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Effect of Cement on Emulsified Asphalt Mixtures

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Emulsified asphalt mixtures have environmental, economical, and logistical advantages over hot mixtures. However, they have attracted little attention as structural layers due to their inadequate performance and susceptibility to early life damage by rainfall. The objective of this article is to provide an improved insight into how the mechanical properties of emulsion mixtures may be improved and to determine the influence of cement on emulsified asphalt mixtures. Laboratory tests on strength, temperature susceptibility, water damage, creep and permanent deformation were implemented to evaluate the mechanical properties of emulsified asphalt mixtures. The test results showed that mechanical properties of emulsified asphalt mixtures have significantly improved with Portland cement addition. This experimental study suggested that cement modified asphalt emulsion mixtures might be an alternate way of a structural layer material in pavement.

Keywords asphalt emulsion, cement, emulsified asphalt concrete, cold mix, mechanical properties

1. Introduction

The use of cement in asphalt mixtures is not a new concept. Portland cement was used primarily as filler in warm-mixed bituminous mixtures to prevent stripping of the binder from previously dried aggregate. It was used to enhance the coating of wet aggregate with bitumen or tar (Ref 1). Schmidt and Graf (Ref 2) indicated that dramatic water resistance and with some aggregates a large increase in the dry resilient modulus (M_r) of the hot mixes were imparted by adding the cement and lime as a slurry to the aggregate 24 h before the hot mix was made.

Schmidt et al. (Ref 3) 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 at the time the 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 (Ref 4) previously showed that the rate of development of M_r in emulsion-treated mixes was greatly accelerated by the addition of cement.

Head (Ref 5) reported the results of research on cement-modified asphalt cold mixes. He 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. Specimens without cement immersed in water after stability tests disintegrated after 24 h, whereas cement-treated specimens indicated no deterioration.

Uemura and Nakamori (Ref 6) reported the use of normal Portland cement in emulsion mixtures for years in Japan. From their laboratory and field studies, they concluded that dust and gaseous emissions were eliminated as the aggregate and emulsified asphalt did not have to be dried for use in mixture. They pointed out that performance of emulsion mixtures was in acceptable level and they were more environmental.

Li et al. (Ref 7) 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 by Brown and Needham (Ref 8) on asphalt emulsion mixtures, or cold mix, 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 to this, field trials indicated that cold mix can be produced by using conventional hot mix plant and laid using similar techniques. 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. (Ref 9) 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 (CSS-1) showed higher strengths and elastic modulus than mortars made with anionic emulsion (SS-1).

Song et al. (Ref 10) 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.

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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 provide an improved insight into how the mechanical properties of cold mix might be improved. Previous studies, usually, included cement addition levels at limited ranges. In this study, the Portland cement was substituted for mineral filler in an increased percent from 0 to 6%. Additionally, there is very limited study on emulsified asphalt mixtures considering temperature susceptibility and creep deformation for dense graded mixtures. It is believed that this study will add new contributions to the literature.

2. 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 aggregate and fine aggregate, together with mineral filler are given in Table 2. Aggregate type has effects on determination of the emulsion type which can be either cationic or anionic. The reactivity of the aggregates depends on the proportion and distribution of negative charges. For example, acidic aggregates contain high silica (SiO_2) and have negative charges on surface of aggregate. These negative charges make the adhesion bond between the aggregate and the cationic emulsion much stronger. The aggregate used in this study contained high silica. Because of this cationic emulsion was selected to make high adhesion bond. 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. The physical and chemical properties of the Portland cement used in this study are given in Table 4 and 5, respectively.

All Marshall Briquettes produced for this research was prepared according to Marshall Method for Emulsified Asphalt-Aggregate Cold Mixture Design (Ref 11). Emulsified asphalt's ability to coat an aggregate is usually sensitive to the premix 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 premixing 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. According to the aggregate gradation given above, aggregate mix was coated with 6.69% emulsion asphalt. Premix water was calculated and observed to be 3.5% along with natural water content of aggregate 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. Optimum water content for compaction was found 3% (i.e., water content resulting in the highest density).

3. Advanced Testing and Results

3.1 Resilient Modulus Test

Specimens of asphalt emulsion mixtures were prepared using different ratios of Portland cement (0-6%) instead of mineral filler. Marshall hammer compaction was applied with 50 blows to each end of the specimen. In addition to the emulsion mixtures, conventional hot mixtures, with aggregate type and grading, were prepared for comparison without cement. A bitumen content equivalent to the residual binder content of the emulsion mixtures was used, which was 5.2%. 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 room temperature (22-25 °C), whereas the hot mix specimens were produced at a temperature of 140 °C. Specimens were demounted after about 20 h and then cured in an environmental conditional room.

The resilient modulus (M_r) test method developed by Schmidt (Ref 12) which is detailed in the ASTM Test Method for Indirect Tension Test for Resilient Modulus of Bituminous Mixtures (D-4123) was used in this study. Specimens of emulsion mixture were first tested after 3 days and periodically, as the specimens cured. The tests were carried out throughout 365 days at various periods. The specimens were tested at 25 °C. Pulse period and rise time were set to 1000 and 40 ms, respectively. The results of these tests are shown in Fig. 1. Additionally, after the specimens of emulsion mixture were cured for 28 days, they were tested at 5, 25, and 40 °C for temperature susceptibility. The results of the tests are shown in Fig. 2. Besides, specimens of emulsion mixtures were used for water-loss measurements, which were simply taken as the loss in mass. Measured relative humidity was 73% during the testing period. The results of the tests are shown in Fig. 3.

Results of the resilient modulus tests shown in Fig. 1 indicated that resilient modulus of the emulsion mixtures increased steadily over several months, in contrast with the hot mix which showed no attractive attention change. The rate of resilient modulus increase of the emulsion mixtures increased with cement addition level. The work further revealed that the ultimate resilient modulus was achieved after curing and the rate of resilient modulus gained increased with increasing cement content up to 6%.

The temperature susceptibility of hot mix (without cement) can be seen clearly in Fig. 2. The resilient modulus of hot mix decreases significantly as the temperature increases. The same trend can be observed for emulsified asphalt mixtures without cement and with low cement addition (1% cement). However, the resilient modulus increases as the addition of cement

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

	Value
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, %, ASTM 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

	Value
Property	
Viscosity, Saybolt-Furol, 25 °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 °C, 100 g, 5 s	125
Ductility, 25 °C, 5 cm/min, cm	84
Solubility, %	99
Ash, %	0.5

Table 4 Physical properties of the Portland cement

Physical properties	
Density, g/cm^3	3.108
Specific surface (Blaine), cm^2/g	2914
Mechanical properties	
7 day compressive strength, N/mm^2	33.2
28 day compressive strength, N/mm^2	43.1

Table 5 Chemical properties of the Portland cement

Content	% (by weight)
SiO_2 (Silicon dioxide)	20.60
Al_2O_3 (Aluminum oxide)	6.33
Fe_2O_3 (Ferric oxide)	3.01
CaO (Calcium oxide)	61.44
MgO (Magnesium oxide)	3.11
SO_3 (Sulfite)	2.89
Loss on ignition	1.35
Na_2O (Sodium oxide)	0.19
K_2O (Potassium oxide)	1.03
Total	99.95

increases and decreases as the temperature decreases. As a result, the level of cement addition in emulsified asphalt results in a significant increase in the resilient modulus and decrease of the temperature susceptibility. The resilient modulus values of emulsified asphalt mixture with high cement levels fall between resilient modulus boundaries (7.7×10^3-23×10^3 MPa) of 5 °C degrees in nomogram given in NCHRP (Ref 13). Although the boundaries are exceeded as temperature increases, this is an advantage. Because, it is known that rutting potential is highly correlated to resilient modulus of hot mix asphalt pavement. The lower the resilient modulus value of the pavement the higher the rut depth under high temperature and heavy traffic loads. The problems of high temperature are deformation and lubrication while the problems of low temperature are cracking and surface abrasion (Ref 13).

From the water-loss results in Fig. 3, the following points are worthy of note:

- The majority of the water loss occurred in the initial weeks after specimen production.
- Generally, it can be said that the addition of cement slowed down and decreased rate of water loss, but the results did not truly follow a trend.
- Evaporate of the water continued over several weeks, but evaporation stopped after about 8-10 weeks.

3.2 Static and Repeated Load Asphalt Creep Tests

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 (Ref 13). Specimens of the same design as those used in the resilient modulus tests were subjected to static load asphalt creep tests. All tests were performed at 25 °C temperature after 28 days of specimen curing. Results of creep tests are given in Fig. 4 and 5.

Results of the uniaxial creep tests shown in Fig. 4 and 5 indicated that increase of sudden deformation occurred by the load applied. Then, increase of deformation slowed down. The rate of deformation increase of the emulsion mixtures decreased with cement addition level. Deformation of the hot mix was even higher than the emulsion mixtures added with 2% cement. As expected, the creep modulus decreased with increased loading time. The results of static creep tests showed the enhancement of mixture creep resistance due to the addition of the cement.

Specimens of the emulsion mixtures were subjected to repeated load asphalt creep tests to determine permanent deformation characteristics of the emulsion mixtures (Ref 14). 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 s loading and 0.5 s unloading for 45,000 cycles. Figure 6 shows the averaged results obtained from the sets of three repeated load asphalt creep tests on specimens with different levels of cement.

From the permanent deformation results in Fig. 6, 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.

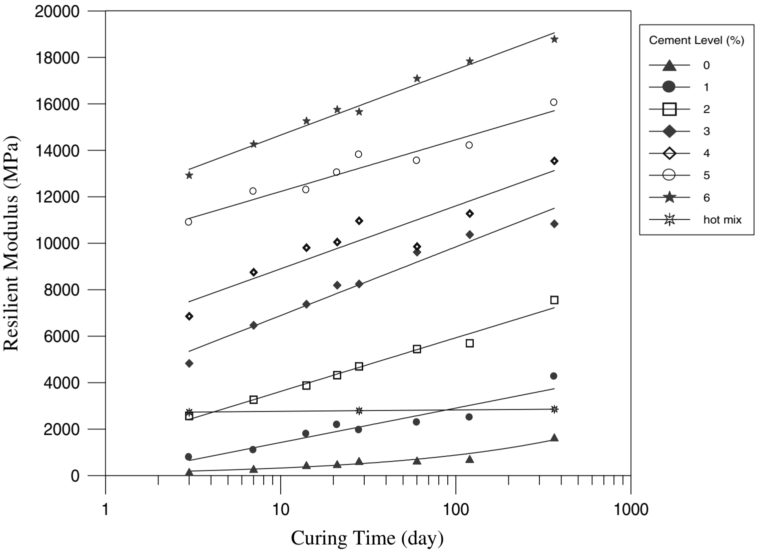

Fig. 1 Effect of cement on resilient modulus

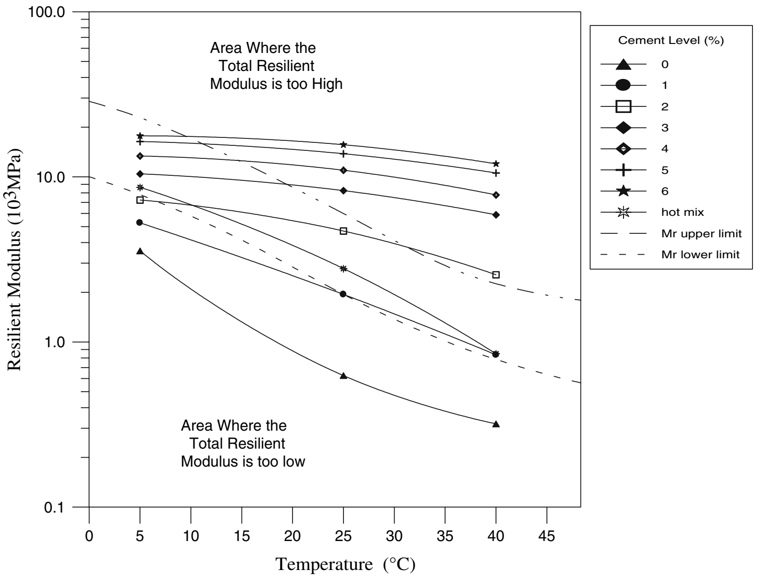

Fig. 2 Effect of cement on resilient modulus for temperature susceptibility

3.3 Moisture Damage Test

The effect of cement on the resistance to water damage of mixtures has been reported by a number of authors including Ishai and Nesichi and Lottman (Ref 15, 16). Moisture damage evaluation can be accomplished using various methods, the most common of which are summarized in a recent publication by the National Research Council in the United States (Ref 17). This method uses either the ratio of the resilient modulus or the indirect tensile strength of wet (moisture conditioned) and of dry (unconditioned) samples as indicators of moisture susceptibility. In this study, the effect of water damage on durability of emulsion mixtures and hot mix was appraised by measuring the resilient modulus of mixtures before and after soaking. Specimens of the emulsion mixtures were tested at 25 °C temperature after 3 days curing time. Then, the specimens were soaked 1 day under water at 50 °C. The ratio of resilient modulus (M_r) value prior to soaking and after soaking was determined. Results of the tests are shown in Fig. 7.

From the results shown in Fig. 7, the following points are worthy of note:

- Without cement, emulsion mix specimens failed after sixth hour of conditioned.
- The resistance to water damage of emulsion mix was increased by the addition of cement.
- The ratio is 0.91 for hot mixture. The ratio obtained for emulsion mixture with 3% cement is 0.85 even only 3 days of curing.
- The results indicate that cement is an effective adhesion agent for emulsion mixtures.

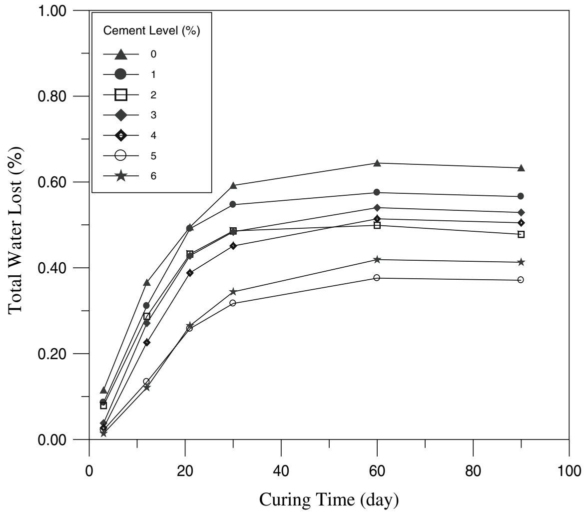

Fig. 3 Water loss from specimens with various levels of cement

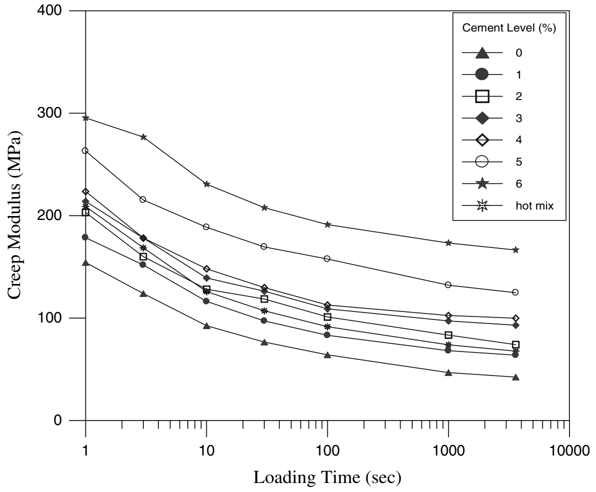

Fig. 5 Effect of cement on creep modulus

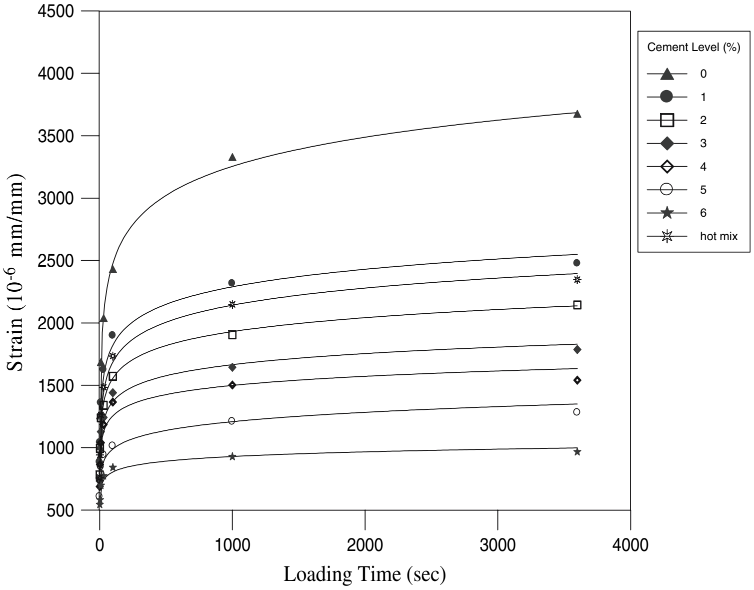

Fig. 4 Effect of cement on creep strain

4. Discussion and Conclusion

This experimental study has focused on the effect of Portland cement in enhancing the mechanical properties of Dense Graded Emulsified Asphalt Mixtures for structural layers in roads.

The results of tests to measure mechanical properties confirmed earlier findings (Ref 3-5) that mechanical properties, resilient modulus, temperature susceptibility, water damage, creep and permanent deformation resistance are all improved by Portland cement addition. The work further revealed that the ultimate resilient modulus achieved after curing and the rate of resilient modulus gain increased with increasing cement content up to 6%.

Resilient modulus, 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 resilient modulus of hot mix decreases significantly as the temperature increases. The same trend can be seen for emulsified asphalt mixtures without cement and with low cement addition (1% cement). However, resilient modulus increases with the level of cement addition and decreases as the temperature decreases. As a result, the level of cement addition in emulsified asphalt results in a significant increase in the resilient modulus and decrease of the temperature susceptibility.

Water in dense graded emulsified asphalt mixtures is a vital ingredient of the process, but becomes a problem since inhibiting compaction and delaying strength gain. Tests showed that most of the water loss was achieved in the first few weeks, but some remained in the longer time period. This is considered to explain the increase in strength over several weeks or months, particularly in dense graded aggregate and in presence of cement.

The emulsion mix specimens without cement failed after less than 30,000 cycles, this indicates that the unmodified

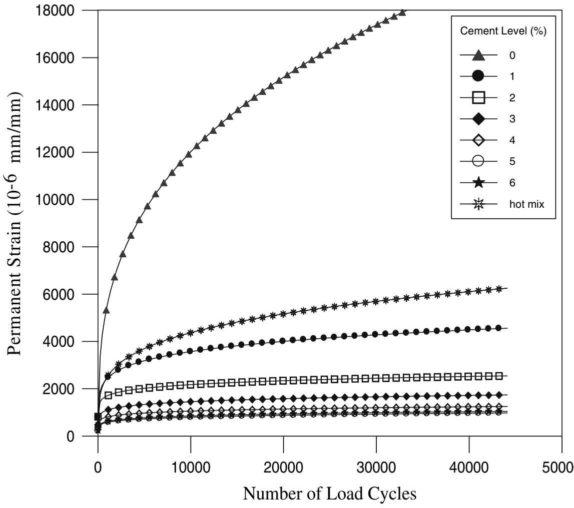

Fig. 6 Permanent strains for various cement contents compared with hot mix

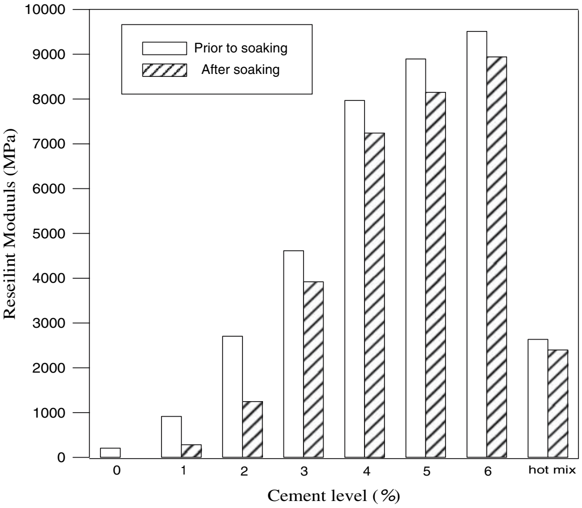

Fig. 7 Effect of cement level on the resistance to water damage

emulsion mix has rather poor resistance to permanent deformation. These results suggest that cement act as a secondary binder in emulsion mixture.

The resistance to water damage of emulsion mix was increased by the addition of cement. The results indicate that cement is an effective adhesion agent for emulsion mixtures.

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