COLD RECYCLED MIXTURES, WITH EMPHASIS ON THE CURING OF FOAMED SPECIMENS - A LABORATORY STUDY

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SYNOPSIS

Because of the continued price escalation in fuel, bitumen and road building materials, there is a continuing interest in the use of cold mixing techniques. The use of bitumen mixtures such as foam, emulsions and cutbacks is especially suitable for low volume roads and shoulders of "highways". In addition more and more salvaged material will become available for recycling, due to the milling of surface material. This material coupled with the use of cold mixing techniques, can make a valuable contribution to the pavement materials for low volume roads, at fairly low costs. In this report, a review of the development of the foamed process, together with a desciption of the process in use today, is included. Data from the literature has been supplemented by a laboratory study. The loboratory study involved an initial evaluation of the different cold mixing techniques, applied to two different field sands. The importance of the water content at mixing as well as the curing effects were evaluated with regard to stability and strength. Upon determing that satisfactory mixtures could be prepared, with reasonable results, a series of tests were conducted on salvaged material. The results of the preliminary study on the sand, were used to determine curing mechanisms. Different mixtures with varying amounts of bitumen were prepared and tested.

SINOPSIS

Weens die toenemende opwaartse aanpassing in brandstof-, bitumen- en padboumateriaalpryse, is daar 'n groot belangstelling in die gebruik van koue mengtegnieke. Die gebruik van bitumenmengsels soos skuim, emulsies en "cutbacks" is veral geskik vir paaie met lae volumes verkeer en ook skouers van hoofweë. Daar sal ook nog meer en meer herwonne padboumateriaal beskikbaar kom weens 'n toename in hersiklering. Hierdie materiaal gekoppel met die koue mengtegnieke kan 'n waardevolle bydrae maak. Die agtergrond van die ontwikkelling van die skuimproses en 'n beskrywing van die proses soos dit vandag in gebruik is word ook in die referaat weergegee. Data uit die literatuur is aangevul met 'n laboratoriumstudie. Hierdie studie het ingesluit 'n aanvanklike evaluering van die verskillende koue mengtegnieke toegepas op twee verskillende sande. Die belangrikheid van die voginhoud tydens die mengproses sowel as die nabehandeling is ondersoek met verwysing na stabiliteit en sterkte. Nadat vasgestel is dat geskikte mengsels voorberei kon word is 'n reeks toetse uitgevoer deur gebruik te maak van herwonne padbou materiaal. Die resultate van die toetse op die sand is gebruik om nabehandelingsmeganismes te bepaal.

1. INTRODUCTION

1.1 The foamed Process

In 1957 Professor L H Csanyi of the Iowa State University (2) demonstrated the effectiveness of preparing low-cost mixed by stabilizing ungraded local aggregates such as gravel, sand, and loess with asphalt cements using the foamed bitumen process.

In this procedure, controlled foam was produced by introducing saturated steam at ± 40 psi into heated bitumen at about 25 psi through a specially designed and properly adjusted nozzle. The reduced viscosity and the increased volume (± 2000 %) and surface energy in the foamed bitumen allowed intimate coating and mixing of the cold wet aggregates or soils. Through the use of bitumen in a foamed state, materials normally considered unsuitable could be used in the preparation of mixes for stabilized bases and surfaces for low traffic road construction.

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By attaching the desired number of nozzles the foamed bitumen can be used in conjunction with any tipe of mixing plant, stationary or mobile.

The patent rights for the Csanyi process were acquired by Mobil of Australia[1] in 1968. They modified the process by replacing the steam with 1 - 2 % cold water and allowing mixing through a suitable mixing chamber. In the USA, Conoco, Inc., has acquired the marketing rights to Foamix.

Foamix is a mixture of mineral aggregate and foamed bitumen, produced in a stationary plant at ambient temperatures under controlled conditions without aggregate heating.

2. SUITABLE MATERIALS FOR THE FOAMED PROCESS

2.1 Aggregates

Bowering and Martin (6) tested foamed bitumen mixtures comprising materials ranging from a sandy clay to a well-graded gravel. (Table 1). Test results indicate that the low plasticity materials with a relatively large percentage of fines (-200 sieve) were best, since the bitumen tends to coat the fines and partially coat the larger particles (4). Acott (7) suggested adding fines to increase low stabilities of foamed bitumen mixtures made with both clean and dirty (sands with organic material) sands. Fine material must be present to enhance the ability of the foam to produce uniform, thin coatings on a large surface area. Soils that benefit the most from the addition of foamed bitumen also show significant strength loss when tested wet.

In addition to using natural aggregates, foamed bitumen mixtures have been prepared with salvaged materials. D.Y. Lee prepared foamed bitumen mixtures using two recycled materials (1). The reclaimed materials were blended with virgin aggregates for the type and amount normally specified in Iowa for hot recycled mixtures.

Brennan, et al (9) produced a foamed recycled bitumen mixture using salvaged material from a state road near Wabash, Indiana, that had an bitu-

TABLE 1. REPF ENTATIVE DATA FOR FOAM-TREATED MATE! LS (REF 6)

SOIL GROUP (UNIFIED-SOIL) CLASSIFICATION	SUITABILITY FOR USE WITH FOAM	RANGE OF BITUMEN, CONTENTS		COHESION	GRAVEL EQUIVALENCY OF MIX	REMARKS
		FULL RANGE	OPTIMUM RANGE (BEST MIX)			
GW	Good	1.5-5.0	2.0-2.5	300-700	1.25-1.5	Permeable Mixtures
GW-GC GW-GM	Good	1.5-5.5	2.0-4.5	300-400	1.25-1.33	Permeable Mixtures
GP-GC	Good	1.5-4.0	2.5-3.0	300-400	1.25-1.33	Low Permeability
GC	Poor	4.0-6.0	4.0-6.0	300-400	1.25-1.33	Impermeable. Bitumen Content critical. Can be improved by adding small percentages lime.
SW	Fair	3.5-5.0	4.0-5.0	100	Nil	Needs addition of -200 mesh filler.
SW-SM	Good	1.0-6.0	2.5-4.0	100-400	1.00-1.33	
SP-SM	Poor	4.5-6.0+	3.0-4.5	100	Nil	Needs lower penetration bitumen and addition of -200 mesh filler.
SP	Fair	1.0-6.0	2.5-5.0	100-300	1.0 -1.25	May need addition of -200 mesh filler.
SM	Good	1.5-6.0	2.5-4.5	100-400	1.00-1.33	
SM-SC	Good	2.5-6.0	4.0	400-700	1.33-1.5	
SC	Alone - Poor (With lime - Good)	3.5-6.0+ ---	4.0-6.0 3.0-4.0	400-700	1.33-1.5 1.33-1.5	Needs addition of small percentage of lime.

men content of 5.4 percent with a penetration of 20. The material was crushed, graded, separated into four sizes, and recombined to produced a 100 percent recycled mixture.

These studies (1 and 9) demonstrate the feasibility of using salvaged material to produce a foamed, recycled mixture with or without virgin material. Generally, the mixture properties were reported to have improved when fines were added to the salvaged material.

2.2 Bitumen

The percentage bitumen included in a foamed bitumen mixture is a function of the soil type and moisture content, and the desired mixture properties. Generally, foamed bitumen mixtures can be prepared at lower bitumen contents and contain about the same properties as conventional cold mixtures (2 and 4) at higher bitumen contents. Typical bitumen contents for foamed mixtures range from 3 to 6 percent. The most significant factors affecting the film thickness of the bitumen are adhesion between the aggregate and the bitumen temperature of both, viscosity, cohesion, and the surface tension as well as quantity of the bitumen at mixing temperature. When the films are too thick, the bitumen simply lubricates the aggregate particles. When the films are too thin there may not be enough bitumen for coating with a resulting decrease in mixture stability and high strength loss when tested wet.

Brennan (9) reported excellent Marshall stabilities by adding 0.5 and 1.0 percent bitumen by total weight, to salvaged material with stabilities peaking at 1 percent bitumen. The effect of water on stability decreased with increasing bitumen content as did the percent adsorbed water.

While almost any bitumen cement (5) can be foamed, Abel (4) reported that the lower viscosity bitumen foamed better than higher viscosity bitumen but the higher viscosity bitumens produce better aggregate coating. Brennan, et al (9) evaluated the foaming characteristics of half-life* and expansion ratios** for three different types of bitumen in common use. Shackel et al (11) reported that mixtures made from higher penetration bitumen were less susceptible to deformation under repeated loading but with subsequent lower resilient moduli.

3. CONSTRUCTION CONSIDERATIONS

3.1 Prewetting of the aggregate and moisture content

From laboratory test conducted by Brennan [9], it is necessary to add a small amount of water to the aggregate prior to mixing so that the foamed bitumen would thoroughly coat and adhere to it. The water content for the fluff point -- the point which gives the material its maximum loose volume -- proved to be the ideal for mixing purposes.

Sufficient water provides good distribution of the bitumen whilst insufficient water can result in a sticky mix that cannot be laid[8].

Excessive water will on the other hand result in unusually long curing times and a drop in density and strength.

Anderson, et al[5], noted that the percentage of water required to produce each of the properties of maximum strength, maximum density, minimum total moisture adsorption, and minimum expansion will be different.

Lee[1] recommended an "optimum mixing moisture content" of about 65 - 85 % of the AAHSTO optimum moisture content, and he stressed that the moisture content of the soil aggregate prior to mixing is the most important factor in foamed bitumen mix design. The repeated load study by Shackel, et al[11], also highlighted the importance of moisture as expressed in terms of degree of saturation (Sr.)

* Half-life -- the time in seconds between completion of the foam sample withdrawal and the time at which the foam level is at half its maximum height.

** Expansion ratio (foam volume ratio)-- the ratio of maximum foam volume for a given sample to the volume of original bitumen in the samples.

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An increase in degree of saturation (Sr) led to an increase in initial strain under repeated loading for all mixes provided, Sr ≥45 %.

In the range 0 - 100 % the initial strain decreased to a minimum and then increased. An increase in degree of saturation also led to a reduction of stiffness, an increase in the ratio of accumulation of strain and a reduction in the ratio of the resilient to peak strains.

The highest resilient modulus was obtained at Sr of 50 - 70 % for foamed mixes. The compaction conditions must be such that material is on the dry side of the optimum moisture content.

3.2 Method of Construction and Curing

Most foamed bitumen mixtures have been mixed in a conventional pugmill, fitted with a special spraybar for mixing the water and bitumen to produce foam.

Acott[7] proposed the use of a drum mixer pugmill and on site mixing for stabilization with foamed bitumen.

The mixture is placed and compacted with conventional equipment. The material looks like, and lays down, like wet untreated aggregate. Foamed mixes can be compacted immdediately after laydown and traffic may be allowed on the pavement shortly after compaction.

The curing of foamed bitumen occurs after mixing when the water in the mix evaporates[4, 5].

Foamed bitumens have a longer curing thime than the conventional, and results of tests show that the foamed bitumen is extremely sensitive to the method and length of curing time.

A positive influence resulting from the long curing time is that the mix can be lifted, reworked and laid with no detrimental effects[8].

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Bowering[10] also stressed the importance of curing and stressed that foamed bitumen specimens did not develop their full strength until they have lost a large percentage of the mixing water subsequent to compaction.

Brennan[9] stated that in order to achieve best compacted density results. It was necessary for most of the water needed for mixing to evaporate. He used a forced draft oven at 140°F for hours after mixing to dry the recycled mix prior to compacting.

From these laboratory studies it is therefore suggested that field mixes must be stockpiled in low stockpiles for several days to facilitate the loss of mixing water prior to spreading out on the road and compacting. Additional curing time should also be allowed after compaction.

DIFFERENCES BETWEEN COLD AND HOT MIXTURES

Besides the obvious differences in heating the mineral aggregates as a part of the specimen preparation, there are two other major differences between cold and hot bitumen mixtures that should be mentioned. First, a curing period is required for cold mixtures bothe in the laboratory before testing, and in the field before being subjected to traffic unless used in stockpile. Second, significant strength losses for colg mixtures occur when the materials get wet. These two differences require that, in the laboratory analysis, factors related to both the curing period and moisture conditioning prior to testing be very carefully defined, so that the results can be compared to data from other studies, and between materials tested as a part of this study.

LABORATORY STUDIES

In order to gain experience with the laboratory foaming device and to evaluate the sensitivity of material properties to variations in mixture variables, a preliminary laboratory study was conducted using a blend of two field sands from District 11 of the Texas State Department of Highways and Public Transportation (SDHPT). This was supplemented with conventional cold mixes using emulsions and a cutback for comparison.

Cold recycled mixtures

Once the preliminary study was completed and the effect on strength of factors such as speciment curing methods, moisture content, and bitumen content was determined, the main laboratory study to evaluate the characteristics of foamed recycled mixtures was conducted. As an adjunct to this study, specimens were also prepared with salvaged material using an MC-800 cutback and two emulsions in order to compare properties of foamed specimens with those prepared using traditional cold-mixed procedures. The properties of the bitumen used in the laboratory study are included in Table 2.

PRELIMINARY LABORATORY STUDY

Speciment Curing

Because of the effect of curing on the properties of foamed specimens, a modification of the accelerated curing system reported by Bowering (10) was adopted Bowering tested a variety of materials in the laboratory and concluded that the speciment moisture content reaches equilibrium after 3 days of curing in a 140°F (60°C) oven with subsequent curing involving either soaking specimens at 75°F (24°C) for 3 to 4 days or dry curing them at 75°F (24°C) for the same period. In this study the curing cycle was modified to fit into a weekly schedule by lengthening the oven cure to 4 days at 140°C (60°C) followed by either the "wet" or "dry" 3-day cure at 75°F (24°C). The "wet" cure consisted of 2 hours of 26 in. vacuum-saturation followed by 3 days of soaking at 75°F (24°C).

Sand Gradation

The sands from Lufkin (SDHPT District 11) consisted of a fine white sand and a coarser sand that were blended in equal parts. The fine sand consisted of particles sized so that 100 percent passed the No. 200 sieve. The coarse sand gradation consisted of particles sized so that 100 percent passed the No. 10 sieve, 70 percent passed the No. 40 sieve, 10 percent passed the No. 80 sieve, and 5 percent passed the No. 200 sieve. (Fig. 1)

Cold recycled mixtures

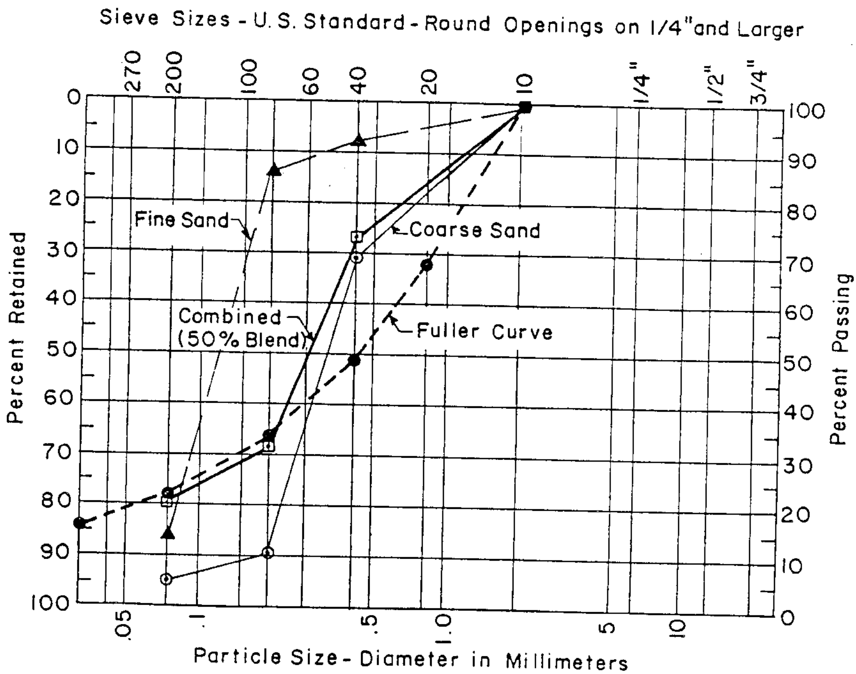

Figure 1 Gradation of Lufkin sand.

TABLE 2. BITUMEN PROPERTIES FOR MATERIALS USED IN LABORATORY STUDY

Tests on Residual bitumen	
Recycle Project	
Penetration (77°F)	37
Ductility (cm)	141
Viscosity @ 140°F (Stokes)	5592: 5549
Tests on New bitumen	
399 Cutback MC-800	
Producer: Cosden Oil & Chemical Co.	
Penetration (77°F)	208
Kinematic Viscosity (140°F)	1266
395 AES - 300	
Producer: Texas Emulsions, Inc.	
Furol Viscosity (77°F)	180
Penetration (77°F)	300
398 EA-11M	
Producer: Texas Emulsions, Inc.	
Furol Viscosity seconds at (77°F)	74
Penetration (77°F)	134
274 AC - 5	
Producer: Dorchester	
Penetration (77°F)	208
Viscosity	

Cold recycled mixtures

Preliminary Test Result Summary

Specimens prepared at different bitumen and initial water contents and tested in the Hveem stabilometer and indirect tensile test (Ref 13) showed that:

(1) There was a significant increase in tensile strengths as curing temperatures increased from 75°F (24°C) to 140°F (60°C). (Fig. 2)
(2) Specimens tested after wet curing had approximately 50 percent of the strength of those tested after dry curing. (Fig. 3)
(3) Stabilities of all specimens were low as is typical of sand-bitumen mixtures and the stability decreased with increased bitumen content.
(4) In figure 4 the effect of moisture content at testing is shown.
(5) Stabilities of foamed bitumen specimens were higher than that for sand mixtures prepared with MC-800 cutback and AES-300 and EA-11M emulsions. (Fig. 5)
(6) Indirect tensile strengths for the foamed sand bitumen were also higher than those for either the cutback or the emulsions. (Fig. 6)

LABORATORY STUDY OF SALVAGED PAVEMENT MATERIAL

After familiarization with the equipment, material handling, and curing of foamed bitumen materials, a laboratory study was conducted to evaluate the characteristics of salvaged materials recycled using foamed bitumen. The purposes of the study were to evaluate the properties of foamed recycled materials and to compare those properties to the properties of more traditional cold mixtures prepared with the same salvaged material, but using two emulsions and a cutback instead of foamed bitumen cement.

Specimen and Preparation

The salvaged material was sieved into two sizes and recombined with 40 percent of material passing the No. 4 sieve and with 60 percent material retained on the No. 4 sieve while material larger than 3/4 inches was discarded. This gradation is shown in Figure 7. In preparing the foamed bitumen materials the mixing water varied from zero to approximately 2 percent by weight of aggregate.

Cold recycled mixtures

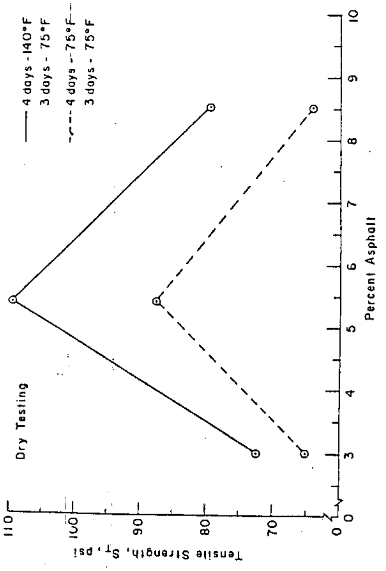

Fig 2. Effect of curing mode on tensile strength of foamed sand specimens.

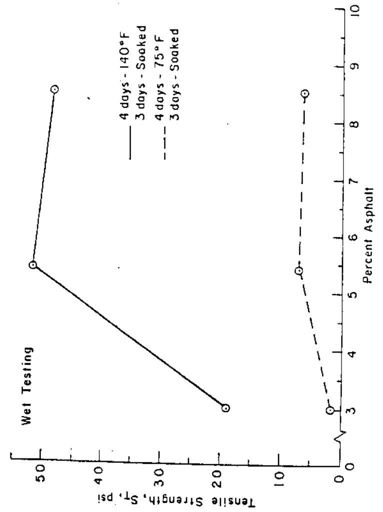

Fig 3. Effect of curing on tensile strength of foamed sand specimens.

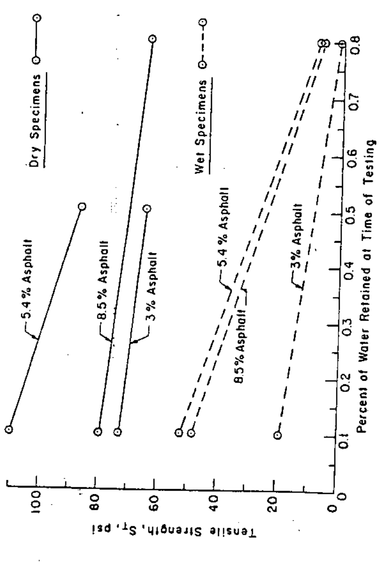

Fig 4. Effect of water content on tensile strength of foamed sand specimens.

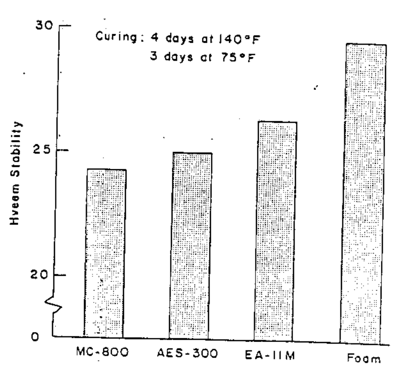

Fig 5. Hveem stabilities of sand mixes all at 5.4% A.C. content.

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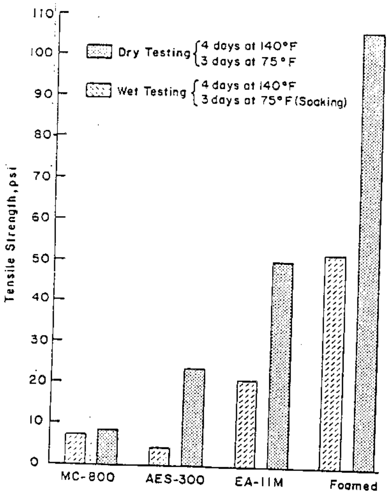

Fig 6. Tensile strengths of sand mixes all at 5.4% A.C. content

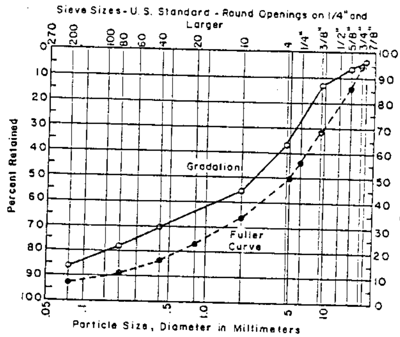

Fig 7. Gradation of salvaged pavement materials from SDHPT District 13.

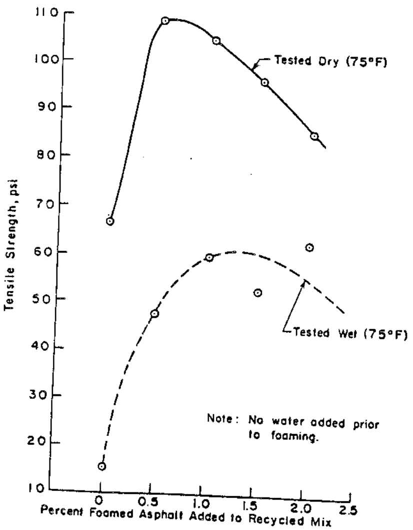

Fig 8. Comparison of tensile strength at various percentages of foamed asphalt (no water in mix prior to foaming).

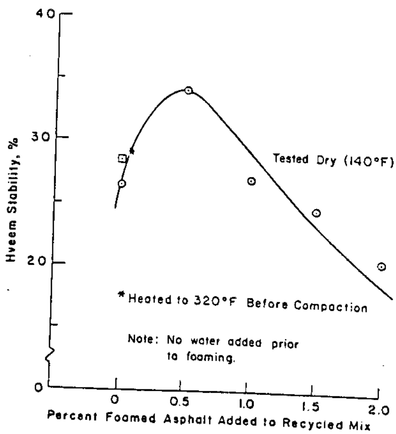

Fig 9. Comparison of Hveem stability to percentages of foamed asphalt with no water added prior to foaming.

EXPERIMENTAL PROGRAM

The first series of tests were performed on specimens prepared from salvaged materials that had no water added before mixing. These specimens were cured for 7 days at 140°F (60°C) with 3 additional days at 75°F (24°C) either dry or submerged in water (wet).

A second series of tests were conducted to evaluate the effect of mixing water content and curing temperature on the strengths of the foamed, recycled bitumen mixtures. The water content before mixing varied from zero to two percent. The curing temperatures ranged from 140°F (60°C) to 75°F (24°C) for the initial 4-day cure and the final 3 days of curing was at 75°F (24°C) either dry or submerged in water (wet).

A third series of tests involved using the salvaged material to prepare specimens with two emulsified bitumen and one cutback bitumen. Test results from these specimens were used to compare the properties of foamed, recycled specimens to those of specimes prepared using traditional cold mixed processes. To ensure accurate comparisons, curing conditions for all specimens were kept constant.

Specimens were tested using the indirect tensile and Hveem stability tests. In addition to engineering properties, various other standard tests were conducted on specimens to determine specific gravity, density, air void content, bitumen content, and gradations to evaluate the characteristics of foamed, recycled bitumen specimens and to compare those results to specimens prepared using other techniques or materials.

TEST RESULTS - SERIES 1 - NO MIXING WATER

Specimens were prepared at bitumen contents varying from zero to 2 percent and tested at 75°F (24°C) after the dry and wet curing periods. Due to the foaming process the amount of water in the mix varied from about 0.5 percent to 1.0 percent, averaging about 0.8 percent at the time of compaction.

Figure 8 contains tensile strength results for dry and wet cured specimens. The dry cured specimens show a very definite optimum at 0.5 percent foamed bitumen while the wet cured specimens achieved a maximum tensile strength at about 1 percent. In general, the strengths of the dry cured specimens were about twice those of the wet cured specimens. Strength losses of this magnitude are fairly typical of foamed bitumen specimens tested wet (9 and 10).

Hveem stabilities for dry cured specimens are contained in Figure 9 along with the stabilities for specimens of salvaged material heated and compacted at 320°F without the addition of new bitumen.

These data show that only specimens with around 0.5 percent foamed bitumen would meet the Texas SDHPT Type B stability requirement of 30. However, it should be noted that the stabilities of the foamed specimens compare favorably with those of the salvaged material that was only heated before compaction and subsequent testing. Since stability tests are performed immediately after curing and since no soaking is prescribed in the procedure, stability tests were performed only on the dry cured foamed bitumen specimens.

The static moduli of elasticity of both dry and wet cured foamed recycled bitumen specimens and of recycled mixtures which were heated to 320°F before compaction and testing are shown in Figure 10. The static moduli were fairly constant for both dry and wet cured foamed bitumen specimens for bitumen contents between 0.5 and 1.5 percent. Above and below this range the static moduli decreased significantly. In the bitumen content range between 0.5 and 1.5 percent the static moduli for the dry cured specimens were approximately three times the moduli for the wet cured specimens, indicating again the significant effect of moisture on the engineering properties of foamed bitumen mixtures. The static moduli for the recycled mixtures which were only heated before compaction and testing were higher than those for the foamed bitumen specimens and the strength loss was much less for the wet specimens.

Figure 11 shows the relationship between foamed bitumen content and density for both the wet and dry cured specimens. The optimum bitumen content for both sets of data indicate that about the same density can be achieved between 0.5 and 1.5 percent bitumen. The percent of theoretical maximum density achieved for the dry cured specimens ranges from about 93 to 95 percent for bitumen contents ranging from 0.5 and 1.5 percent bitumen. The density for the recycled mixtures which were only heated before compaction and testing was about 7 pcf higher than that for the foamed, dry cured specimens.

TESTS RESULTS - SERIES 2 - EFFECT OF MIXING WATER ON PROPERTIES

Specimens were prepared at 0.5 and 1.0 percent bitumen with the water content at compaction varying from 0 to slightly greater than 2 percent. Both the foaming process and the premixing water contributed to the total water in the material at compaction; therefore, water contents were determined from the weights of specimens immediately after compaction and after curing 4 days at ± 40 °F.

The effect of mixing water content and bitumen content on tensile strength are shown in Figure 12. For both those specimens tested wet and those tested dry the total liquids at optimum were about the same, i.e., the percent water in the specimens with 1.0 percent bitumen is about 0.5 percent less than for the specimens with 0.5 percent bitumen. In addition, the loss of tensile strength between the dry and wet specimens is consistent with that previously shown in Figure 8 and in the preliminary testing.

No significant differences in density were observed for the wet specimens at either 1.0 or 0.5 percent bitumen. The increased wet tensile strength at 1.0 percent bitumen is apparently due to the cohesion from the extra bitumen.

Figure 13 shows the effect of both bitumen content and moisture content at compaction on Hveem stability. As expected, the stabilities are lower for specimens prepared with 1.0 percent foamed bitumen since at the same water centent the total volume of liquids is larger than for 0.5 percent bitumen, producing additional lubrication and hence lower stability. The optimum moisture content is about 0.5 percent lower for the 1.0 percent bitumen

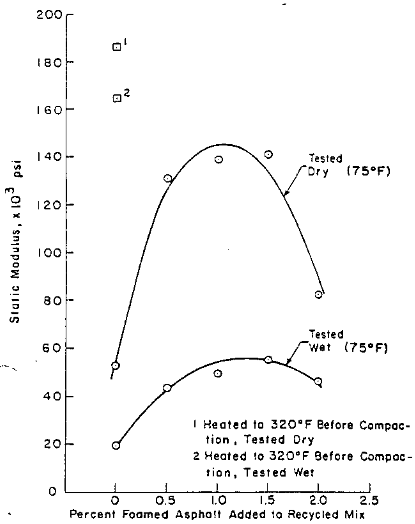

Fig 10. Comparison of modulus values to percentage of foamed asphalt with no water added prior to foaming.

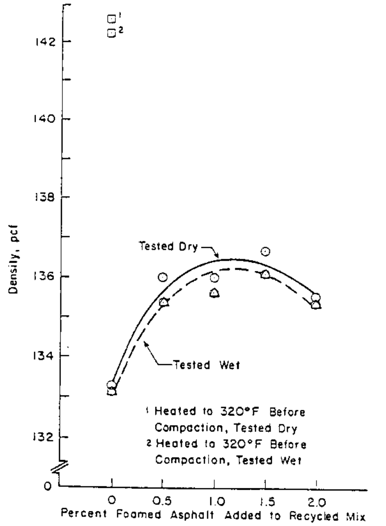

Fig 11. Relationship between density and percentage of foamed asphalt with no water added prior to foaming.

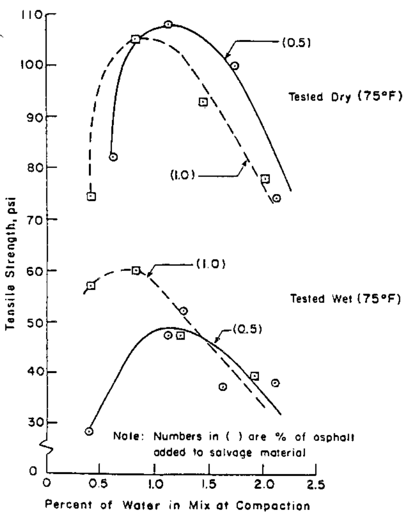

Fig 12. Comparison of results of foamed specimens at different mixing water and asphalt contents.

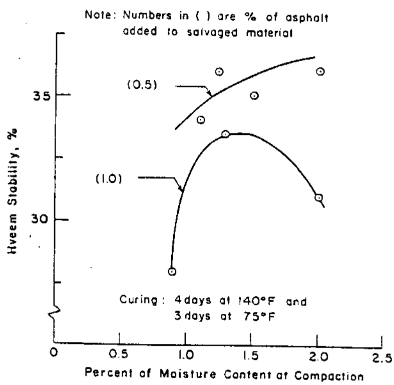

Fig 13. Effect of moisture content at compaction on the Hveem stability of foamed specimens.

curve than for the 0.5 percent bitumen, again as a result of the effect of the total liquids in the mixture. In fact, the optimum stability for both curves occurs at about the same total liquids content of approximately 2.2 percent.

The effect of temperature during the initial 4-day curing period on the tensile strength of specimens tested dry and wet is shown in Figure 14. These specimens were compacted from a different mixture. Due to variations in AC content of the slavaged material, the results are different from those obtained in Series 1 (Fig 8). The foamed bitumen content varied from 0 to 1.0 percent. For the specimens tested dry, the optimum foamed bitumen content was 0.5 percent. However, for the specimens tested wet, however, the effect of curing temperature was much more significant than the effect of bitumen content, indicating the tremendous impact of curing conditions on the properties of this type of pavement material. The higher the initial curing temperature the less the effect of moisture for the wet tests and the lower the strength loss due to wetting. For the specimens tested dry, the effect of bitumen content was much less than for those tested wet; however, a well-defined optimum bitumen content occured at 0.5 percent.

The effects of the temperature during and the length of the curing period on tensile strengths were also investigated and the results from specimens tested wet after curing are shown in Figure 15. These specimens were prepared from a different mixture. Due to variability of bitumen content of salvaged material, results are somewhat different from those of Figure 14. These results show that the higher the temperature during curing the higher the tensile strength, but that about 75 % of the strength was developed after 4 days of curing for all curing temperatures. After curing begins, if the curing temperature is increased to 140°F, the tensile strength also increased, but at a lower rate than for specimens that began curing at 140°F.

TEST RESULTS - SERIES 3 - COMPARISON WITH EMULSIONS AND CUTBACKS

To evaluate the engineering properties of foamed bitumen specimens a series

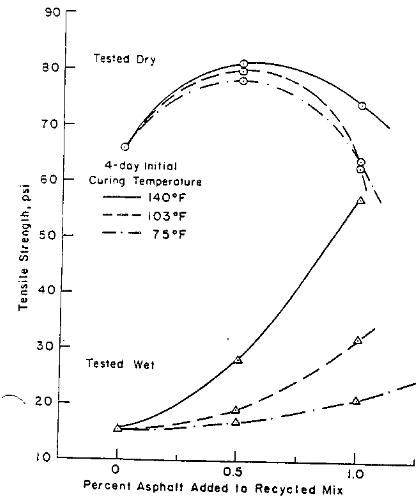

Fig 14. Effect of curing on tensile strength with "dry" mixing of foamed specimens.

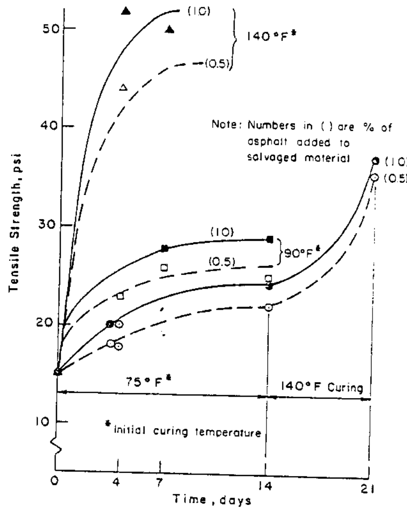

Fig 15. Effect of curing temperature and length of curing period on tensile strength of specimens tested after soaking.

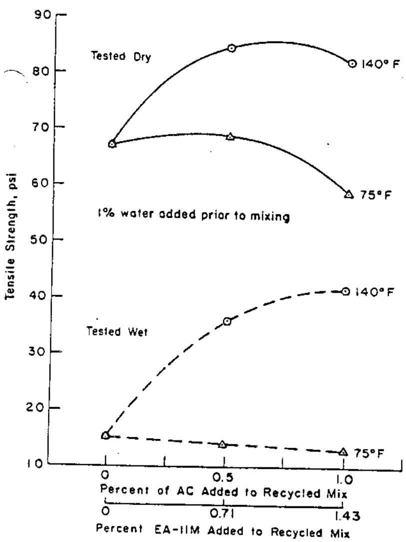

Fig 16. Comparison of tensile strengths at various percentages of emulsion EA - 11M (70/30).

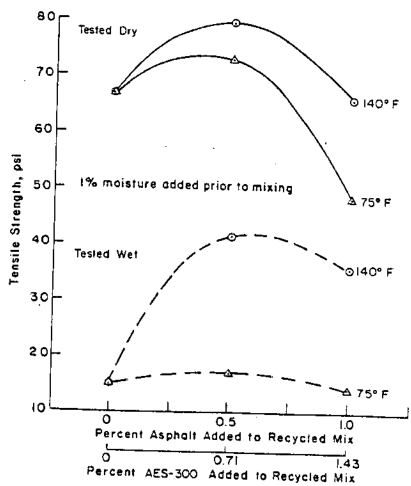

Fig 17. Comparison of tensile strength at various percentages of emulsion A.C. and curing effects AES - 300 (70/30).

of comparison tests were conducted on cold mixed specimens prepared using selected emulsions and a cutback bitumen. The foaming process caused a moisture content of ± 1 percent at compaction. Pre-mixing water of 1 percent was added to the emulsion mixed for consistency. Specimens were prepared and cured in the same manner as for the foamed bitumen specimens. One set at 140°F for 4 days followed by 3 days of either wet or dry curing at 75°F, and a second set at 75°F for 4 days and then either wet or dry cured for 3 days at 75°F. The specimens were then tested immediately after dry curing were designated as "tested dry" while those tested after wet curing were designated as "tested wet".

Test results for the specimens prepared with EA-11M and AES-300 emulsions are shown in Figure 16 and 17 while the results for specimens prepared with the MC-800 cutback are shown in Figure 18. The same basic trends as for the foamed, recycled bitumen are evident in these relationships. The tensile strength of the dry specimens cured at 140°F for 4 days exhibited a fairly well defined optimum bitumen content of 0.5 percent for both the dry tested specimens and the wet tested specimens cured at 140°F. Generally, the strengths of the specimens prepared with emulsions and cutbacks compared favorably with those of similar specimens prepared with foamed bitumen. However, as shown in Figure 19, the tensile strengths for the specimens prepared with foamed bitumen were consistently higher than those for specimens prepared with either of the other bitumen materials, the differences were as significant for the specimens cured at 75°F for 4 days, wet cured (soaked) at 75°F for 3 days, and then tested.

Hveem stabilities from specimens prepared with foamed AC5, EA-11M, AES-300 and MC-800 and then dry dured are shown in Figure 20. Specimens prepared using the foamed AC5 and EA-11M bitumens showed higher stabilities than those prepared using AES-300 and MC-800. Except for the MC-800 specimens, the optimum bitumen content for stability occurred at 0.5 percent. Stabilities were low at both 0.0 and 1.0 percent added bitumen with no bitumen added, the air voids ranged from about 4.3 to 6.5 percent as shown in Figure 21. It is obvious that the foamed bitumen specimens were compacted to a higher density than were specimens prepared with either the emulsions or the cutback. This ease of compaction could have resulted from better distribution of the bitumen because of the thinner films produced by the

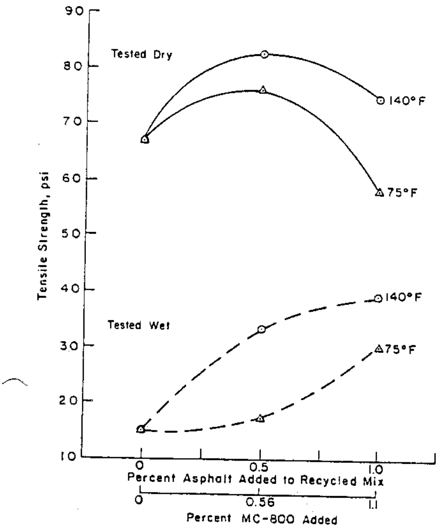

Fig 18. Comparison of tensile strengths at various percentages of cutback MC - 800.

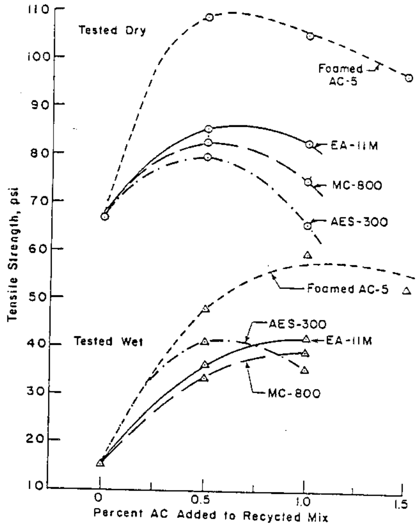

Fig 19. Comparison of tensile strength results for foamed, emulsions, and cutback specimens.

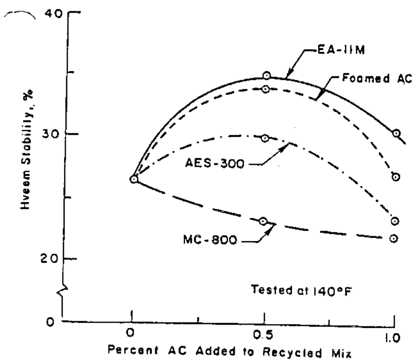

Fig 20 Hveem stability in relation to emulsions, cutbacks, and foamed specimens at various percentages of asphalt.

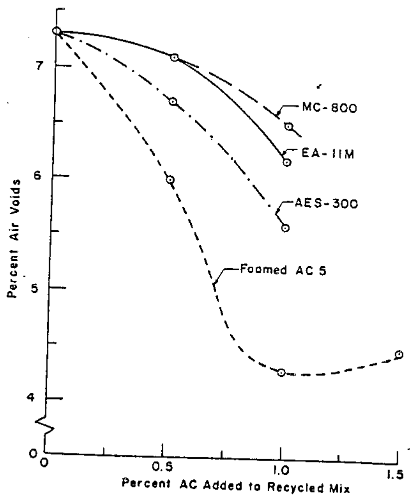

Fig 21 Air void contents for mixtures prepared using different asphalts.

foaming process and from the lubricating effects of extra water introduced into the foamed materials from the cold water that produced the foaming of the bitumen. It is recommended that pre-wetting of the aggregate (≤1 percent water) will assist in lubrication of both foamed and emulsion mixes.

CONCLUSIONS AND REMOMMENDATIONS

Based on the data collected in this limited laboratory study using one salvaged pavement material, one blend of field sands, an AC-5 bitumen, two emulsions, and one cutback, the following tentative recommendations and conclusions were prepared.

CONCLUSIONS

1. The foamed bitumen specimens prepared from both the salvaged pavement materials and the Lufkin sand exhibited equivalent engineering properties to specimens prepared using either the emulsions or the cutback.

2. Curing temperature, length of curing and moisture conditions dramatically affected the strength of foamed bitumen mixtures prepared using either the sand or the salvaged pavement materials.

3. Conventional cold-mixed materials are also dramatically influenced by curing temperature and moisture conditions.

4. All cold specimens lost at least 50 percent of their strength when tested "wet" as compared to the strengths when tested "dry".

5. The engineering properties of the foamed salvaged bitumen specimens were substantially less than the properties of mixtures prepared by heating the salvaged materials before compaction. Specimens prepared from the heated materials were compacted to much higher densities than were achieved for any of the cold-mixed materials.

6. Within the range of values investigated, increases in bitumen content for specimens prepared from foamed bitumen recycled materials increased the strength of the specimens tested wet but decreased the strength

of the specimens tested dry.

7. Hveem stabilities were significantly affected by the total volume of liquids added to the salvaged materials with these changes being more pronounced at higher bitumen contents.

RECOMMENDATIONS

Although foamed mixtures do not appear to be suitable for high quality wearing courses, partly due to lack of coating of the larger sized aggregates, they should perform very well in the base course.

In the conservation of energy by the utilization of all types of local aggregate, the cold-mixed materials offer a real economic solution to low cost paving.

In this day and age of rapid depletion of good aggregate sources, cold mixed material sould point the way to the cost savings atteinable, by using sub-standard aggregates. Together with the savings of vast amounts of money if costly transportation of aggregates is no longer necessary, it can contribute to make the cold mixed product such that it will extend the construction rand considerably.

Another use with real savings potential is in the paving of gravel roads and roads in the sparsely populated rural areas. The savings in maintenance on these roads should pay for the cold mixed paving within a couple of years.

Another major usage is for shoulders on major highways as well as base courses of rural roads. It may even be used in the base course of major highways provided that the possiblility of damage due to outside water is remote.

The largest drawback of cold mixes is the water susceptibility with an enormous drop in tensile strength with saturation.

It is also of the utmost importance that curing must take place before traffic is allowed onto the pavement.

From results of tests conducted to determine the effect of curing prior to compaction, the conclusion can be drawn that foamed mixes should be cured in low stockpiles prior to spreading and compacting.

ACKNOWLEDGEMENTS

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