a flat 1/4" neoprene disc of 50-60 durometer hardness, 1-1/8"Ø rather than a 1"Ø plug cut from an automobile tire. The procedures used may be found in Appendix A (ISSA Technical Bulletin TB #139 12/82). The pressure exerted on the foot is 92.3% of the gauge reading. The test pressure is set @ 200 kPa (28.44 psi) and the cylinder foot is lowered against the centered specimen and allowed to compact the specimen for 5 to 6 seconds. The torque meter is placed on the upper cylinder rod end and twisted by hand in a firm smooth horizontal motion through 90° to 120° of arc within .7 to 1.0 seconds. The maximum torque pointer is read and the results recorded, the foot raised and cleaned and torque pointer is reset.

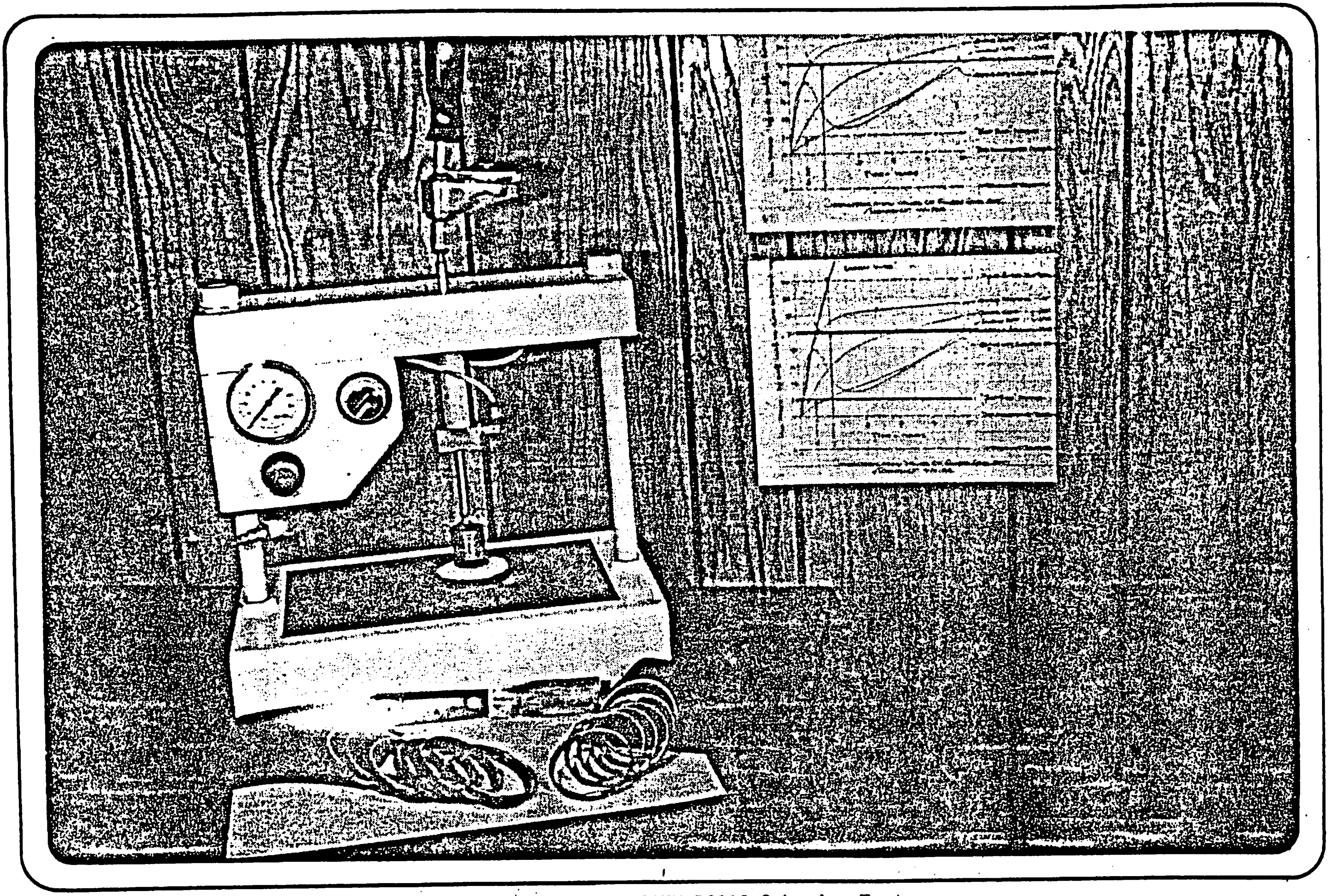


Figure 8: Modified ASTM D3910 Cohesion Tester

A series of specimens are prepared by casting a fresh mixture into 60 mmØ rings 6 or 10 mm thick and centered on a non-absorbent surface such as 10 cm. squares of 15-pound saturated roofing felt. The number of data points during a specified time span determines, of course, the number of specimens and amount of mix required.

Peak torques are recorded at 30, 60, 90, 120 minutes and so on. Moisture contents may be also determined for each test. The data acquired may be conveniently recorded on a data form (Appendix "A" ISSA Proposed TB #139) and on a graph form as in figure 9.

The vertical axis shows the torque as kilogram-centimeters or pound-inches at the 200 kPa pressure while the horizontal axis records time. Shown on the graph forms are torque values for:

1. Instrument limit
2. Fully cured slip torque
3. Assumed "early rolling traffic torque" of 20 kg-cm.
4. Calibration torque for 100 grit sand paper
5. Calibration torque for 220 grit sand paper
6. Assumed "set torque" of 12 kg-cm.
7. The torque value of the dry aggregate being tested
8. Ottowa sand 20-30 mesh
9. Friction free cylinder pressure torque

After all data is recorded, graphic plots may be made showing:

1. Torque-Time (rate of cohesive strength development in kg/cm or lb/in units)
2. Torque-Moisture (rate of wet strength development)
3. Moisture-Time (rate of moisture loss)

## "SET", "SET-TIME" AND "QUICK-SET SYSTEM" DEFINED

From our initial research we have observed that the "set" of any system, quick-set or slow-set, occurs at the 12 to 13 kg/cm torque level. Our old definition of the "set" of an emulsion aggregate system is: "The point in time where no free emulsion remains to lubricate the mixture or to stain blotter paper, is incapable of being re-mixed into a fluid mixture and is water resistant, and, upon depressing the specimen surface there is no horizontal displacement (the finger test)." Simply stated, the set time of an emulsion aggregate system is 12 kg/cm when measured by the modified cohesion tester.

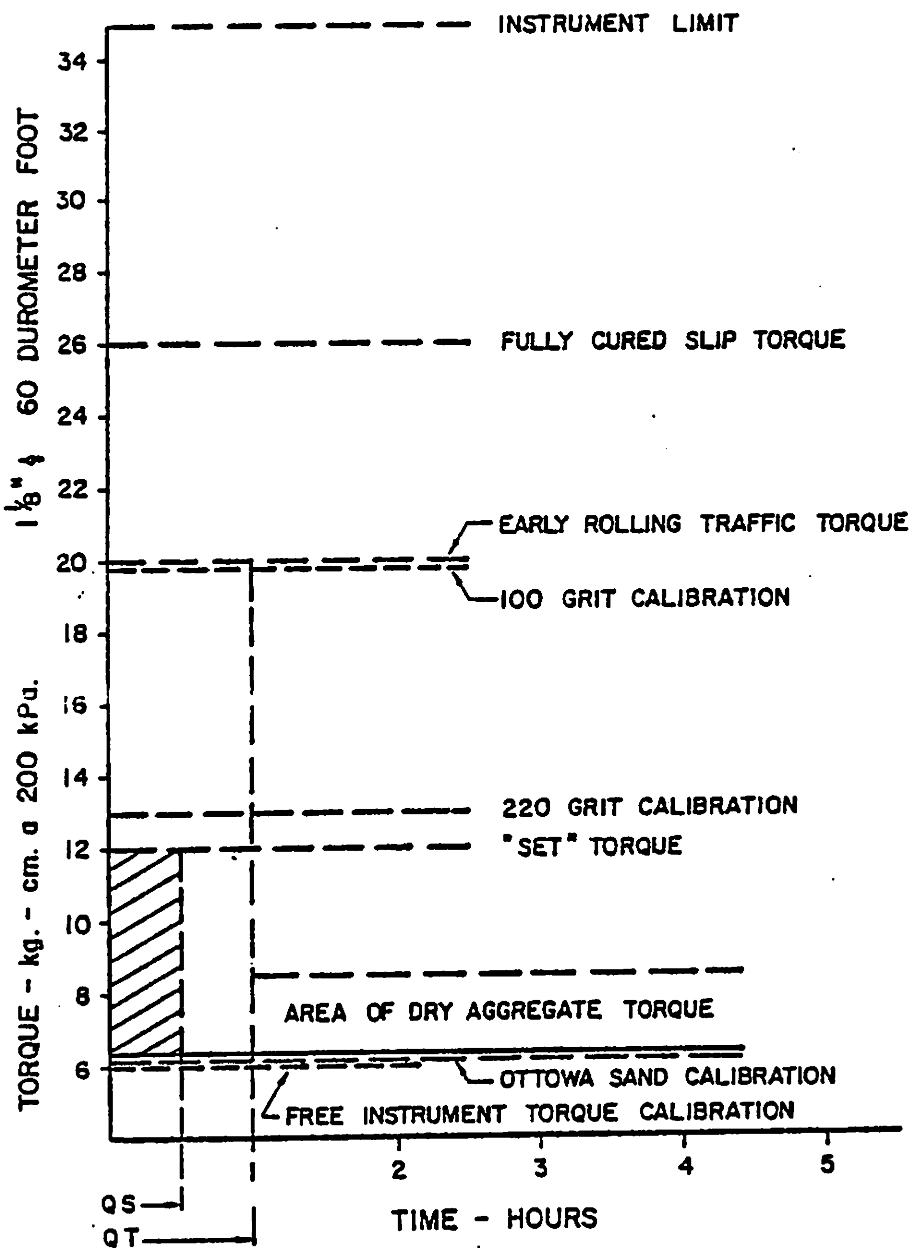



FIGURE 9. COHESION TESTER TORQUE LEVELS

By limiting the time required to reach a set, a quick-set system may be defined as bituminous emulsion/aggregate mixture which develops a cohesive strength of 12 kg/cm torque within 30 minutes.

## "TRAFFIC-TIME" AND "QUICK-TRAFFIC SYSTEM" DEFINED

Also, during our research we have observed that early rolling traffic may be supported by the freshly laid emulsion/aggregate system when the cohesive strength as measured by the modified cohesion tester reaches the 20-22 kg/cm torque level.

A Quick-Traffic System, then, may be defined as a bitumen emulsion-aggregate system which develops a cohesive strength of 20 kg/cm torque within 60 minutes.

Theses values of 12 and 20 kg/cm for set and early rolling traffic may be shown on the graph along with set and traffic time lines and calibration lines.

## CLASSIFICATION OF EMULSION-AGGREGATE MIX SYSTEMS

The generalized curves shown in (figure 10) represent 5 types or categories of cohesive strength development. All of the initial system curves investigated seem to fit into one of these generalized categories, which, using the previous definitions of set time and traffic time, may be termed:

1. SS - ST Slow Set - Slow Traffic
2. QS - ST Quick Set - Slow Traffic
3. FS - ST False Set - Slow Traffic (set relapse)
4. QS - QT Quick Set - Quick Traffic
5. QS - LQT Quick Set - Linear Quick Traffic

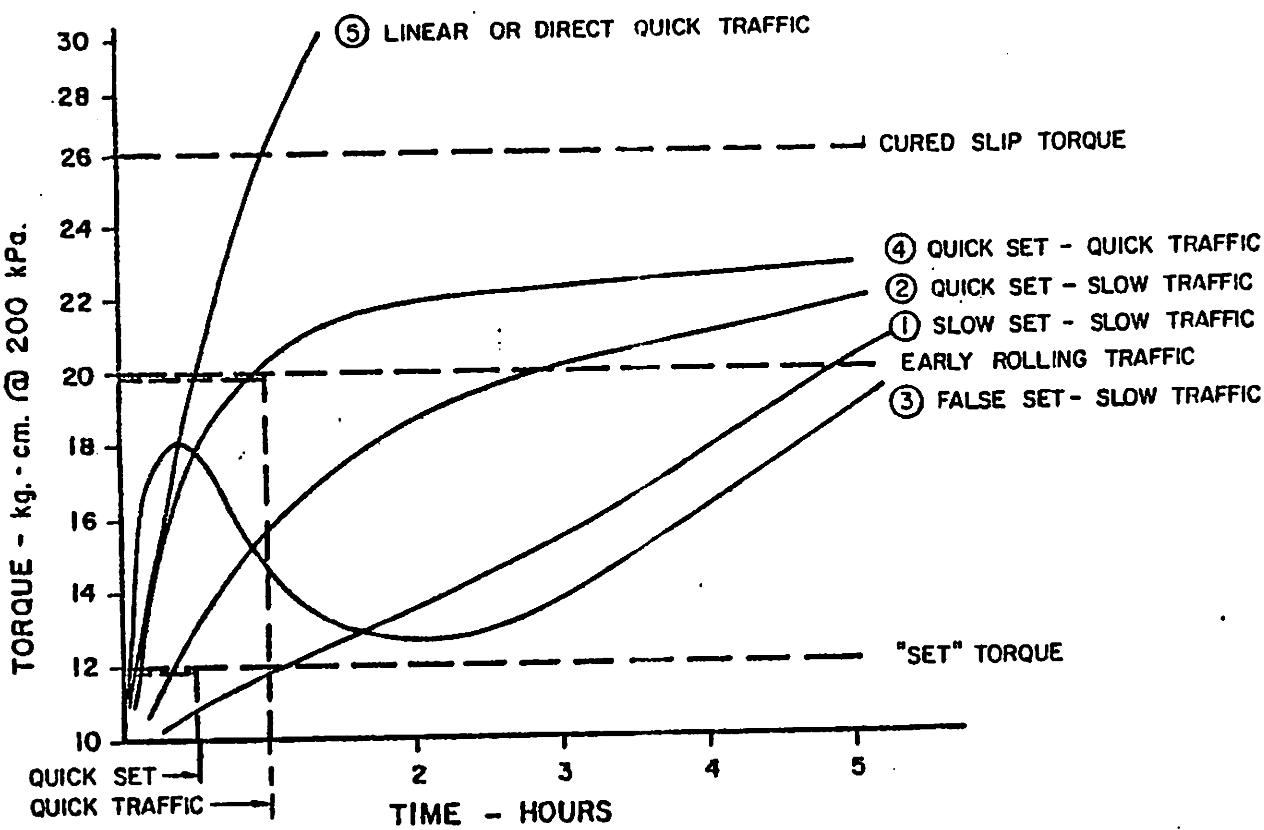



FIGURE 10. CLASSIFICATION OF MIX SYSTEMS BY MODIFIED COHESION TEST CURVES

## VARIABLES AFFECTING COHESION CURVES

As stated, the rate of set and traffic cure in emulsion mixes is a complex phenomenon. The following partial list of 28 variables shows the complexity. A small change in any one of these variables may affect the set and cure characteristics of a particular mix system---sometimes dramatically:

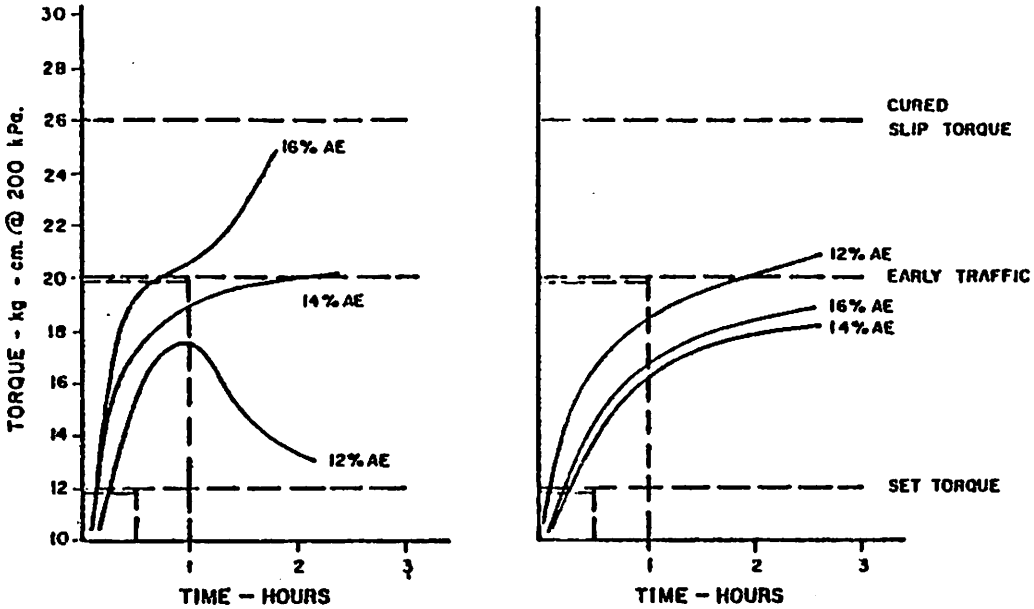
1. Bitumen type
2. Bitumen chemical activity or properties
3. Emulsifier type
4. Emulsifier concentration
5. pH of emulsifier
6. Emulsion particle size distribution
7. Emulsion age and stability
8. Viscosity-percent bitumen relationships
9. Bitumen emulsion design, % added to mixture
10. Aggregate chemical type
11. Aggregate chemistry or chemical reactivity
12. Aggregate gradation
13. Aggregate sand equivalent
14. Aggregate surface area
15. Aggregate impurities & contamination
16. Aggregate absorbtion, internal and external moisture
17. Mineral filler type (portland cement type, hydrated lime, Aluminum sulfate, etc.)
18. Concentration of mineral filler
19. Chemical additive type, accelerator, retarder, set initiator, etc.
20. Concentration of chemical additive
21. Mix water percent
22. Salts and organic impurities in water
23. Substrate surface absorbtion
24. Atmospheric temperature
25. Surface temperature
26. Humidity
27. External energy sources or lack thereof, sun, shade, base, wind
28. Mixing sequence, mixing time and shear exposure

The preponderance of variables may help to explain why emulsion manufacturing and its application remains an art requiring constant subjective judgments.

## USES OF THE COHESION TESTER

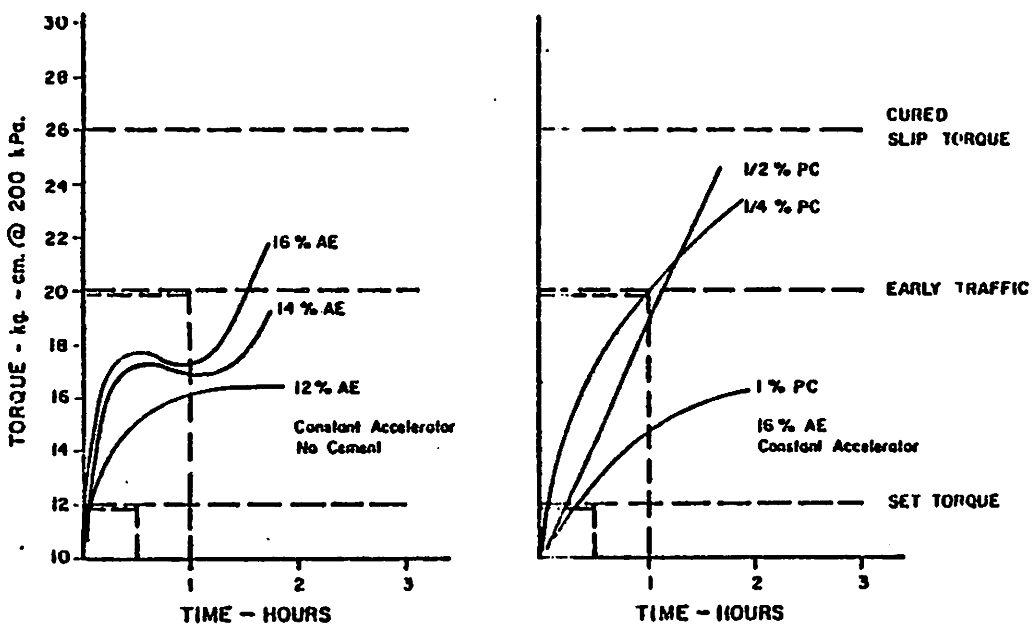
The most important fact we have demonstrated in our initial research is that each system is its "own thing". That is, there are no hard universal facts that can be applied to all systems. Further, there is no such thing as a "quick-set emulsion". There are, however, "quick set" or "quick traffic" emulsion-aggregate mixture systems. That is, the set and traffic times are dependent on the interaction of all the ingredients of a particular system.

The following twelve examples are used to illustrate this assertion as well as to show how the cohesion tester may be used to help formulate an emulsion and to design an emulsion-aggregate system to achieve a given set time or traffic time requirement or to compensate for field variables.



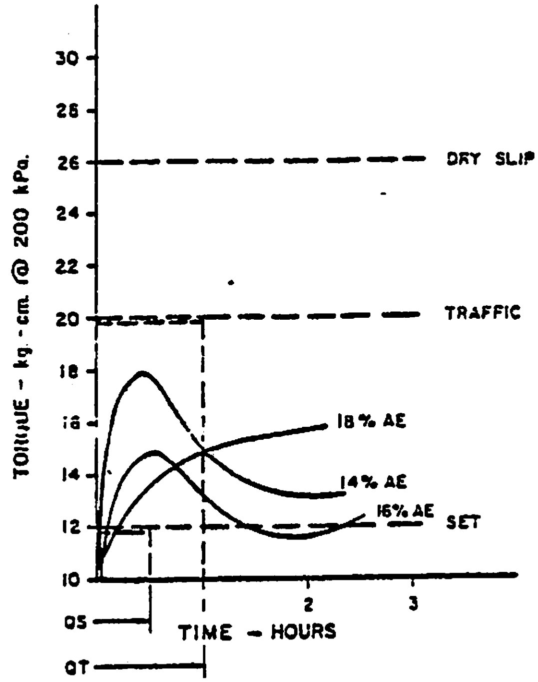

EXAMPLE 1. EFFECT OF EMULSION CONTENT ON TRAFFIC TIME

The design of slurry seal requires an adjustment in AC quantity for various traffic counts; i.e., higher traffic count designs require lower emulsion quantities. Example 1 a. shows a satisfactory traffic time of 40-60 minutes at 16% emulsion but when it becomes necessary to reduce the emulsion content to 12% the traffic time vanishes. Example 1 b. shows the reverse phenomena, i.e., a reduction AE content improves the traffic time.



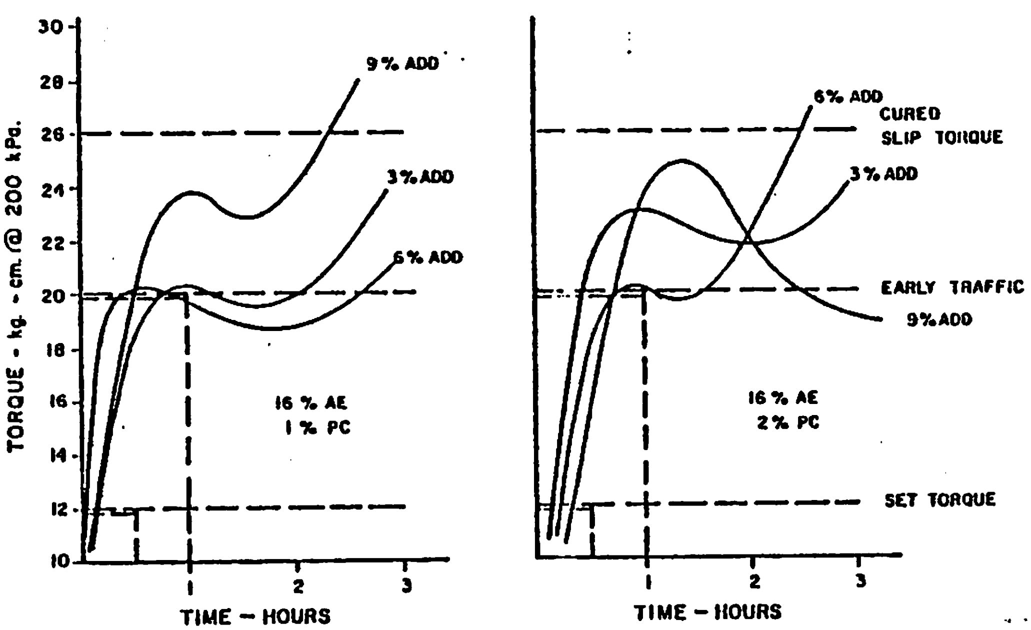

EXAMPLE 2. EFFECT OF FILLER CONTENT ON TRAFFIC TIME

Example 2 a. shows a similar effect to 1 a. where reduced AE gives reduced traffic time when no cement is used. The same emulsion used in example 2 a. with ¼% portland cement added gives a satisfactory traffic time, or when 1% PC is added gives a very poor result(2 b.).



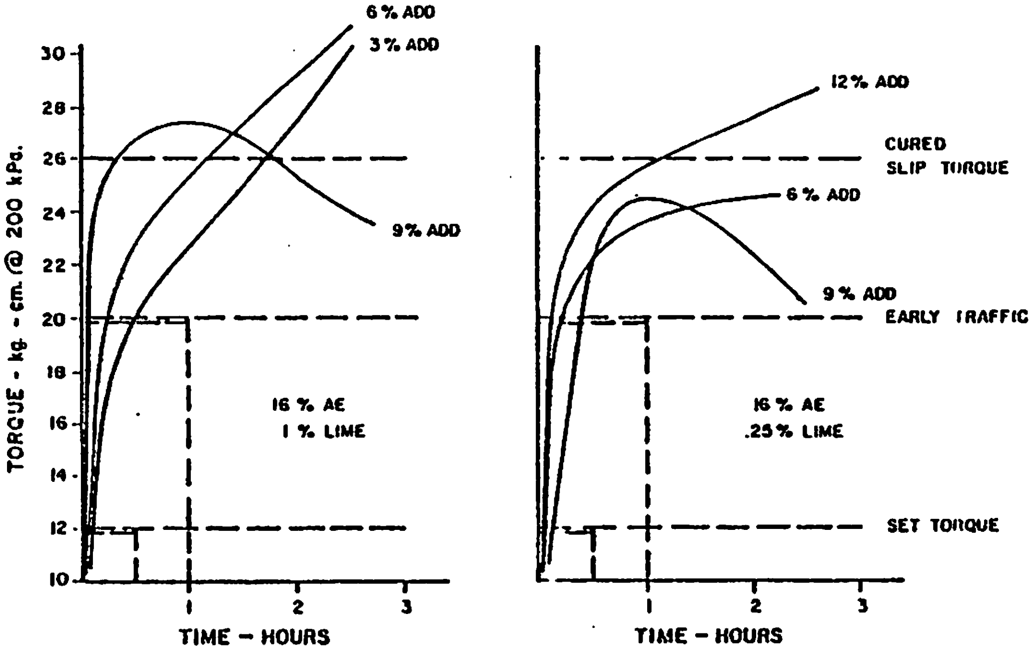

EXAMPLE 3. FALSE SET AND EFFECT OF AE CONTENT

Example 3 may boggle one's mind where the lowest AE %, 14%, sets very quickly but shortly suffers a relapse of set while at 18% AE a somewhat steadier increase in strength occurs. This particular configuration---The "false set" has been indentified with severe low temperature coalescense problems and the subsequent loss of all slurry after wintering through repeated freeze-thaw cycles.



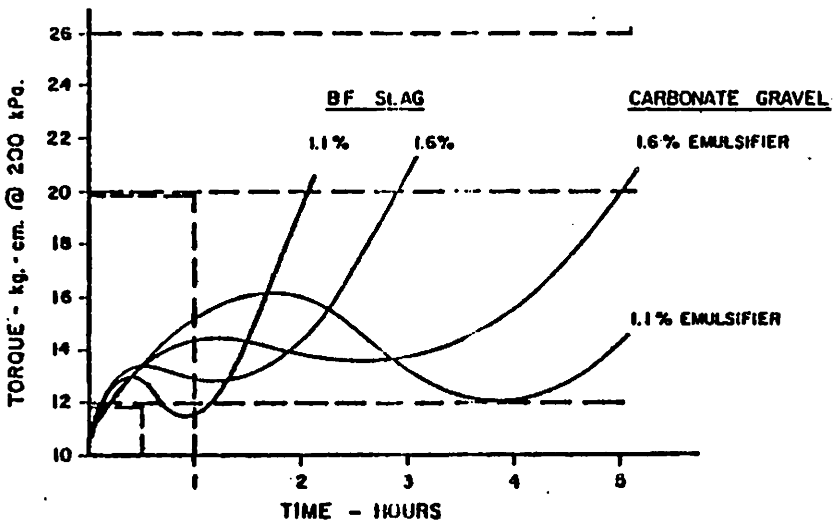

EXAMPLE 4. EFFECT OF CEMENT FILLER ON AN INITIATOR SYSTEM

Example 4 a. and 4 b. have used set initiators at 16% AE and 1% and 2% portland cement. Note the reversal of the optimum additive % from 9, 3 & 6% additive at 1% PC to 6, 3 & 9% additive when 2% PC is used.



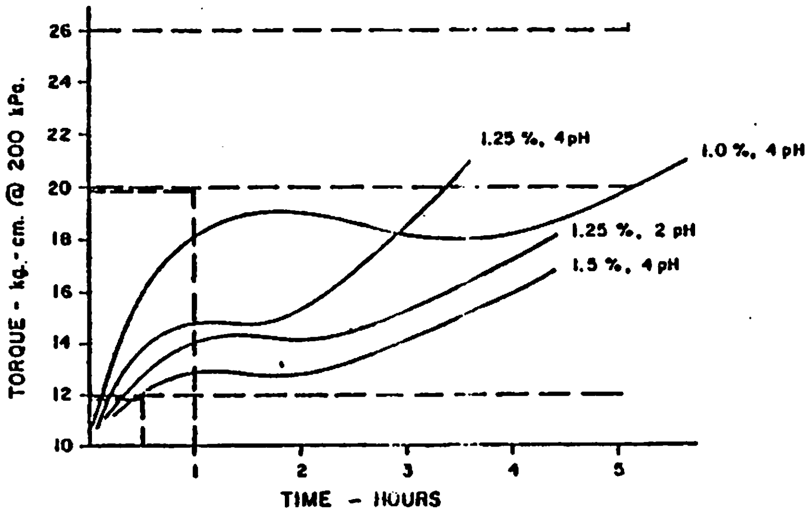

EXAMPLE 5. EFFECT OF LIME FILLER CONTENT ON AN INITIATOR SYSTEM

Example 5 a. and 5 b. shows a similar set reversal when ¼% and 1% lime initiators give optimums of 6, 3 & 9% respectively.



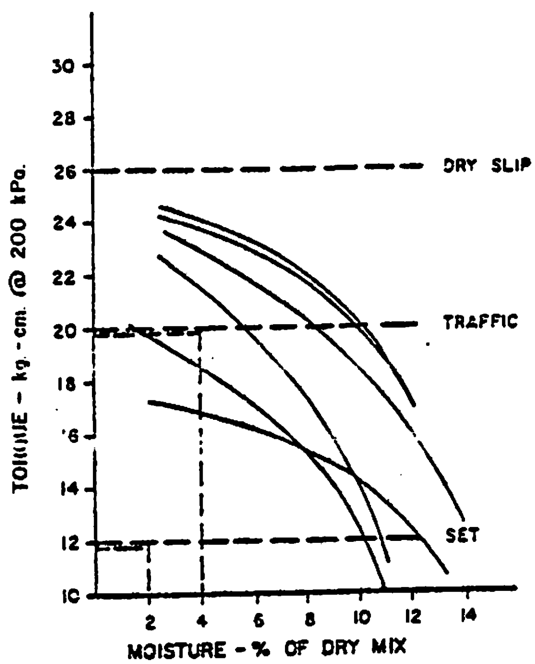

EXAMPLE 6. EFFECT OF EMULSIFIER CONTENT AND AGGREGATE TYPE ON SETTING CHARACTERISTICS

Example 6 shows another kind of set reversal when the aggregates are changed from a calcareous gravel to a blast furnace slag. The 1.1% and 1.6% emulsifier roles are reversed when the aggregate types are changed. Incidentally these are all quick set systems but relapse into a false set and slow traffic classification and this particular system is identified with both poor adhesion and poor cohesion.



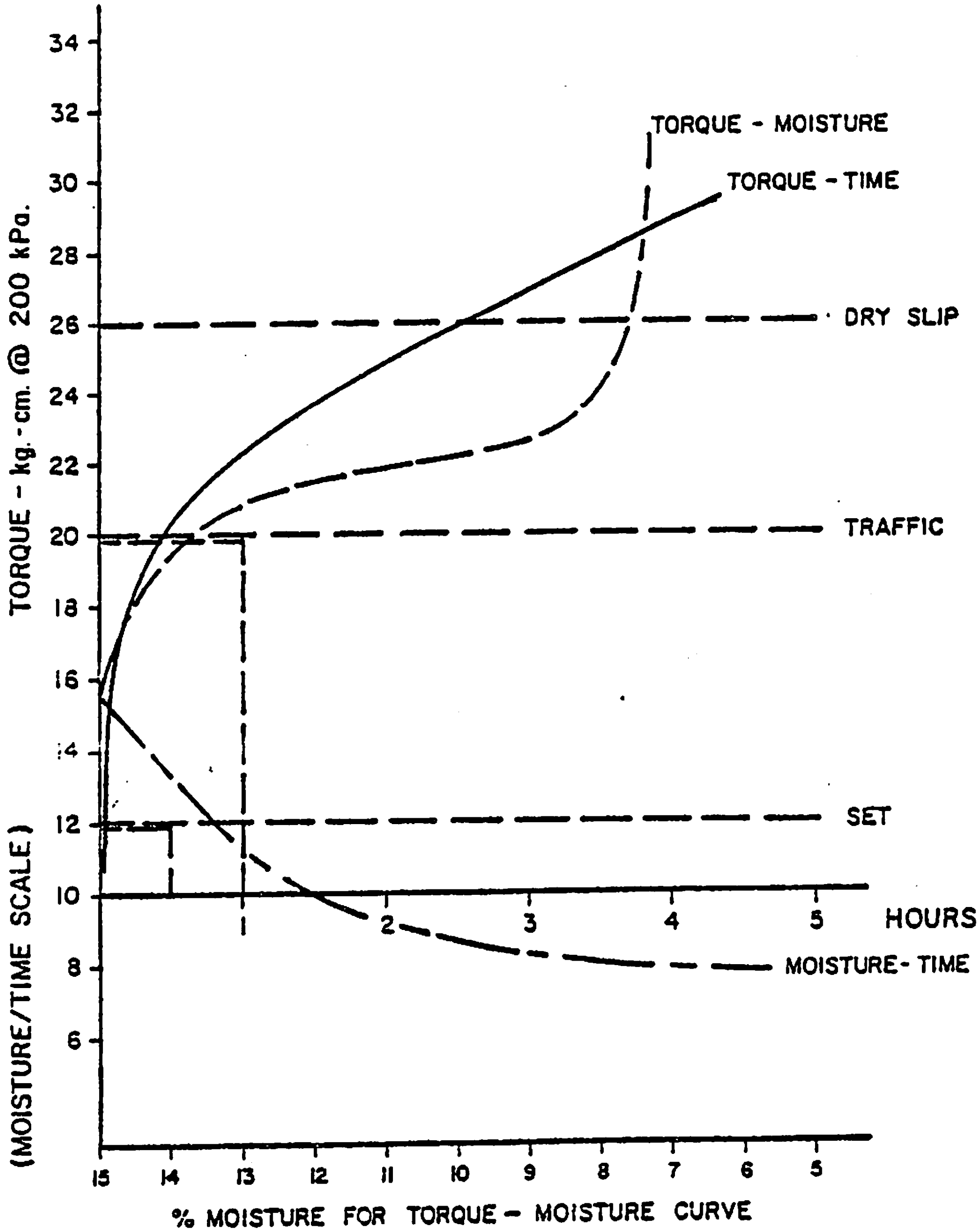

EXAMPLE 7. EFFECT OF EMULSIFIER CONTENT AND pH ON TRAFFIC TIME

Example 7 shows the effect of emulsifier concentration and pH where:
1.0% @ 4 pH emulsifier shows good set and very slow traffic and
1.5% @ 4 pH shows a weak set and a similar very slow traffic cure.
1.25% emulsifier shows the quickest traffic time at a higher pH.




EXAMPLE 8. TORQUE-MOISTURE OR WET STRENGTH VARIATIONS

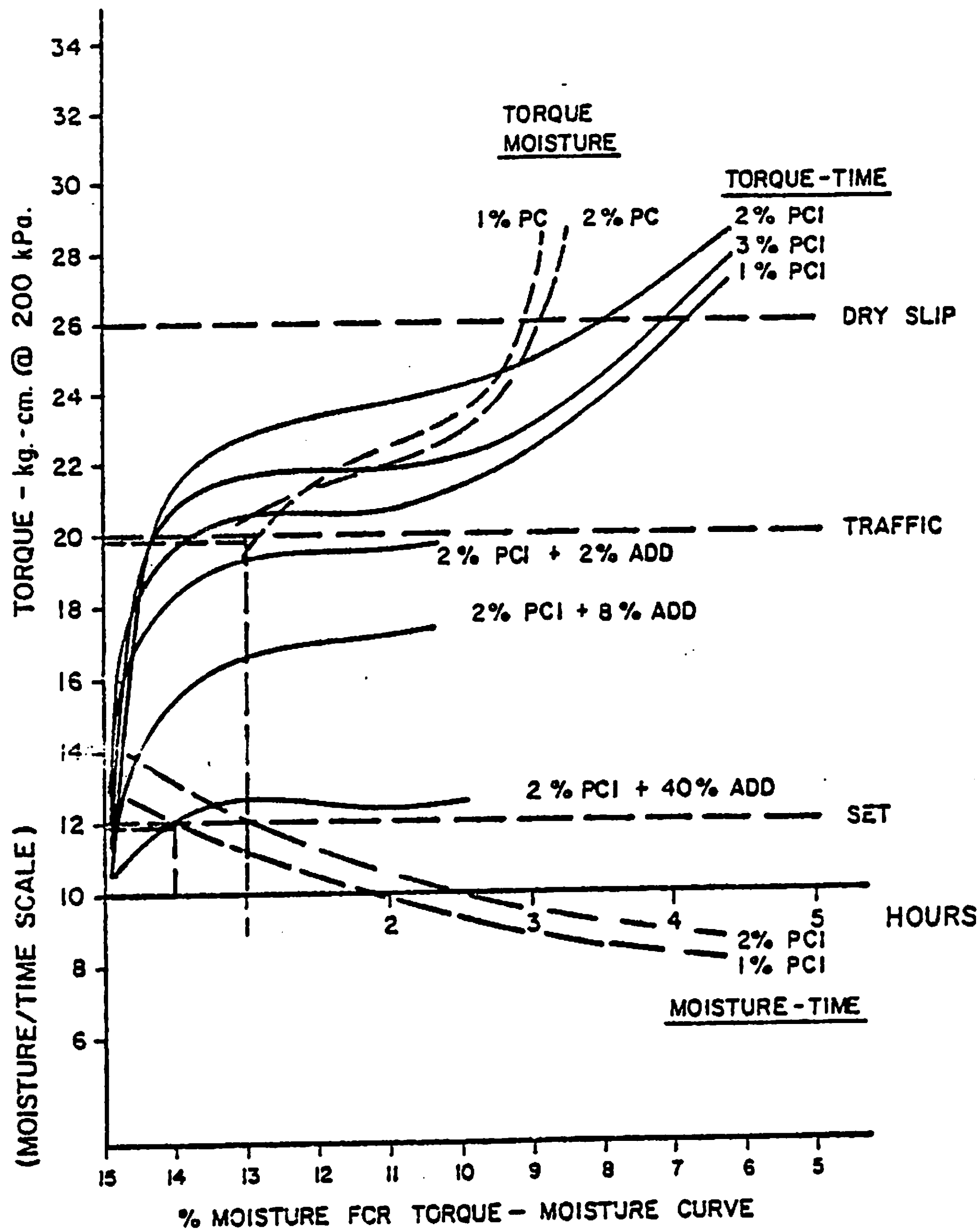
Example 8 compares the torque-moisture curve of 6 systems and illustrates clearly that "wet strength" is not totally a function of the % moisture but rather a function of the particular chemistry involved.




EXAMPLE 9. TORQUE-TIME, TORQUE-MOISTURE, (WET STRENGTH) MOISTURE-TIME COMBINED CURVES

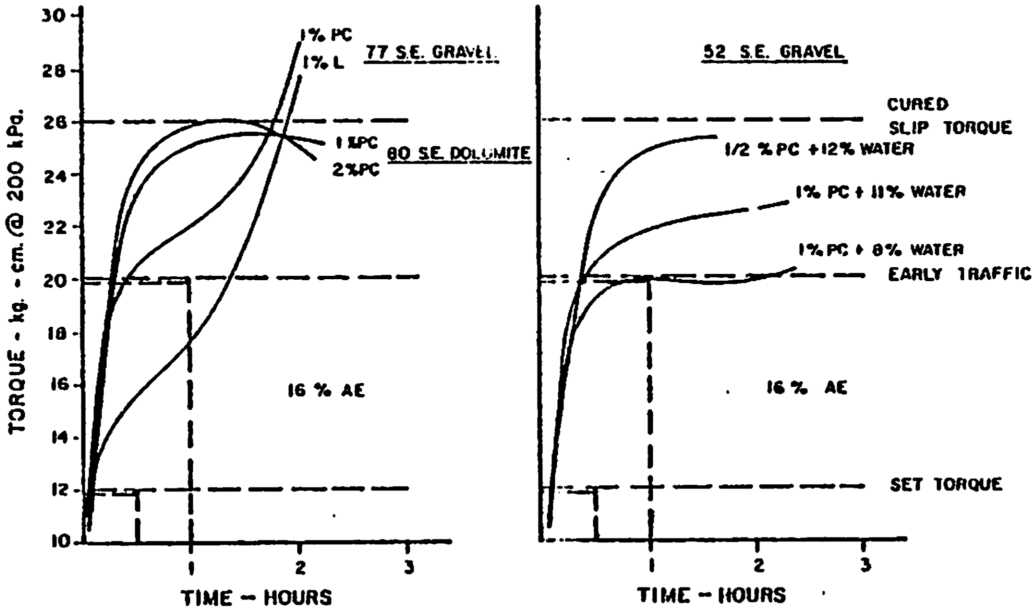
Example 9 combines all the information from the cohesion tester into 1 graph:

(a) torque-time (QS-QT system),
(b) moisture-time (very typical) curve for QS system,
(c) torque-moisture or "wet strength" curve.
I'm not sure what's happening in this system where the wet strength appears to rocket at about the 7½% moisture content.



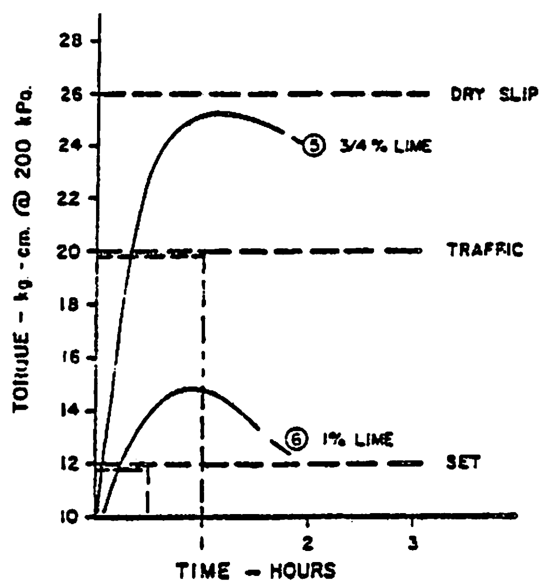

EXAMPLE 10. A COMPLETE STUDY OF THE EFFECTS OF FILLER AND ADDITIVE CONTENT AT 16% EMULSION CONTENT

Example 10 illustrates how complicated a cohesion graph can be made. The aggregate and emulsion content is held constant here while the cement is varied and various quantities of an additive (a retarder in this case). Note the extremely wide range of results from a fairly super-set to a no-set situation. Also note a similar ascendency of the wet strength or torque-moisture curve at about 8½% moisture content.




EXAMPLE 11. EFFECT OF FIELD VARIABLES: AGGREGATE SOURCE, SAND EQUIVALENT, FILLER AND WATER CONTENT

Example 11 a. shows some rather interesting variations in a Q.T. system where 2% PC with a 77 SE gravel gives the same curves as ½% lime with an 80 SE dolomite, but, 1% lime with the gravel and shows that 1% PC is too much and that by reducing the cement to ½% and increasing the water somewhat the same curve as in 11 a. is found by using 2% PC! This indicates that a portion of the fines in the 52 SE is acting the same as cement.




① 100/0 - 0L - 13.5/0 - 16 10 SEC. MIX
② 100/0 - 1/4L - 13.5/0 - 16 20 SEC. MIX
③ 100/0 - 1/4L - 7.0/6 - 16 30 SEC. MIX
④ 100/0 - 1/2L - 13.0/0 - 16 30 SEC. MIX
⑤ 100/0 - 3/4L - 13.5/0 - 16 120 SEC. MIX
⑥ 100/0 - 1 L - 13.5/0 - 16 300 SEC. MIX

EXAMPLE 12. PRECISION RESULTS REQUIRES PRECISION

Example 12 is a final dramatic illustration to show the critical need for precise design and precise material proportioning is shown in example 12 where a Virginia Gneiss and lime are used. Too short a mix time occurs at ½% lime but 3/4% lime gives excellent mix time and traffic time. ¼% more lime (1%) however, completely destroys the quick traffic characteristic of this otherwise excellent system.

## SUMMARY

1. In a complete study, the effects of the environment (temperature) on the mixing and setting characteristics should be studied. The WTAT, LWT and compatibility characteristics should also be studies before a final design is selected.
2. Tentative definitions and procedures have been presented, but should be verified by others.
3. A simple laboratory test, the modified cohesion test as presented here provides a method to objectively classify the setting and early traffic time characteristics of bituminous emulsion-aggregate mix systems.

## NOTES

1. Most of the systems shown have used different emulsion types, but, unless noted, the aggregate used was Xenia, Ohio calcareous crushed gravel, 100% minus #4 sieve. All tests performed under laboratory conditions of 72-75°F, no external heat, no wind, with specimens cast on a non-absorbtive surface.
2. Type 3 gradations (0/8mm) seem to compare well with the type 2 (0/5mm) gradations. Type 1 gradations appear to offer some correlation problems, but not enough work has been accomplished to report at this stage of the research.
3. All work here has been done at laboratory temperatures and using surface dry aggregates. Much work needs to be done to study the effect of temperature, and the effect of absorbtive surfaces.
4. We have noted certain systems which are "water poppers"; i.e., very slippery, soapy water is expressed to the surface of the specimen. This soapy water may lubricate the cohesion tester foot and cause lower than true readings. Work proceeds which uses a serrated steel foot which could penetrate such lubricating films.
5. We have also noted certain systems which form a continuous thin surface film composed of fines, salts and residual asphalt on the specimen surfaces and which may "seal" a soapy lubricating layer between the surface film and an underlying, strongly cohesive mix. This phenomena may also cause lower than true readings.
6. The work presented here is of a preliminary nature. The procedures, torque level, definitions for "set" and "traffic" and calibrations should be verified and agreed upon by the industry as a future project. Previous work done by the ASTM D 04.4 committee members during their round robin studies of the cohesion test may be helpful.

## References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## Cohesion Tester Experimental Calibration Data

12/24/82

Page 6 SUMMARY

| | AVERAGE kg-cm @200kPa | RANGE |
|---|---|---|
| CYLINDER-RAISED: | 9.0 | (.2) |
| CYLINDER-FREE: | 6.0 | (.2) |
| CYLINDER DEPRESSED @ 200kPa: | | |
| 20-30 MESH OTTOWA SAND-6mm. | 6.02 | (.2) |
| * 20-30 MESH OTTOWA SAND-10mm. | 6.04 | (.2) |
| XENIA GRAVEL 1cm DRY (100%-#4) | 6.90 | (1.0) |
| 6mm DRY | 7.29 | (.4) |
| 1cm WET | 7.81 | (1.0) |
| 6mm WET | 7.84 | (.3) |
| RICHMOND GNEISS 1cm WET (100%-#4) | 7.65 | (.8) |
| 6mm DRY | 7.83 | (1.5) |
| 1cm DRY | 8.07 | (.3) |
| 6mm WET | 8.19 | (1.2) |
| 35 DUROMETER GUM RUBBER-SMOOTH | 9.90 | (.7) |
| * 3M 220 GRIT SILICON CARBIDE PAPER | 12.92 | (.3) |
| 15-LB. ROOFING FELT-SMOOTH SIDE | 12.24 | (1.7) |
| 15-LB. ROOFING FELT-ROUGH SIDE | 13.14 | (1.3) |
| ** CARBORUNDUM-100 GRIT PAPER (SiC) | 19.77 | (.8) |
| 3M-80 GRIT SiC PAPER 3/16" RUBBER BACK | 21.25 | (2.7) |
| 3M-80 GRIT SiC PAPER - | 22.36 | (2.1) |
| 3M-36 GRIT SiC PAPER-3/16" RUBBER BACK | 22.18 | (3.0) |
| 3M-36 GRIT SiC PAPER- | 24.22 | (3.1) |

*,** POSSIBLE CALIBRATION STANDARDS.

# COHESION TESTER CALIBRATIONS - EXPERIMENTAL 12/24/8?
Kg-cm @ 200 kPa (kg./cm²)

| CYLINDER RAISED | CYLINDER MIDWAY | | OTTOWA SAND, 1CM, DIRTY FOOT: DRY | | 4% H₂O | | 4% H₂O 2% ... | |
|---|---|---|---|---|---|---|---|---|
| 9.0 | 6.1 | 6.1 | 6.9 | | 7.0 | | 6.9 | |
| 8.9 | 5.9 | 6.0 | 7.0 | | 7.8 | | 6.2 | |
| 9.0 | 5.9 | 5.9 | 7.0 | | 6.3 | | | |
| 9.1 | 5.9 | 6.1 | 6.4 | | | | | |
| 9.0(.2) | 6.0 | 6.1 | 6.9 | | | | | |
| | 5.9 | | | | | | | |
| | 5.9 | | | | | | | |
| 9.0(.2) | 6.0 | (.2) | 6.84 | (.6) | 7.03 | (1.5) | 6.55 | (.7) |

OTTOWA SAND (USED) CLEAN, SMOOTH FOOT:

| 6mm. | 1cm. |
|---|---|
| 5.9 | 6.0 |
| 6.0 | 6.0 |
| 5.9 | 6.0 |
| 5.9 | 6.1 |
| 6.1 | 5.9 |
| 6.1 | 6.0 |
| 6.1 | 6.1 |
| 6.1 | 6.1 |
| 6.0 | 6.1 |
| 6.1 | 6.1 |
| 6.02 (.2) | 6.04 (.2) |

2.



CONTINUOUS SERIES, FOOT NOT RAISED (DIRTY FOOT)

OTTOWA SAND (FRESH) DRY - 1CM. THROUGH 90°-100°

| 1CM. DRY | | | | 1CM 4% WATER: | | | | 1CM 4% H₂O 2% ... | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 7.0 | 6.4 | 6.9 | (.6) | 7.0 | 7.8 | 6.3 | (1.5) | 6.9 | 6.2 | (.7) |
| 8.2 | 7.8 | 8.1 | (.4) | 8.3 | 8.5 | 7.8 | (.7) | 8.0 | 8.1 | (.1) |
| 8.6 | (9.9) | 8.6 | (.0) | 8.3 | 8.9 | 8.3 | (.6) | 8.9 | 8.8 | (.1) |
| 9.3 | 9.0 | 8.9 | (.4) | 9.3 | 9.3 | 9.0 | (.3) | 9.2 | 9.0 | (.2) |
| 9.4 | 9.3 | 9.3 | (.1) | 10.0 | 10.0 | 9.2 | (.8) | 9.1 | 9.8 | (.7) |
| 9.5 | 9.9 | 9.2 | (.7) | 9.4 | 10.0 | 9.8 | (.6) | 9.6 | 9.8 | (.2) |
| 9.6 | 9.9 | 9.1 | (.8) | 9.9 | 10.2 | 9.9 | (.3) | 9.9 | 9.8 | (.1) |
| 10.0 | 9.9 | 9.9 | (.1) | 10.0 | 10.0 | 10.0 | (.0) | 10.0 | 9.7 | (.3) |
| 9.9 | 10.0 | 10.0 | (.1) | 10.0 | 9.9 | 10.3 | (.4) | 9.9 | 10.1 | (.2) |
| 10.4 | 10.3 | 9.9 | (.5) | 9.9 | 10.2 | 10.0 | (.3) | 9.9 | 9.9 | (.0) |
| 11.1 | 10.8 | 9.9 | (.3) | 10.6 | 10.2 | 10.0 | (.6) | 9.9 | 9.9 | [illegible] |
| 10.9 | 10.3 | 10.1 | (.8) | 10.0 | 10.4 | 10.3 | (.4) | 10.0 | 10.9 | [illegible] |
| 10.7 | 11.1 | 10.0 | (1.1) | 10.0 | 10.7 | 10.4 | (.7) | [illegible] | 10.2 | [illegible] |
| 11.1 | 11.3 | 10.8 | (.5) | 10.0 | 10.6 | 10.6 | (.6) | 10.1 | 10.5 | [illegible] |
| 10.9 | 10.9 | 11.1 | (.2) | 10.3 | 10.3 | 10.7 | (.4) | 10.0 | 10.4 | (.4) |
| 10.9 | 11.1 | 10.8 | (.3) | 10.1 | 10.9 | 11.0 | (.9) | 10.0 | 10.6 | [illegible] |
| 10.9 | 11.4 | (12.8) | (.5) | 10.4 | 10.4 | 10.2 | (.2) | 10.5 | 10.6 | [illegible] |
| 11.2 | 11.4 | 10.9 | (.5) | 10.8 | 10.8 | 10.8 | (.8) | 10.7 | [illegible] | [illegible] |
| 11.1 | 11.8 | 10.9 | (.9) | 10.2 | 11.3 | 11.2 | (1.1) | 10.7 | 10.4 | (.3) |
| 11.1 | 12.0 | 10.9 | (1.1) | 10.3 | 10.9 | 11.1 | (.8) | 10.2 | 10.8 | (.6) |

Continuous Series, Foot Not Raised - Experimental
Wet Bottom Boiler Slag - Dry - Sl. Dirty Foot

| -8 +16 (1cm) | | | | -8+16 (6mm) | -16+30 1cm | -30 1cm |
|---|---|---|---|---|---|---|
| 6.8 | 6.9 | 6.2 | (.6) | 8.0 | 5.9 | 6.0 |
| 8.8 | 7.9 | 7.2 | (1.6) | 8.1 | 6.9 | 7.2 |
| 10.1 | 8.9 | 8.8 | (1.3) | 8.9 | 8.2 | 8.0 |
| 9.8 | 9.2 | 9.8 | (.6) | 9.9 | 9.2 | 8.2 |
| 11.2 | 9.9 | 9.9 | (1.3) | 10.2 | 9.4 | 8.7 |
| 10.8 | 10.2 | 9.8 | (1.0) | 10.2 | 9.8 | 9.0 |
| 10.9 | 10.4 | 9.9 | (1.0) | 10.0 | 10.4 | 9.2 |
| 12.2 | 11.0 | 10.6 | (1.6) | 10.2 | 10.1 | 11.8 |
| 12.8 | 10.5 | 11.0 | (2.3) | 11.0 | 10.8 | 10.0 |
| 11.8 | 10.4 | 10.0 | (1.8) | 10.1 | 10.6 | 10.6 |
| 11.5 | 10.1 | 9.6 | (1.9) | 10.8 | 10.8 | 10.6 |
| 11.5 | 10.1 | 10.3 | (1.4) | [illegible] | 10.6 | [illegible] |
| 13.8 | 9.9 | 10.8 | (3.9) | 10.6 | 11.0 | 10.9 |
| 10.4 | 10.7 | 10.5 | (.3) | 10.2 | 10.2 | 10.6 |
| 12.8 | 10.0 | 9.4 | (2.4) | 10.2 | 10.8 | 11.2 |
| 11.8 | 10.1 | 9.7 | (2.1) | 10.9 | 11.8 | 11.6 |
| 10.7 | 10.3 | 10.0 | (.7) | 10.4 | 11.4 | 11.0 |
| 11.1 | 11.7 | 9.9 | (1.2) | 10.4 | 11.3 | 11.3 |
| 11.3 | 11.7 | 10.6 | (.7) | 11.1 | 11.3 | 11.1 |
| 10.2 | 10.6 | 10.3 | (.5) | 11.2 | 11.2 | 11.2 |



| 35 Duro, Smooth Gum Rubber ③ | ④ | 3M 220 Grit: Dirty Foot Start ⑤ | ⑥ | After 90 & 36 Grit - Clean ⑫ | ⑬ | ⑭ | ⑱ | 15# Felt Smooth Rough ⑲ | ⑳ |
|---|---|---|---|---|---|---|---|---|---|
| 10.2 | 10.0 | 17.0 | 15.0 | 12.0 | 12.2 | 12.8 | 12.2 | 12.2 | 13.2 |
| 10.3 | 9.9 | 16.9 | 15.9 | 13.5 | 13.0 | 13.0 | 12.9 | 12.3 | 14.0 |
| 10.6 | 9.4 | 16.9 | 15.0 | 12.5 | 13.0 | 12.8 | 12.1 | 12.9 | 13.3 |
| 10.6 | 10.0 | 16.2 | 15.0 | 11.8 | 12.9 | 12.8 | 12.8 | 12.1 | 12. |
| 10.4 | 9.9 | 16.0 | 15.2 | 12.8 | 12.2 | 13.1 | 12.9 | (11.5) | 13. |
| 10.1 | 9.9 | 16.9 | 15.6 | 13.2 | 12.2 | 12.9 | 13.0 | 12.3 | 13. |
| 10.3 | 10.1 | 16.3 | 16.0 | 12.3 | 12.5 | 13.0 | 12.4 | 12.1 | 13. |
| 10.0 | 10.0 | 16.1 | 14.9 | 11.5 | 13.2 | 13.0 | 12.9 | 12.1 | 12. |
| 10.0 | 9.9 | (15.2) | 15.9 | 12.8 | 12.1 | 12.9 | 13.0 | (13.2) | 12. |
| 10.0 | 9.9 | 16.0 | 14.9 | 12.0 | 12.9 | 12.9 | 13.1 | 11.8 | 12. |
| 10.25 | 9.90 | 16.35 | 15.34 | 12.44 | 12.62 | 12.72 | 12.73 | 12.29 | 13.- |
| (.6) | (.7) | (1.8) (1.0) | (1.1) | (2.0) | (1.1) | (.3) | (.7) | (1.7) | (1.3) |

| 3M - 90 Grit; on RBR ⑦ | ⑧ | ⑨ | 3M 36 Grit on RBR ⑩ | ⑪ | Carborundum - 100 Grit ⑮ | ⑯ | ⑰ |
|---|---|---|---|---|---|---|---|
| 23.9 | 23.1 | 22.3 | 23.6 | 22.6 | 18.1 | 19.4 | 19.3 |
| 22.1 | 22.0 | 21.9 | 26.2 | 22.9 | 18.6 | 19.1 | 19.8 |
| 22.1 | 20.3 | 20.1 | 23.1 | 21.8 | 18.2 | 19.0 | 19.4 |
| 21.0 | 24.0? | 21.0 | 24.0 | 23.9 | 18.9 | 19.4 | 19.5 |
| 22.2 | 22.2 | 22.9 | 24.1 | 22.1 | 18.9 | 19.1 | 20.0 |
| 21.8 | 21.9 | 20.2 | 25.1 | 21.3 | 17.9 | 18.4 | 19.9 |
| 21.2 | 21.1 | 20.2 | 25.6 | 21.6 | 19.9 | 18.1 | 20.1 |
| 22.0 | 23.9 | 21.9 | 24.3 | 22.8 | 19.9 | 20.0 | 20.0 |
| 21.3 | 23.2 | 20.2 | 22.9 | 21.9 | 19.9 | 20.2 | 20.1 |
| 21.4 | 21.9 | 21.8 | 23.3 | 20.9 | 18.0 | 18.2 | 19.6 |
| 21.90 | 22.36 | 21.25 | 24.22 | 22.18 | 18.83 | 19.09 | 19.77 |
| (2.9) | (2.1) | (2.7) | (3.1) | (3.0) | (2.0) | (2.1) | (.8) |

(5)

## Richmond Gneiss

**1 cm Dry:**

| ① | ② | ③ | |
|---|---|---|---|
| 8.1 | 7.9 | 8.1 | |
| 8.1 | 8.1 | 8.1 | |
| 8.0 | 8.2 | 8.0 | |
| 8.07 | 8.07 | 8.07 | = 8.07 (.3) |

**6 mm Dry:**

| | | | |
|---|---|---|---|
| 7.9 | 8.6 | 7.2 | |
| 7.1 | 7.9 | 8.0 | |
| 7.9 | 8.1 | 7.8 | |
| 7.63 | 8.20 | 7.67 | = 7.83 (1.5) |

**1 cm. Wet: (5% $H_2O$)**

| | | | |
|---|---|---|---|
| 7.7 | 7.6 | 7.4 | |
| 7.9 | 8.0 | 7.2 | |
| 7.8 | 7.4 | 7.8 | |
| 7.80 | 7.67 | 7.47 | = 7.65 (.8) |

**6 mm Wet (5% $H_2O$):**

| | | | |
|---|---|---|---|
| 8.2 | 7.8 | 8.6 | |
| 8.6 | 7.9 | 9.0 | |
| 7.8 | 7.8 | 8.0 | |
| 8.20 | 7.83 | 8.53 | = 8.19 (1.2) |

## Xenia Gravel

**1 cm Dry:**

| ① | ② | ③ | |
|---|---|---|---|
| 6.8 | 7.0 | 6.3 | |
| 7.0 | 7.1 | 6.8 | |
| 6.8 | 7.3 | 7.0 | |
| 6.87 | 7.13 | 6.70 | = 6.90 (1.0) |

**6 mm Dry:**

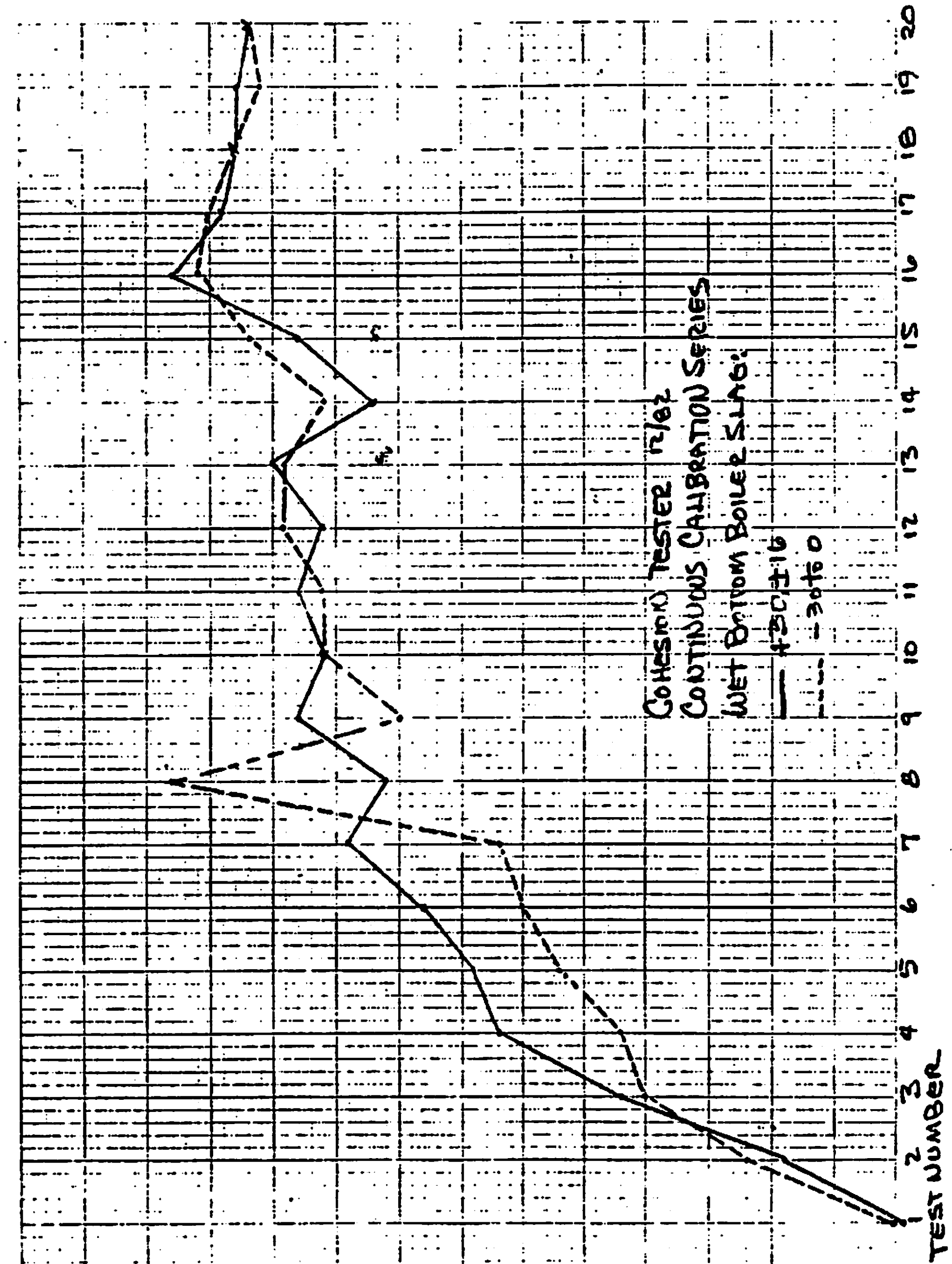
| | | | |
|---|---|---|---|
| 6.9 | 7.3 | 7.3 | |
| 7.0 | 7.1 | 7.2 | |
| 7.3 | 7.1 | 7.1 | |
| 7.07 | 7.60 | 7.20 | = 7.29 (.4) |

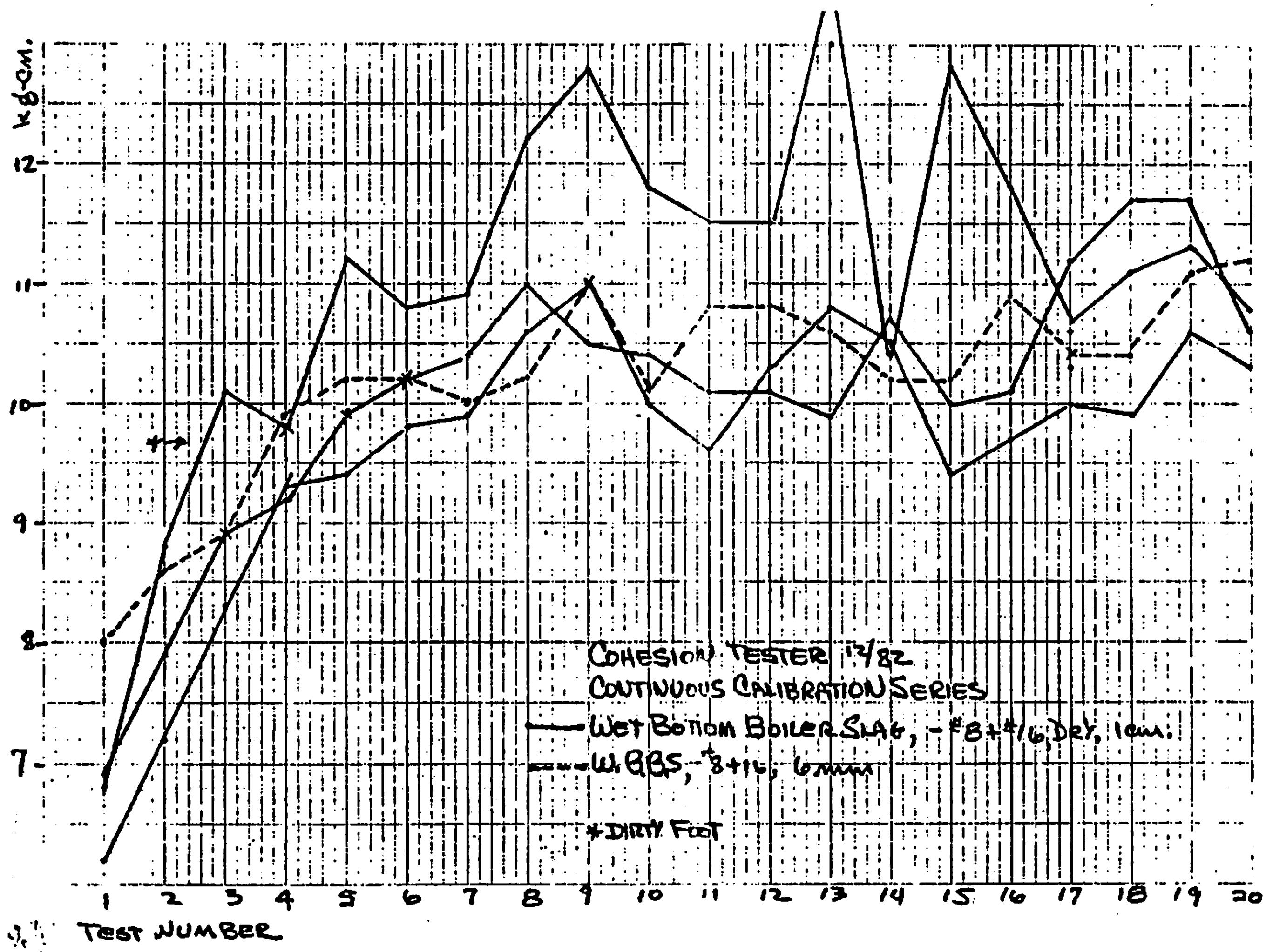
**1 cm. Wet (5% $H_2O$):**

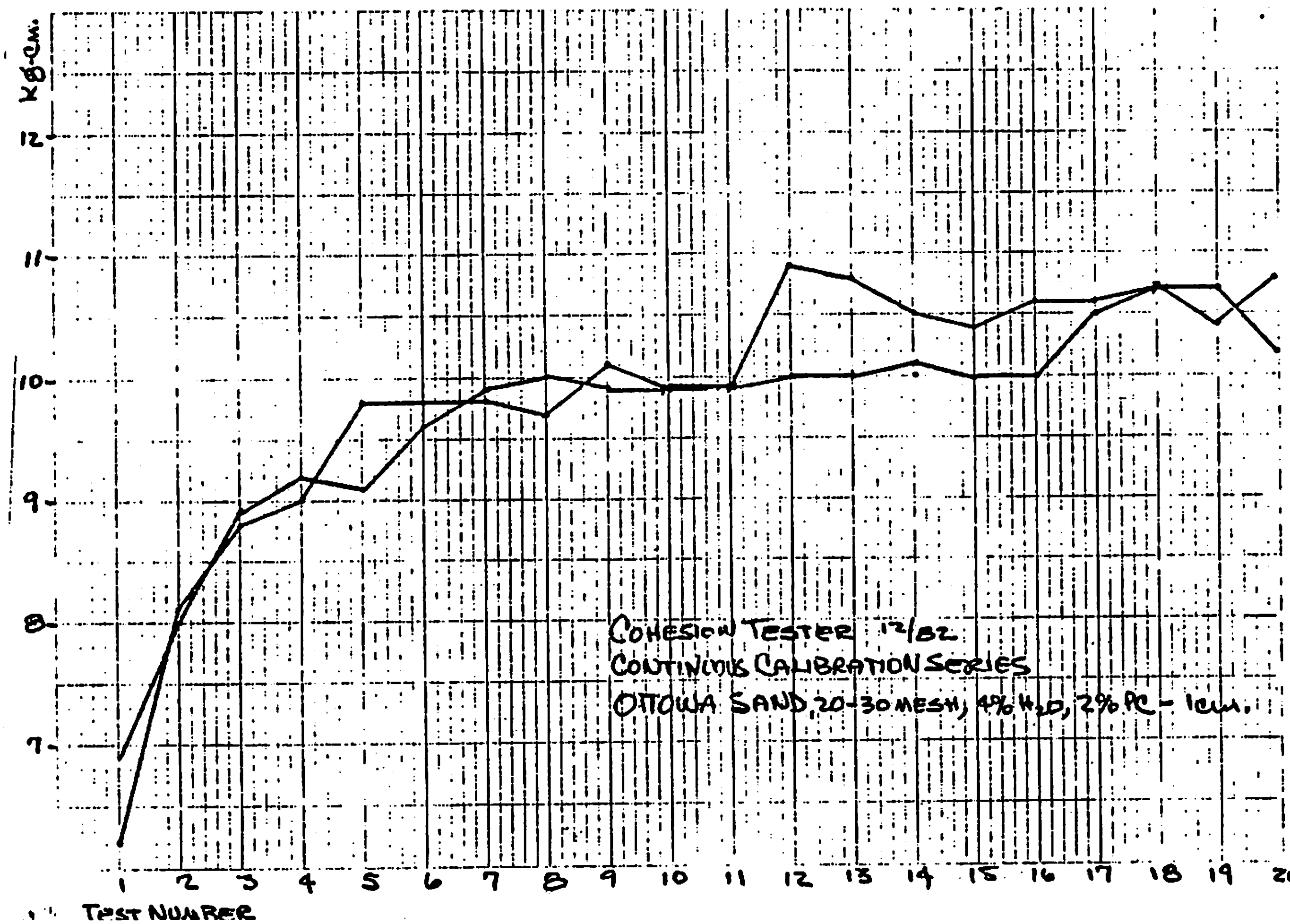
| | | | |
|---|---|---|---|
| 7.6 | 7.6 | 7.3 | |
| 8.3 | 8.0 | 8.0 | |
| 7.8 | 8.0 | 7.8 | |
| 7.90 | 7.87 | 7.70 | = 7.81 (1.0) |

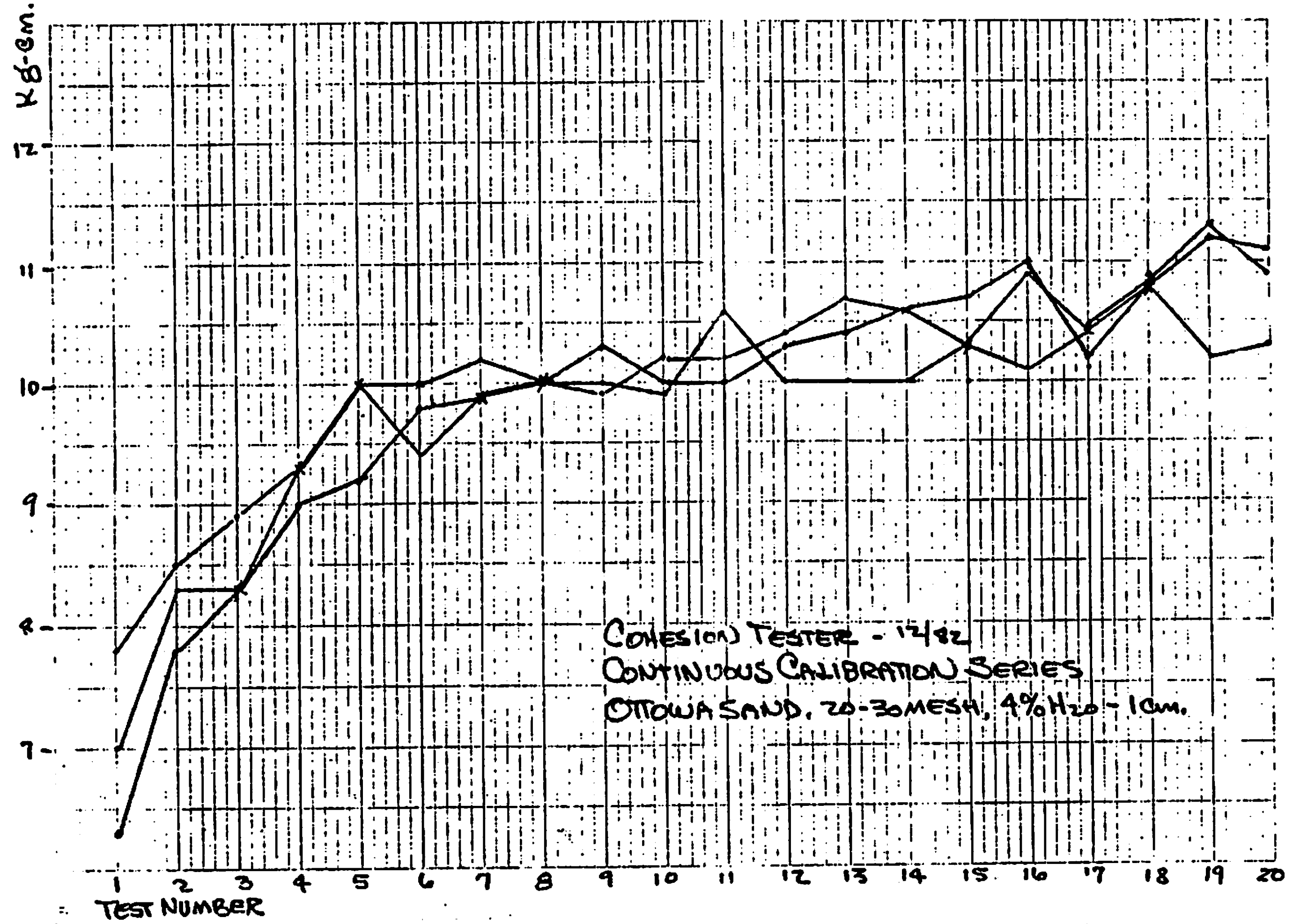
**6 mm Wet (5% $H_2O$):**

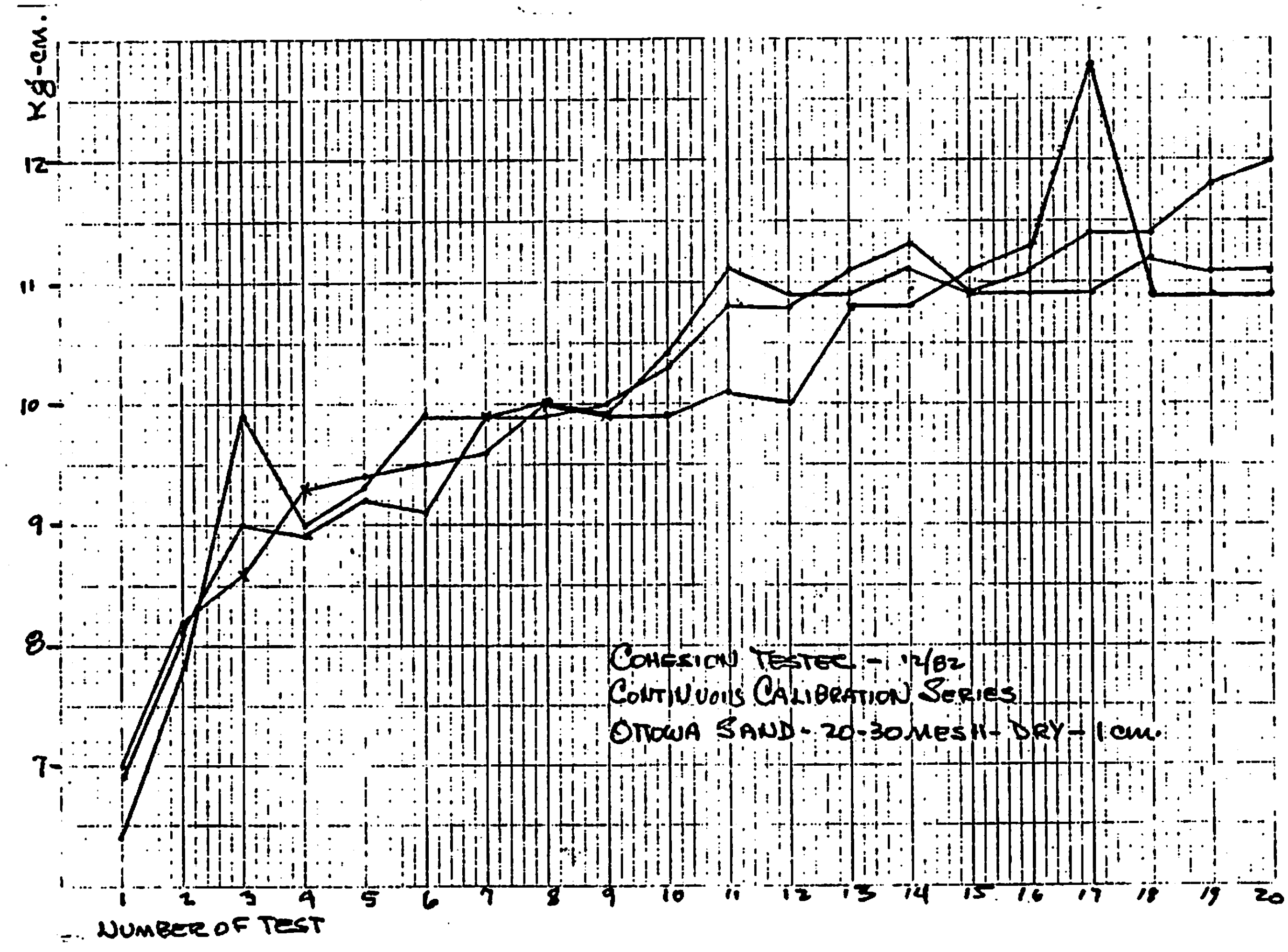
| | | | |
|---|---|---|---|
| 7.9 | 7.7 | 7.1 | |
| 8.0 | 7.8 | 7.8 | |
| 8.0 | 7.7 | 7.8 | |
| 7.97 | 7.73 | 7.83 | = 7.84 (.3) |




KG-CM.
12
11
10
9
8
7
COHESION TESTER 12/82
CONTINUOUS CALIBRATION SERIES
WET BOTTOM BOILER SLAG, -#8+#16, DRY, 1cm.
W.BBS, -8+16, 6mm
*DIRTY FOOT
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
TEST NUMBER


KG-CM.
12
11
10
9
8
7
COHESION TESTER 12/82
CONTINUOUS CALIBRATION SERIES
OTTOWA SAND, 20-30 MESH, 4% H2O, 2% PC - 1cm.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
TEST NUMBER


Kg-cm.
12
11
10
9
8
7
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
TEST NUMBER
COHESION TESTER - 12/82
CONTINUOUS CALIBRATION SERIES
OTTOWA SAND, 20-30 MESH, 4% H2O - 1 cm.


Kg-cm.
12
11
10
9
8
7
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
NUMBER OF TEST
COHESION TESTER - 12/82
CONTINUOUS CALIBRATION SERIES
OTTOWA SAND - 20-30 MESH - DRY - 1 cm.

INTERNATIONAL SLURRY SEAL ASSOCIATION
TECHNICAL BULLETIN
1101 CONNECTICUT AVE., N.W., WASHINGTON D.C. 20006

No. 139
December 1982
Proposed

# TEST METHOD TO CLASSIFY EMULSIFIED ASPHALT/AGGREGATE MIXTURE SYSTEMS BY MODIFIED COHESION TESTER MEASUREMENT OF SET AND CURE CHARACTERISTICS.

See: ISSA TB 102, "Mixing, Setting and Water Resistance Test to identify 'Quick-Set' Emulsified Asphalts"; ISSA TB 135, "Cure Time Measurement by ARMAK Cohesion Tester"; and ASTM D 3910-80 a. "Recommended Practice for Design, Testing and Construction of Slurry Seal". Section 5.2 and 5.3.

While the ASTM test records only the time required to reach a constant maximum torque or until the time when the rubber foot rides freely over the slurry mat without dislodgment of aggregate particles, the present test measures torque during the development of set and cohesive strength and defines "set-time" and "early rolling traffic time" as a function of developed torque and time.

1.0 Apparatus and Materials

1.1 Modified Cohesion Tester, similar to the ASTM D 3910-80 a. machine but modified as follows:

a. 1-1/8"Ø double rod end air cylinder with 5/16"Ø rods and 3" stroke

b. 1/4" x 1-1/8"Ø 60 durometer foot

c. Air pressure regulator with a variable down stream bleed valve so that constant pressure is maintained.

d. Four-way directional control valve with exhaust port regulating valves.

e. Air pressure gauge with a 0 to 700 k Pa (kilograms/sq.cm)pressure gauge.

f. 700 k Pa (100 psig) air supply

g. Torque meter capable of measuring and marking at least 35 kilogram-centimeters (kg-cm) torque.

1.0 Apparatus and Materials - continued

1.2 A supply of 10 $cm^2$, 15-pound saturated roofing felt or other suitable non-absorbtive specimen mounting pads.

1.3 6 mm x 60 mm diameter and 10 mm x 60 mm diameter specimen molds.

1.4 4.75 mm and 8.00 mm standard ASTM E-11 sieves.

1.5 Suitable mixing and weighing equipment as in ISSA TB #113, "Trial Mix Procedure for Slurry Seal Design".

1.6 When moisture content determination is desired, a suitable forced draft oven or microwave oven is required.

1.7 Suitable spatula such as a 1" to 1¼" putty knife for cleaning the neoprene foot.

1.8 For Calibration:

a. 20-30 mesh standard ASTM C-190 Ottawa Sand

b. 220 grit silicon carbide "3-M" brand sand paper

c. 100 grit silicon carbide "Carborundum" brand sand paper

2.0 Procedure

2.1 Type 2 and Type 3 aggregate gradations are screened through the 4.75 mm or 8 mm screens respectively and the portion retained is discarded. A suitable number of identical specimens are mixed and cast in the 6 mm (for type 2, 0/4.75 mm) or 10 mm (for type 3, 0/8 mm) ring molds centered on the roofing felt squares. Care is taken to produce uniform specimens whose surfaces are horizontally parallel.

2.2 Torque measurements are made at suitable intervals such as 30, 60, 90, 150, 210 and 270 minutes after casting. The specimen is centered under the neoprene foot, instrument air pressure set at 200 kPa and the foot is lowered against the specimen at a rate of 8 to 10 cm. per second. After 5 to 6 seconds of compaction, the torque meter is "zeroed" and placed on the top cylinder rod-end and twisted in a smooth, firm, horizontal motion through a 90° to 120° arc within .7 to 1.0 seconds. The torque reading is recorded along with the time, the cylinder raised and foot cleaned by scraping.

2.3 When moisture contents are desired, it is necessary to tare-weigh the specimen mounting pads before casting the specimen.

3.0 Calibration:

3.1 A series of tests may be made with 220 grit sand paper until a series of 10 tests read a constant average within a .3 kg-cm range.

3.2 After the rubber disc is "polished" with the 220 grit sand paper to a constant reading, the 20-30 mesh Ottowa sand (ASTM C190 Standard Sand) contained in a 1 cm. mold, and the 100 grit sand paper may be tested and the calibration readings recorded.

3.3 The dry aggregate used for the test mix should be tested as in 3.2 and recorded on the cohesion graph.

4.0 Recording the Results:

4.1 Results should be recorded at the appropriate time intervals (30, 60 minutes, etc.) until a definite trend is established. Plots on a suitable graph paper will show a curve that is characteristic of the development of cohesive strength of the particular system tested.

4.2 The graph form should include the calibration values.

5.0 Set Time and Traffic Time Defined:

5.1 Set Time is defined as the laspsed time after casting when a slurry system may not be remixed into a homogeneous slurry; when no lateral displacement is possible when compacting the specimen; when an absorbtive paper towel is not stained when depressed lightly into the surface of the slurry; or, when an emulsion has coalesced and is not available to lubricate the mixture; and, when no free emulsion may be diluted and washed away with water.

Simply stated: The set occurs at the torque level of 12 (12-13) kg-cm.

5.2 Traffic Time: i.e., early rolling traffic time occurs at a torque level of 20 (20-21) kg-cm.

5.3 A quick-set system is defined as a slurry system which reaches a 12-13 kg-cm. cohesion torque within 30 minutes.

5.4 A quick-traffic system is defined as a slurry system which reaches a 20-21 kg-cm. cohesion torque within 60 minutes.

6.0 Classification of emulsified asphalt dense graded aggregate mixture system follows:

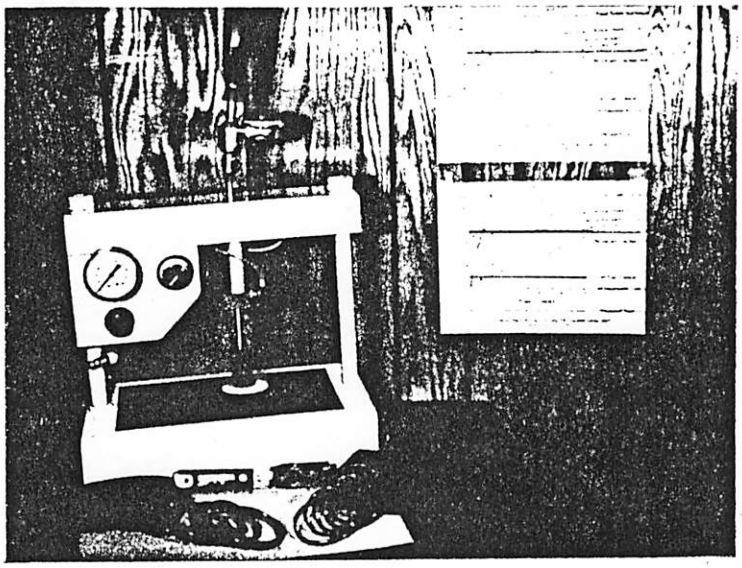
1. SS - ST Slow Set - Slow Traffic
2. QS - ST Quick Set - Slow Traffic
3. FS - ST False Set - Slow Traffic (set relapse)
4. QS - QT Quick Set - Quick Traffic
5. QS - LQT Quick Set - Linear Quick Traffic

NOTES:

1. This method and classification system has not been widely verified by the industry. Work has been done only on Types 2 and 3 aggregates. Results may not be applicable to Type 1 gradations. Cohesive strength is the only consideration here. Surface tackiness or tenderness has not been considered here.

2. See Benedict, "Classification of Asphalt Emulsion/Aggregate Mixture Systems by Cohesion Tester Measurement of Set and Cure Characteristics", presented to the 21st Annual ISSA Convention, Phoenix, Arizona, January 24-28, 1982.

3. The plans for the modified cohesion test apparatus or the apparatus itself is available from C. Robert Benedict, ~~320 Northview Road, Dayton, Ohio 45419,~~ P.O. Box 74, Alpha, OH 45301 (513-298-6647).



The Modified ASTM D3910-80a Cohesion Tester

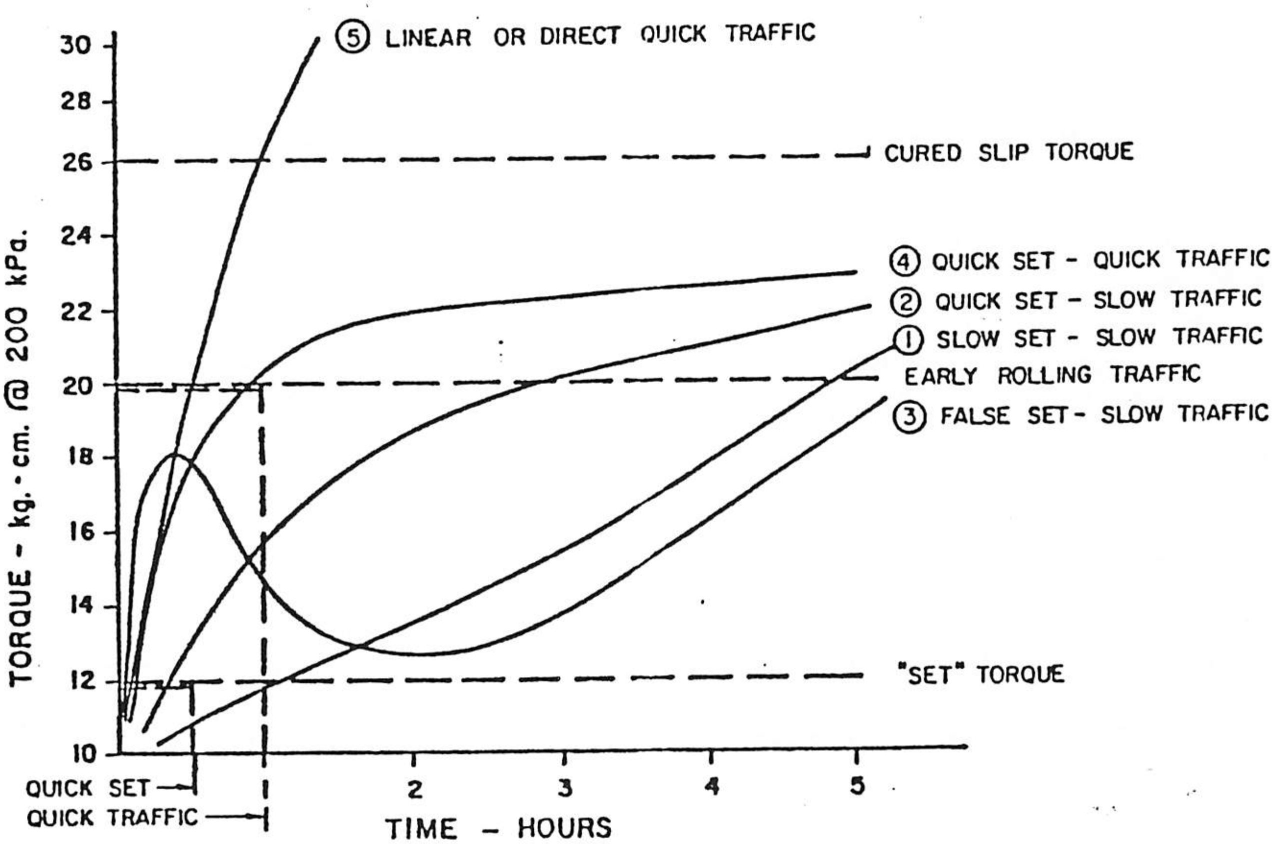



FIGURE 10. CLASSIFICATION OF MIX SYSTEMS BY MODIFIED COHESION TEST CURVES

COHESION TEST DATA SHEET

Emulsion:
Source ____________
Date ____________
Base AC ____________
Formulation: Emulsifiers, Type %
% AC Res. pH

Aggregate type ____________
Source ____________
Date ____________
S.E ____________
% -16 ____________
% -200 ____________

Filler:
Type ____________
Temp. Humd. ____________
Additive:
Type Water ____________
% Concentration ____________

| | TIME | SERIES SAMPLE# | TARE | Ⓣ TO OVEN | Ⓣ FROM OVEN | GRAMS LOSS | DRY NET WT. | % $H_2O$ NET DRY | REMARKS | | TORQUE KG-CM | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IX DESIGN | | | | | | | | | | | | |
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| IX DESIGN | | | | | | | | | | | | |
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| IX DESIGN | | | | | | | | | | | | |
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