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Effect of Residual Asphalt Content on Creep Strain of Cement Modified Emulsified Asphalt Mixtures

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ORIGINAL ARTICLE

ABSTRACT: Objective of this paper is to determine the rutting performance of residual asphalt content on cement modified emulsified asphalt mixtures at heavy duty highways. For this purpose, emulsified asphalt specimens with dense graded aggregate were prepared according to Marshall method for emulsified asphalt-aggregate cold mixture design. The specimens were prepared in such a way that portland cement was substituted for mineral filler in an increased percent from 0 % to 6 %. In this way, three asphalt emulsion mixtures with different residual asphalt contents of 4.2 %, 5.2 %, and 6.2 % by the mass of dry aggregate were produced. Static load asphalt creep tests were performed on the specimens. Based on the experimental work, it has been reached that dense graded cement modified emulsion mixtures are of great performance in rutting compared to hot mixtures with the same aggregate grading and bitumen content. Results showed that cement acts as a secondary binder in emulsion mixture. Creep and permanent deformation resistance are all improved by portland cement addition but the resistance to creep deformation of emulsion mixture was decreased by the increase of residual asphalt content.

Keywords: Asphalt Emulsion, Residual Asphalt Content, Cement, Rutting, Creep And Permanent Deformation

INTRODUCTION

Portland cement has been used primarily as filler in warm-mixed bituminous mixtures to prevent stripping of the binder from previously dried aggregate. It has also used to enhance the coating of wet aggregate with bitumen or tar (Transport and Road Research Laboratory, 1969). Schmidt and Graf (1972) also indicated that dramatic water resistance and a large increase in the dry resilient modulus (M_r) of the hot mixes with some aggregates by adding the cement and lime as a slurry to the aggregate before 24 h by the production of hot mixture.

Schmidt et al. (1973) studied the effect of adding cement in an attempt to improve the slow development of strength of emulsion-treated mixes. The cement was added to the aggregate in the course of asphalt emulsion was incorporated. Their study showed that mixes treated in this way cured faster, developed a high M_r more rapidly, and were more resistant to water damage. Terrel and Wang (1971) had also shown that the rate of development of M_r in emulsion-treated mixes is greatly accelerated by the addition of cement.

Head (1974) has reported the results of research on cement-modified asphalt cold mixes. This research indicated that addition of cement had a very significant effect on mix stability; addition of 1 % cement produced an increase in stability of 250-300 % over that of untreated samples. Uemura and Nakamori (1993) have reported use of portland cement in emulsion mixtures for years in Japan. They pointed out that performance of these mixtures was acceptable level and more environmental.

Li et al. (1998) conducted experiments to evaluate the mechanical properties of a three-phase cement-asphalt emulsion composite (CAEC). Through experimental investigation, they reported that CAEC possessed most of the characteristics of both cement and asphalt, namely the longer fatigue life and lower temperature susceptibility of cement concrete, and higher toughness and flexibility of asphalt concrete.

In a study carried out on asphalt emulsion mixtures, or cold mix (Brown and Needham, 2000), it was put forward that mechanical properties were affected by a number of parameters, including binder grade, void content, curing time and additives such as cement. In addition, field trials indicated that cold mix can be produced using conventional hot mix plant and laid using similar techniques. Besides, in the study, it was indicated that emulsion droplet coalescence was affected by pressure, bitumen type, emulsifier level, cement and temperature and that cement causes emulsion charges to become more positive (or less negative) but other parameters had no effect on charge.

Pouliot et al. (2003) aimed at understanding the hydration process, the microstructure, and the mechanical properties of mortars prepared with a new mixed binder made of a cement slurry and a small quantity of asphalt emulsion (SS-1 and CSS-1). They indicated that the cement hydration process was nominally influenced by the presence of a small quantity of emulsion. They also indicated that mortars made with the cationic emulsion

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(CSS-1) showed higher strengths and elastic modulus than mortars made with anionic emulsion (SS-1).

Song et al. (2006) purposed to evaluate the feasibility on the use of an asphalt emulsion as a polymeric admixture. They showed that waterproofness, carbonation resistance and chloride-ion penetration resistance of the asphalt-modified mortars were markedly improved with the increase in the polymer-cement ratio, while their compressive strength and adhesion to mortar substrates were reduced with the increase in polymer-cement ratio.

Wang and Sha (2010) studied characteristics of interface between cement asphalt emulsion mastics and aggregate is different from that of interface between cement and aggregate or asphalt and aggregate. A novel method was put forward to evaluate interface character of mixtures in the paper. MH-5 micro hardness apparatus was adopted to study influences of fillers' fineness, aggregate lithology and different type of cement on micro hardness of the interface between the mastics and aggregate; and some micro test apparatuses, such as SEM, XRD and EPMA, were used to analyze its mechanism. Results indicate that the increase of cement and mineral filler fineness is favorable to improve micro hardness of the interface, but over fine mineral filler is disadvantageous.

Wang (2010) studied the effects of cement and emulsified asphalt on structure formation of cement emulsified asphalt mixtures. The results indicate that binders' dosages can greatly influence structure formation and mechanical performances, such as Marshall stability and compression strength of cement emulsified asphalt mixtures. Effects of cement on structure formation can be summarized that to make the structure denser, to form net structure, to make up structure deficiencies, and to enhance interface adhesion. Effects of emulsified asphalt lie in that to form the mixtures structure, to deteriorate interface structure and to retard cement hydration.

Al-Khateeb and Al-Akhras (2011) investigated the effect of cement additive on some properties of asphalt binder using Superpave testing methods. Six cement-to-asphalt (C/A) ratios were considered in the study. The experimental tests that were conducted in the study included the Superpave rotational viscosity (RV) test and the dynamic shear rheometer (DSR) test. Results of the study showed that the addition of Portland cement to asphalt binders increased the rotational viscosity (RV) of asphalt binders at 135 °C and different rotational speeds. The C/A ratio had insignificant effects on the Newtonian behavior, the phase angle (δ), and the elastic behavior of asphalt binders. The increase in C/A ratio increased the stiffness of asphalt binders represented by the complex shear modulus (G*) value. The increase in the C/A ratio improved the rutting parameter, G*/sin δ value at all temperatures.

Al Nageim et al. (14) reported the experimental test results of a research project aimed at developing a new cold bituminous emulsion mixtures (CBEM's) containing fly ash from incinerated domestic and industrial by-products compared with those results of traditional control cold containing OPC and hot mix asphalt. The main objectives of the experiments were to investigate the improvement in mechanical properties of CBEM's due to incorporating OPC, and detect the possibility of replacing the OPC with waste fly ash materials. The mixtures mechanical properties investigated were: ITSM, creep stiffness. Durability in term of water sensitivity was investigated too. The results have shown comparative mechanical properties of CBEM's to HMA. Furthermore, the new CBEM's with fly ash used as a replacement of filler achieved outstanding results compared with traditional CBEM with and without addition of OPC. Therefore, this paper introduces a new CBEM's having outstanding mechanical characteristics, cost effective, and environmental friendly

The use of asphalt emulsion in Turkey is largely restricted to various types of surface treatment (such as slurry surfacing and surface dressing) and bond/tack coat. Recently, efforts have been directed to the use of emulsions in mixtures used for trench reinstatements and patching. Its use as a binder in cold mix for structural layers has attracted relatively little attention largely because of the problems associated with the time taken for full strength to be achieved after paving and the susceptibility to early life damage by rainfall. This research is done in order to solve the problems and to determine the influence of cement and asphalt content on emulsified asphalt mixtures in rutting on heavy duty highways.

MATERIALS AND METHODS

The aggregate used in this study is crushed limestone and the aggregate gradation is given in Table 1. Physical properties of the aggregate both coarse and fine aggregate, together with mineral filler are given in Table 2. Cement used in the study is PC 42.5 cement with a specific gravity of 3.108 g/cm^3 (Oruc, 2002 and Oruc et al., 2007).

Cationic slow setting emulsion (CSS-1) was used in the experimental program. The results of characterization tests of the emulsion and emulsion residue are shown in Table 3.

All of Marshall briquettes produced for this research was prepared according to Marshall method for emulsified asphalt-aggregate cold mixture design (Asphalt Institue, 1989). Emulsified asphalt’s ability to coat an aggregate is usually sensitive to the pre-mix water content of the aggregate. This is especially true for aggregates containing a high percentage of material passing a 75 µm (No. 200) sieve, where insufficient pre-mixing water results in balling of the asphalt with the fines and insufficient coating. For this reason, coating tests were performed at varying aggregate water contents. Total pre-mix water before mixing with emulsified asphalt was calculated as 3.5 % from coating tests. The total water content of the mixture was 5.97 %. Mixture properties are closely related to density of the compacted specimens. Thus, it was necessary to optimize the water content for compaction to maximize the desired mixture properties. To obtain reliable results, triplicate specimens were prepared for varying water content at compaction. Optimum water content for compaction was found as 3 % (that is water content resulting in the highest density).

Table 1. Aggregate gradation

Sieve	3/4 in.	1/2 in.	3/8 in.	No. 4	No. 10	No. 40	No. 80	No. 200
Passing (%)	100	86	74	56	38	18	9	6

Table 2. Aggregate properties

Coarse Aggregate (ASTM C 127)	
Bulk specific gravity (g/cm^3)	2.698
Apparent specific gravity (g/cm^3)	2.714
Absorption	0.33
Fine Aggregate (ASTM C 128)	
Bulk specific gravity (g/cm^3)	2.683
Apparent specific gravity (g/cm^3)	2.735
Absorption	0.62
Filler (ASTM D 854)	
Apparent specific gravity (g/cm^3)	2.743
L.A. Abrasion (%, C 131)	23.57
Polishing value (BS 813)	0.47
Sodium sulfate soundness (%, ASTM C 88)	2.44

Table 3. Test results of emulsion and emulsion residue.

Property	Value
Viscosity, Saybolt-Furol, 25 ^{o}C, s.	22
Settlement, 5 day, %	0.1
1 Day Storage Stability, %	0.03
Sieve Test, %	0.01
pH	5.37
Residue by Distillation, %	63.0
Residue Tests	
Penetration, 25 ^{o}C, 100 g, 5 s.	125
Ductility, 25 ^{o}C, 5 cm/min, cm	84
Solubility, %	99
Ash, %	0.5

Static and Repeated Load Asphalt Creep Tests

Specimens of asphalt emulsion mixtures were prepared for different ratios of portland cement instead of mineral filler using Marshall hammer compaction with 50 blows to each end of the specimen. The specimens were prepared with three levels of residual asphalt content of 4.2 %, 5.2 % and 6.2 %. Besides, conventional hot mixtures, with same aggregate type and grading, were prepared without cement for comparison. A bitumen content equivalent to the emulsion mixtures that the residual binder content was 5.2 % was used. Both the emulsion and hot mixtures were prepared in sufficient quantity to allow three 1100 g specimens to be produced from each mixture. The emulsion mixtures were prepared and compacted at ambient temperature, whereas the hot mix specimens were produced at a temperature of 140 ^{o}C. Specimens were demounted after about 20 hours and then cured in an environmental conditional room. Specimens of emulsion mixture were first tested after 3 days and periodically, as the specimens cured. Measured relative humidity is 73 % during the testing period.

RESULTS AND DISCUSSION

Uniaxial compression loading was used to determine the effect of cement on creep and permanent deformation of emulsified asphalt mixtures. Creep and permanent deformation tests were conducted in accordance with producers outlined in NCHRP (Quintus et al., 1991). Specimens were subjected to static load asphalt creep test for three levels of residual asphalt content; 4.2%, 5.2% and 6.2%. All tests were performed at 25^{o}C temperature after 28 days. At various cement additives, effects of bitumen amount on creep deformation (strain) are given in Figures 1-7. Besides, effects of cement on creep deformation are given in Figures 8, 9, and 10.

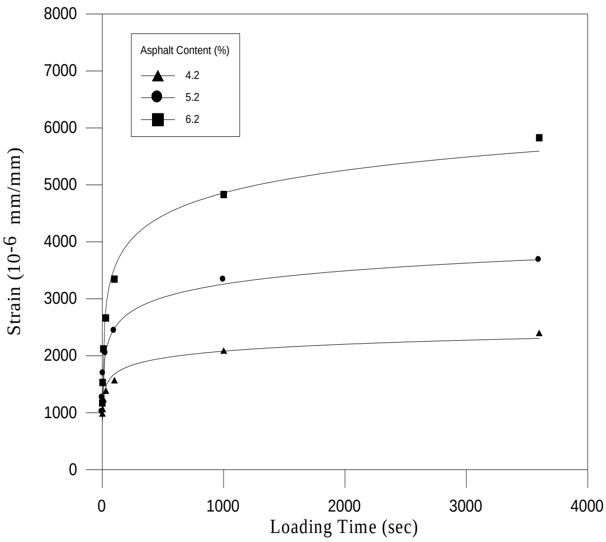

Figure 1. Effect of asphalt content on creep strain without cement

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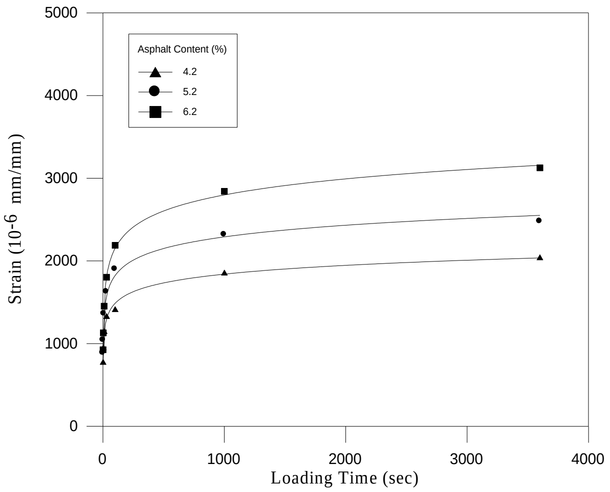

Figure 2. Effect of asphalt content on creep strain for 1% cement additive

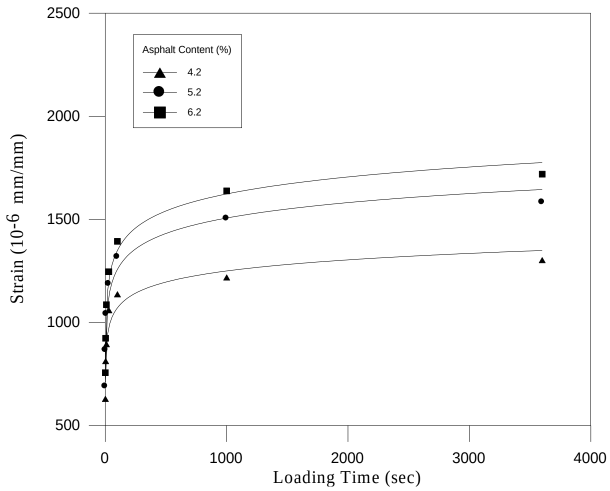

Figure 5. Effect of asphalt content on creep strain for 4% cement additive

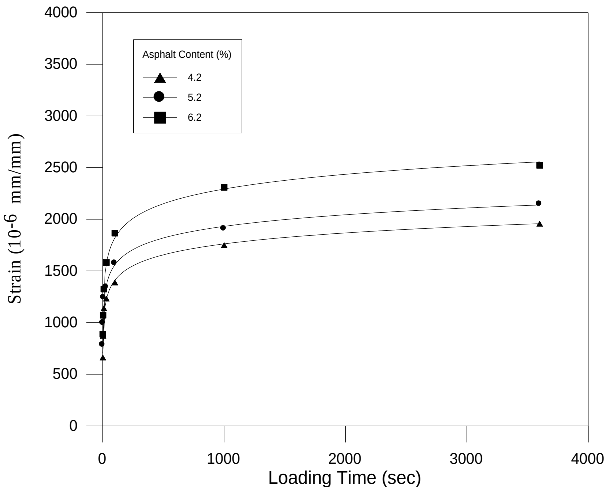

Figure 3. Effect of asphalt content on creep strain for 2% cement additive

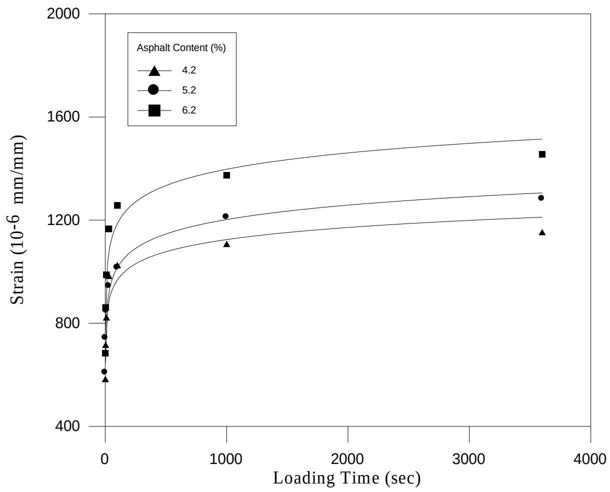

Figure 6. Effect of asphalt content on creep strain for 5**%** cement additive

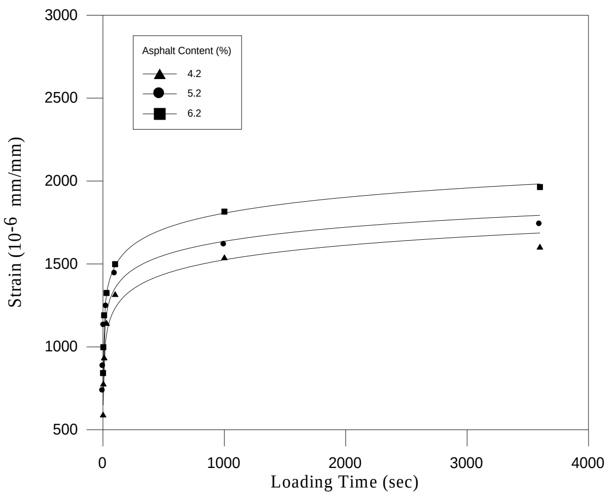

Figure 4. Effect of asphalt content on creep strain for 3% cement additive

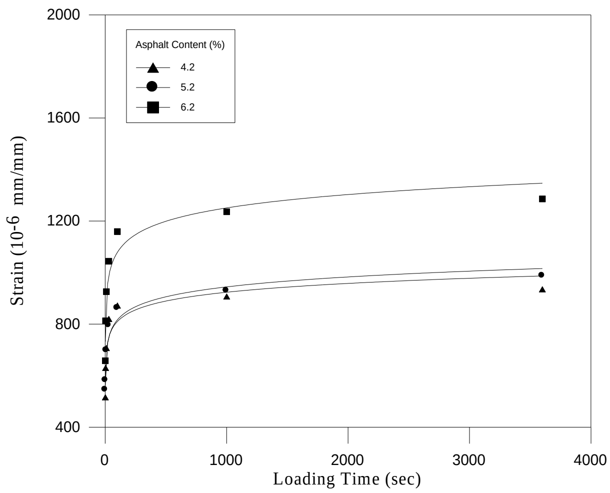

Figure 7. Effect of asphalt content on creep strain for 6% cement additive

Results of the uniaxial creep tests shown in Figures 1-7 indicated that increase of sudden deformation occurred by load applied. Then, increase of deformation slowed down. The rate of deformation increase of the emulsion mixtures increased with residual asphalt content. On the other hand, from results in Figures 8-10, the rate of deformation increase of the emulsion mixtures decreased with cement addition level.

Results of given in Figure 9 indicated that deformation of the hot mix was higher than the emulsion mixtures added even cement of 2 %. As expected, the creep modulus decreased with increased loading time.

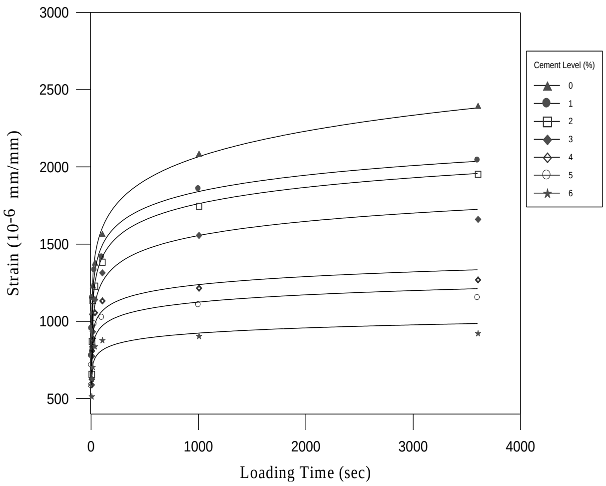

Figure 8. Effect of cement on creep strain for 4.2 % residual asphalt content

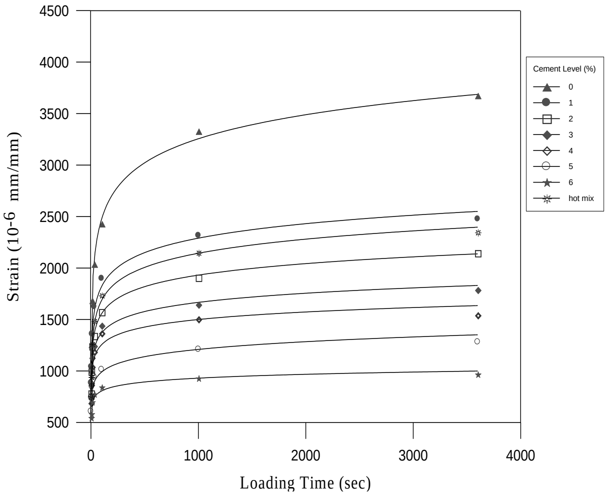

Figure 9. Effect of cement on creep strain for 5.2 % residual asphalt content

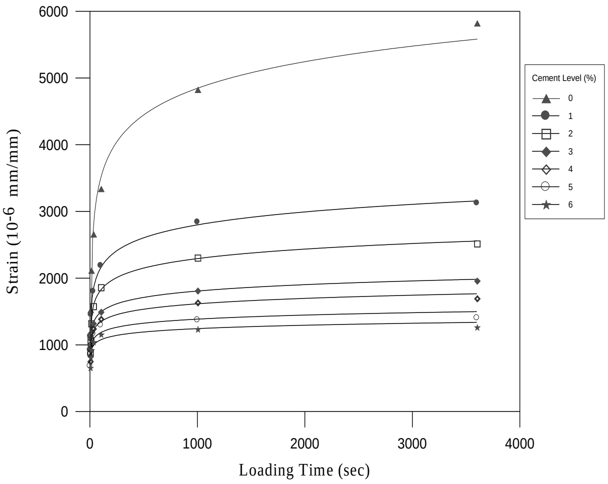

Figure 10. Effect of cement on creep strain for 6.2 % residual asphalt content

The results of static creep tests showed the enhancement of mixture creep resistance due to the addition of the cement, but, the results showed the decrease of the emulsion mixture creep resistance due to increase of asphalt content. Specimens of the emulsion mixtures prepared at 5.2 level of residual asphalt content were subjected to repeated load asphalt creep tests to determine permanent deformation characteristics of the emulsion mixtures (Alderson, 1995). The specimens were tested at 25°C temperature after 28 days curing time. The tests were performed at a load frequency of 1 Hz with 0.5 second loading and 0.5 second unloading for 45000 cycles. Figure 11 shows the averaged results obtained from the sets of three repeated load asphalt creep tests on specimens with different levels of cement (Oruc et al., 2007).

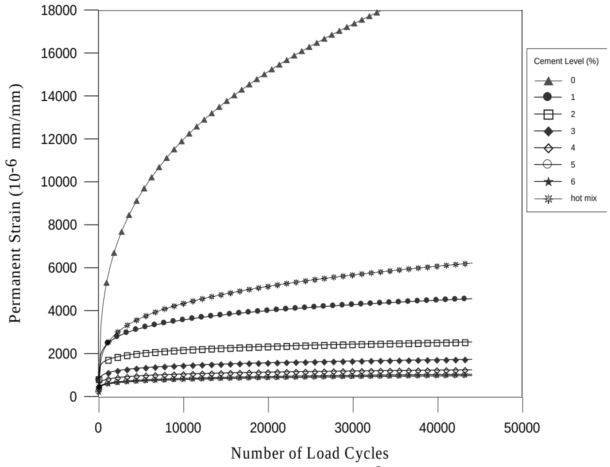

Figure 11. Permanent strains at 25°C for various cement contents compared with hot mix

From the permanent deformation results in Figure 11, the following points are worthy of note:

Without cement, emulsion mix specimens failed after less than 30,000 cycles, indicating that the unmodified emulsion mix has rather poor resistance to permanent deformation. The resistance to permanent deformation of emulsion mix was increased by the addition of cement. The emulsion mix specimens with cement offered better resistance to permanent deformation than hot mix (without cement). These results suggest that cement acts as a secondary binder in emulsion mix.

CONCLUSIONS

This experimental study has focused on the effect of asphalt content on creep properties of cement modified emulsified asphalt mixtures for structural layers in roads. Creep and permanent deformation levels in cement modified asphalt emulsion mixture are comparable with equivalent hot mixture. These properties take some time to develop but cement addition certainly improves the critical early life properties as well. The results of tests to measure creep properties confirmed earlier findings that the two key mechanical properties, creep and permanent deformation resistance are all improved by portland cement addition. But, the resistance to creep deformation of emulsion mixture was decreased by the increase of asphalt content. The work further revealed that the ultimate resistance to creep deformation achieved after curing and with increasing cement content up to 6% level and 4.2 asphalt content applied here. The rate of creep and permanent deformation increase of the emulsion mixtures increased with residual asphalt content. On the other hand, emulsion mix specimens without cement failed after less than 30,000 cycles, this indicates that the unmodified emulsion mix has rather poor resistance to permanent

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