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Research Article

Evaluation of the Effects of Anti-Stripping Materials on the Performance of Cold Bitumen Emulsion Mixtures (CBEMs)

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Abstract

Stripping is defined as the loss of adhesion between bitumen and aggregate. Replacement of bitumen film of the aggregate surface by water. It is one of the most commonly occurring distresses in asphalt pavements. Impacts of traffic loading, aggregate type, bitumen characteristics and properties of the additives. The main objective of this study is determining the effects of two different anti-stripping materials, namely hydrated lime and fly ash on cold bitumen emulsion mixture (CBEMs). Moisture susceptibilities of the samples were determined by Modified Lottman test (AASHTO T283), Index of retained strength, retained marshall stability, and double punch test. These tests were performed on mixes containing 1%, 1.5% and 2% of hydrated lime and mixes containing 1%, 2% and 3% of fly ash. The results specified that the addition of hydrated lime and fly ash increased moisture resistance of cold bitumen emulsion mixtures to some extent. Moreover, it was found that mix samples prepared using hydrated lime additive give greater resistance to water damage, compared with control mixes and those containing fly ash.

Keywords: *Emulsified asphalt, Cold mix asphalt, Hydrated lime, Fly ash, Anti-stripping.*

Introduction

Cold bituminous emulsion mixtures produced by mixing asphalt emulsion with aggregate at ambient temperature. Currently, trails to save energy and reduce emissions from asphalt paving applications have led to an expansion in the employment and approval of sustainable pavement design practices, the use of cold bitumen emulsion mixtures is one of these practices (Dulaimi, Al Nageim, Ruddock, & Seton, 2016). Many advantages could be achieved when cold bitumen emulsion mixture used as an alternative to traditional hot mix asphalt such as pavement produces less environmental impact, is more cost effective, and requires less energy consumption (Al-Busaltan, Al Nageim, Atherton, & Sharples, 2012). The use of (CBEMs) resultant mix has low early strength, thus it has been used in limited applications such as low/medium low trafficked roads, footways and reinstatements(Read & Whiteoak, 2003; I. Thanaya, 2003). Fillers can play a prime role predominating the engineering properties of asphalt mixtures. It has been observed that filler can significantly impact permanent deformation resistance, fracture resistance, stiffness, and moisture susceptibility of asphalt concrete (Kim, Little, & Song, 2003; Kim, Lutif, Bhasin, & Little, 2008)

Many attempts have been investigated to improve cold mixes. (I. Thanaya, Forth, & Zoorob, 2006) indicated that pulverized fly ash (PFA) can be used as suitable filler in cold mixes at full curing conditions. They additionally found the stiffness of the cold mix achieved was very comparable to hot mixtures.

(Al-Busaltan et al., 2012) utilized (LJMU-FA1) which was a waste domestic fly ash, within the CBEM's to improve the mechanical properties, namely Indirect Tensile Stiffness Modulus and Creep Stiffness. The results stated a comparative enhancement in the mechanical properties of the new cold mixtures.

Study by (Wang & Sha, 2010) indicated that the limestone and limestone filler impact upon hardness was significant when compared with granite and granite fillers.

(Dash, 2013) study the effect of cement, fly ash, and hydrated lime on performance and design of cold mix asphalt and stated that among the additives, though the stability value has been found to be improved by fly ash, lime and cement, performance of cement modified mix is observed to be superior in every aspect. Comparing lime and fly ash as substituted for filler, greater stability but higher air void content is noticed in case of cold mixes modified with lime.

(Niazi & Jalili, 2009) study the effect of Portland cement and lime additives on properties of cold in-place recycled mixtures with asphalt emulsion and illustrated that the addition of Portland cement and

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lime increase the Marshall stability, bulk specific gravity, resilient modulus and tensile strength and reduces void content and flow of the recycled mixtures. Also, stated that Marshall stability ratio (MSR) and tensile strength ratio (TSR) results show that Portland cement and lime can improve resistance to moisture damage of CIR mixtures, moreover, use of Portland cement and lime can reduce the permanent deformation of recycled mixtures and decreased rut depth.

(Nassar, Mohammed, Thom, & Parry, 2016) study the mechanical, durability and microstructure properties of cold asphalt emulsion mixtures with different types of filler, they were used ordinary portland cement (OPC), fly ash (FA) and ground granulated blast furnace slag (GGBS) for the binary blended fillers (BBF) whereas silica fume added to (BBF) to obtain ternary blended fillers (TBF). The mechanical and durability results stated that the TBF was more suitable microstructural assessment illustrated that the influence of BBF of the internal microstructure of CAEMs was slightly negative and more noticeable in CAEMs containing FA.

Another study conducted by (Dulaimi et al., 2016) with cold asphalt concrete binder course mixtures containing binary blended cementitious filler (BBCF). They use binary blended filler material produced from high calcium fly ash (HCFA) and a fluid catalytic cracking catalyst (FC3R). The result indicated that balanced oxide compositions within the novel filler were identified as responsible for an enhanced hydration reaction, resulting in a very high early strength and a significant improvement in permanent deformation and fatigue resistance. Improved water sensitivity for progressive hydration with the new binary filler was also established.

Recently, (Du, 2015) was study the effect of chemical additives on recycled mixture performance including composite Portland cement (CPC), hydrated lime (HL), and a combination of HL and GGBS. The effect of additives was investigated by volumetric and strength tests, rutting resistance test moisture susceptibility test,, and low temperature bending test. The results showed that the hydration products from CPC or a combination of HL and GGBF behave as additional binder materials, and the CPC, HL, and a combination of HL and GGBF can improve the moisture resistance and rutting resistance.

Experimental Program

Materials Properties

The aggregate utilized in this research is crushed gravel quartz, it is brought from local asphalt concrete mix plant, in Jurf Alnaddaf was its source is Al-Nibaay quarry. Table (1) illustrated the Physical properties of the aggregate whereas, the chemical composition of the aggregate presented in table (2).

Table 1 Physical properties of Nibaay Aggregates

Laboratory Test		ASTM Specification	Results			
Specific gravity	Coarse aggregate	ASTM C127	Sieve size	Bulk Gs	App. Gs	Abs.%
			3/4''	2.621	2.657	0.5%
			1/2''	2.635	2.664	0.4%
			3/8''	2.605	2.649	0.6%
			NO #4	2.605	2.662	0.5%
	Fine agg.	ASTM C128	Crashed sand (<#4)	2.663	2.691	0.4%
Angularity for Coarse aggregate		ASTMD 5821, Min 95%	93 %			
Soundness for Coarse aggregate		ASTM C88, 10-20% Max	4.3 %			
Flat & Elongation for coarse aggregate	Flat	ASTM D4791, Max 10%	0 %			
	Elongation		0 %			
Toughness By (Los Angeles Abrasion)	Aggregate Size < 25 mm	ASTM C131, 35-45% Max	21.1 %			
Equivalent sand for fine aggregate (clay content)		ASTM D2419, Min 45%	96 %			

Table 2: Results of Chemical Composition

Chemical Composition	Dust	HL	FA	CA
Silica, SiO_2	4.06	1.88	57.76	80.73
Lime, CaO	37.48	67.9	1.35	6.77
Magnesia, MgO	0.91	0.45	0.5	0.63
Sulfuric Anhydride, SO_3	5.4	0.56	0.5	2.3
Alumina, Al_2O_3	1.02	0.38	19.45	0.66
Ferric Oxide, Fe_2O_3	3.02	0.23	6.42	0.98
Loss on Ignition	7.7	5.8	9.3	6.3

The nominal maximum aggregate size selected for the cold mixes was (19.0mm), this gradation is within the limits recommended by the specification limits of the State Corporation for Roads and Bridges in Iraq (SCRB). The type of mineral filler in the control mixture was used the limestone dust (from lime factory in Kerbala) and the specific gravity for the limestone of filler was (2.72). In this study hydrated lime (HL) and fly ash (FA) were used as a partial replacement for the traditional filler with (1%, 1.5%,and 2%) and (1%, 2%, and 3%), respectively. The specific gravity for (HL) and (FA) were (2.63) and (2.27), respectively. The chemical composition of the limestone dust, hydrated lime, and fly ash as shown in table (2). To produce a dense – graded mixture, the slow setting cationic emulsified asphalt low viscosity type (Css-1) from MEGA INSAAT (Turkish company) was used in this study, because of its compatibility with a wider range of aggregate and its common utilization all over the world.

Mixture Production

Mixture design and testing procedures vary amongst the various road authorities, research institutions and asphalt researchers.

Generally, the design procedures include the following steps:

- Determination of aggregate gradation:

The Superpave mix design procedure was used to select the aggregate gradation, three trail blends were selected in this study, coarse, mid, and fine gradation was chosen, these trail blends gradations are within the limits recommended by the specification limits of the State Corporation for Roads and Bridges in Iraq (SCRB) and (AASHTO M323, 2012) as shown in figure (1).

- Estimation of Initial Residual Asphalt Content (IRAC) and Initial Emulsion Content (IEC)

The residual asphalt content was initially estimated for the three trail blends by utilizing the Asphalt Institute empirical formula as shown below.

$$P = (0.05\,A + 0.1\,B + 0.5\,C) * (0.7) \quad (1)$$

Where: P= % Total emulsified asphalt Content by weight of' dry Aggregate, A= % of' aggregate retained on sieve 2.36 mm, B = % of' aggregate passing sieve 2.36mm and retained in 0.075mm, and C= % of aggregate passing 0.075mm.

To compute the initial asphalt content that used to produce mixtures, the Asphalt Institute empirical formula was used as shown below.

$$IEC = \left(\frac{P}{X}\right) * 100\% \quad (2)$$

Where: P =% Initial Residual Bitumen Content and X= % residue content of the emulsion (53.1%).

From the above equations the initial emulsion content (IEC) for the three blends and the results found at (7.62%, 8.36%, and 6.85%) for the blend (1), blend (2), and blend (3) respectively.

According to above values and to the previous studies (Al-Mishhadani & Al-Baid, 2014; Mohsin, 2016) trail mixes derivative of (IEC) were adopted to be used in this study that was (5%, 5.5%, 6%, 6.5%, and 7%) for all blends.

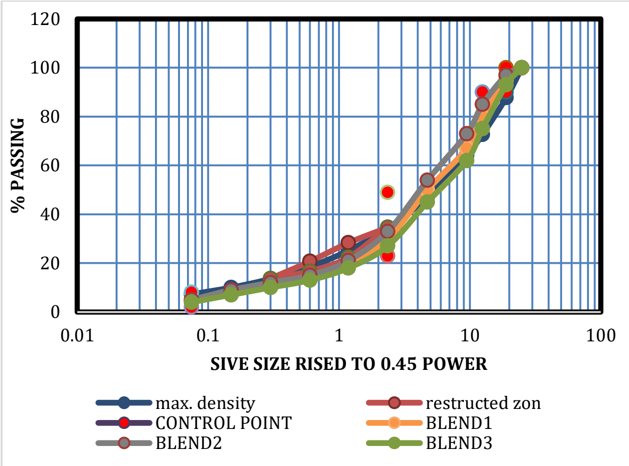

Figure 1 Trail Gradations for 19 mm Nominal Maximum Size

Select the Design Asphalt Emulsion Content

Normally, by using Superpave mix design procedure, The mixture was prepared by blending the initial asphalt emulsion content with aggregate and filler at ambient temperature for (2-5) minutes manually until an even coating obtained. For the maximum theoretical specific gravity, Samples prepared and kept at room temperature for 24 hours (Mohsin, 2016) before test in accordance to (ASTM D2041). Samples prepared for gyratory were immediately compacted after mixing by using the Superpave Gyratory Compactor, after compacting each sample by using SGC for 160 cycles, it was extruded from the mold and permitted for 10 min and then transferred it and allowed to cure for 24 hours at ambient temperature, then the specimen transmitted and placed in an oven at 40 °C for 24 hours. After curing, samples were cooled to room temperature for (2-4) hours before testing them for the bulk specific gravity in accordance to (ASTM D 2726). To check the volumetric properties, from the SGC software archive, the data were taken and the percent air voids (Va %), voids in mineral aggregate (VMA %), voids filled with asphalt (VFA %) and percent G_{mm} were being calculated. The results obtained compared with the requirement of Superpave volumetric mix design criteria, then blend three at 5.5% initial emulsion content (IEC) with 3.41% estimated residual asphalt content was selected to be the design blend. After the aggregate structure was chosen, then, start to choose the design asphalt emulsion content, the specimens are compacted at varying emulsion content (estimated residual asphalt content %, estimated residual asphalt content ±0. 5%, and estimated residual asphalt content +1%).

Finally, the previous steps in mixing, compaction and curing were conducted for the design emulsion content specimens. Then, the mixture properties were evaluated to determine the design emulsion content by drawing figures of the volumetric properties with different asphalt emulsion contents, it is found that the design emulsion content at 4% air voids was (6.37%).

Testing program

Many mixtures were prepared with limestone dust for control mix and with different percent of hydrated lime and fly ash as anti-stripping materials. All mixtures were evaluated with some tests used to estimate moisture damage potential such as indirect tensile strength, index of retained strength, retained stability, and double punch test. These tests were conducted for all specimens after curing protocol that was let them (in the mold for Marshall Specimens and in the room for Superpave specimens) for one day at ambient temperature, then 24 hrs. in an oven @ 40 °C.

Indirect Tensile Strength and Tensile Strength Ratio

(Santucci, 2002) stated that the susceptibility to stripping or moisture can be evaluated by using this test. A Superpave gyratory compactor was used to produce testing specimens, 150 mm in diameter and 115 mm height with 7% ± 0.5 air voids. Six specimens were prepared for each type of mixtures, The first three specimens kept at room temperature without any condition until testing for indirect tensile strength, the other three specimens subject to partial vacuum saturation (55-80) %, followed by one freeze-thaw (F–T) cycle prior to being tested. Compressive load was applied to a cylindrical specimen through two diametrically opposed rigid platens to induce tensile stress along the diametral vertical axis of the test specimen and a peak compressive load was recorded to obtain the tensile strength of the sample.

Tensile strength ratio (TSR) which is the ratio of the average tensile strength of the conditioned specimens to the average tensile strength of the unconditioned specimens was then calculated. The TSR represents a reduction in the mixture integrity due to moisture damage. A minimum of 80% TSR has been typically used as a failure criterion.

Index of Retained Strength

This test method was used to measure the loss of compressive strength resulting from the action of water on compacted bituminous mixtures, and conducted for all prepared mixtures according to standard specifications (ASTM D 1075). Six specimens were prepared according to standard specifications (ASTM D 1074) for each type of mixtures with batch weight 1850 gm. A Superpave gyratory compactor was used to produce testing specimens, 100 mm in diameter and 100 mm height with approximately 6% ± 0.5 air voids. The specimens sorted into two subsets. For subset 1, the specimens were stored in room temperature for more than 4 hours, then their compressive strength was determined at 25.0± 1ºC, the specimens for subset 2 were conditioned by submerging them in water bath at 60.0 ± 1ºC for 24 hours. Then, the specimens were transferred to another water bath maintained at 25.0 ± 1ºC and storing them for 2 hours, lastly the compressive strength was determined.

The index of retained strength of resistance of bituminous mixtures to the damaging impact of water can be determined as the ratio of average compressive strength for condition specimens to unconditional specimens, which should be a minimum of (70%) as adopted by (SCRB/R9, 2003) for binder course.

Retained Marshall Stability

The Retained Marshall Stability is the ratio of soaked or wet stability to dry stability (Read & Whiteoak, 2003; I. N. A. Thanaya, 2007). (I. Thanaya, 2003) was stated that a minimum of (50%) Retained Stability shall be achieved for cold bituminous emulsion mixtures, whereas (Read & Whiteoak, 2003) regarded a value of more than (75%) retained Marshall stability is usually accepted.

This test was carried out according to (AASTHO T245-08). Six specimens were prepared for each type of mixtures with batch weight 1200 gm in the same method of mixing used for design, and compacted by means of Marshall compactor were compacted with 75 (SCRB/R9, 2003) blows on each face for heavy traffic. Three samples for determination of an average dry stability value, the samples were immersed in the water bath at 25°C for 30 minutes (Asphalt Institute MS-14), instead of at 60°C which was used in HRM. The other three samples were used for determination of an average soaked stability, the samples were water conditioned. In this test half thickness of each compacted specimen was soaked in water at room temperature for 24 hrs. And the specimens, then inverted and the other half were soaked for a further 24 hrs (Al-Mishhadani & Al-Baid, 2014; I. Thanaya, 2003). The specimens are subsequently to well dried, and they are then tested for Marshall stability at room temperature.

Double Punch Test

This test was utilized to measure the stripping of the binder from the aggregates; this method was advanced by Jimenez at the University of Arizona. (Jimenez,

1974) was explained the severity of this test by comparing predictions on similar mixtures using the immersion–compression test. This test was reported by numerous studies (Mashkoor, 2015; Mohsin, 2016; Sarsam & Alwan, 2014; Solaimanian, Harvey, Tahmoressi, & Tandon, 2003; Turos, 2010). The same procedure of prepared specimens for retained marshall stability was used to prepared samples for this test, after curing the samples were conditioned in water bath at 25ºC for 30 min, then they were tested, the compacted cylinder specimens were placed between two steel rods (2.54cm in diameter), at either end of the specimen in a punching configuration where the specimen is centered between the two steel rods, perfectly one over the other, then loaded at a rate of 2.54cm /minute until failure was occurred by using marshall apparatus. The maximum load resistance is recorded and the punching strength is calculated.

Result and discussion

Effect of moisture and anti-stripping materials on (ITS) and (TSR)

The results of ITS and TSR are given in fig. (2) and fig. (3), respectively. Fig (3) illustrates the reduction in tensile strength for all wet mixtures because loss the adhesion between aggregate and binder due to action of moisture or water.

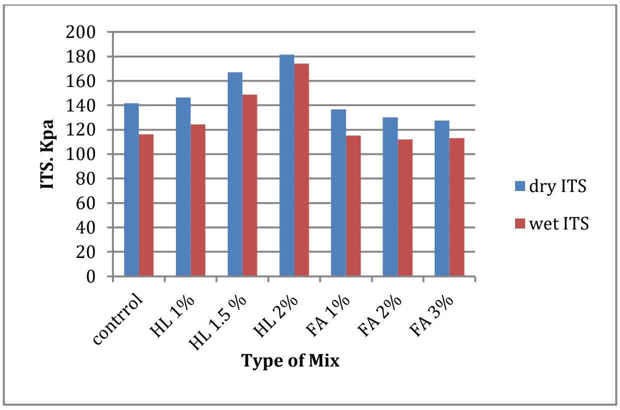

Figure 2 ITS (By condition and unconditioned Specimen) For All Mixtures

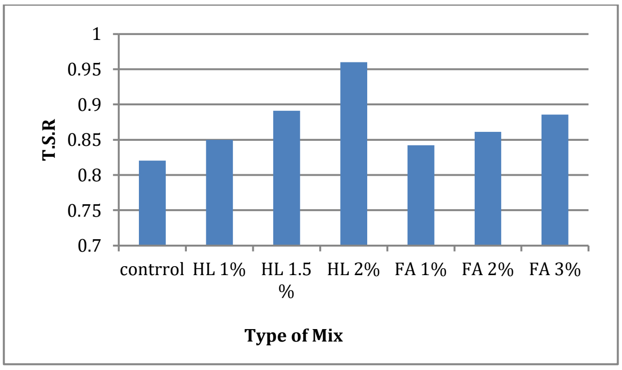

Figure 3 ITS For all Mixtures

It is clearly that the ITS increase with increase of HL content in contrast for FA, whereas fig (3) present the effect of hydrated lime and fly ash on the TSR results. It can be noticed that the TSR increase as the content of HL or FA was increased. Also, it could be recognized that HL with 2% content is the greatest of TSR, This is because the developed hydration in the presence of water and HL actually stiffens the asphalt film and reinforces it. Furthermore, the lime makes asphalt mixtures less sensitive to moisture effects by improving the aggregate-asphalt bond.

The Effect of moisture and anti-stripping materials on compressive strength and (IRS)

Increase in HL content led to increase in compressive strength as demonstrated in fig (4) and the compressive strength decrease when FA content increases for dry specimens, this is maybe because of the higher air voids content. While the (IRS) was increased as the FA percent was increased as shown in fig. (5). This reflects the effect of pozzolanic materials, the pozzolanic and hydraulic materials needed an agent to active, limestone dust works as an agent but not acted active filler as OPC. Also, as the HL content was increased the IRS was increased. All values of (I.R.S) exceeding the percent recommended by (SCRB /R9, 2003) for binder course which was 70%. But the adding HL with 2% and FA with 3% by increase the IRS values by (16.3% and 11.5%), respectively.

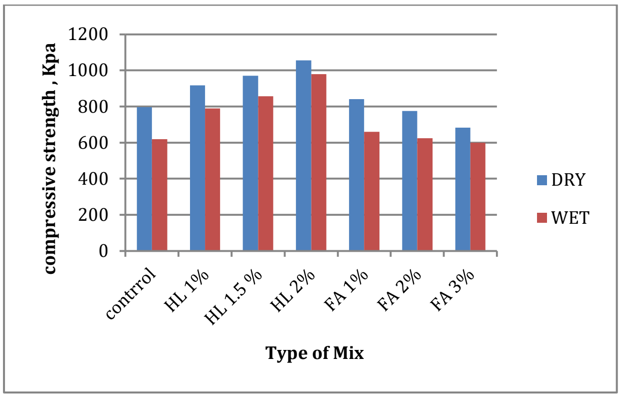

Figure 4 Compressive Strength (By Dry and Wet Specimen) for All Mixtures

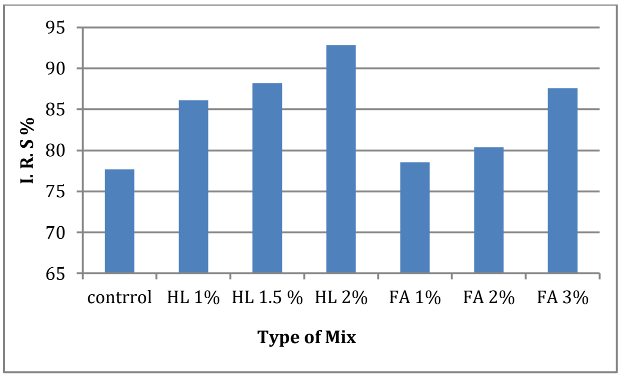

Figure 5 IRS for All Mixtures

Effect of moisture and anti-stripping materials on (Marshall stability) and (RMS)

It is observed that the stability was increased with increase the replacing percent of HL as illustrated in fig (6) this is may be retain to the ability of HL to absorb the water of the mixture. In contrast, the stability was declined to increase the replacing percent of HL by about (2.7%, 9.4%, and 13.5%) for 1%, 2%, and 3% FAcontent respectively, when compared with control mixture. This is may be due to the particle shape plays the role in gain the cracking resistance. Fig (7) presents the results of RMS. It is clearly that the RMS incrementally rise as the content of HL or FA was increased. This may be due to reasons mentioned earlier. Accepts the control mix, all mixtures satisfy the percent of RMS that recommended by (Read & Whiteoak, 2003; I. Thanaya, 2003).

the mix with 2% HLcontent is the superior.

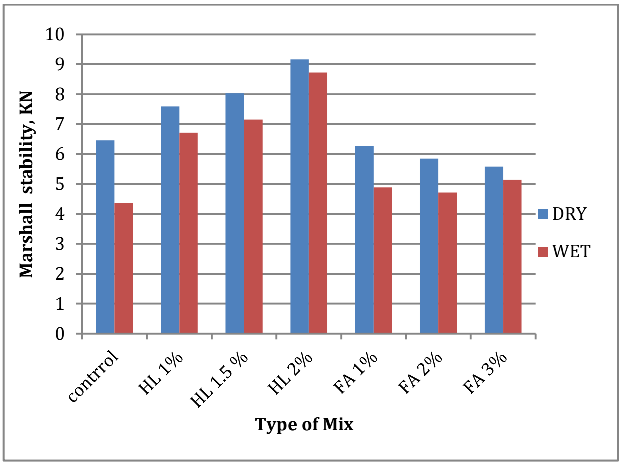

Figure 6 Marshall Stability (By Dry and Wet Specimen) For All Mixtures

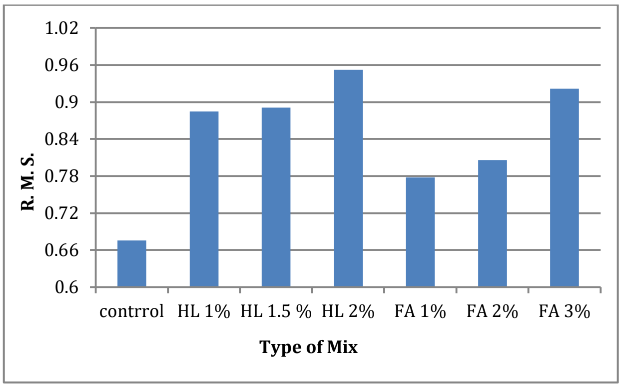

Figure 7 RMS for All Mixtures

The Effect of anti-stripping materials on Punching strength

Double punch test suggests the stripping behavior between binder and aggregate. The results of the double punch test show that the punching shear strength for mixture contained HL or FA as a replacement is more than control mix by 95.2 %, at 2% HL content and by 55.7 % at 3% FA content as shown in fig (8). In addition, it is noted that the punching strength increases as HL or FA content increase, but

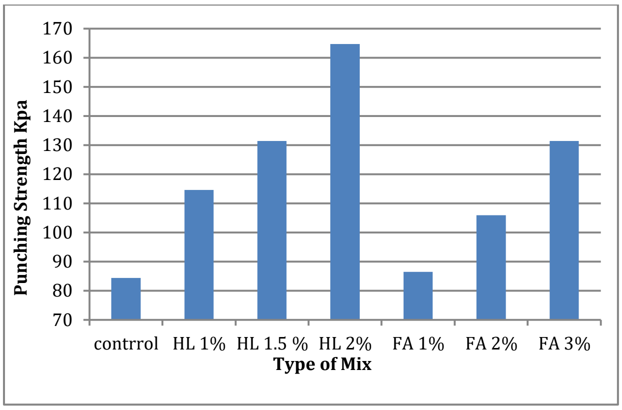

Figure 8 Punching strength for all mixtures

Conclusions

On the basis of the experimental results of this study, the following can be concluded:

1) TSR, IRS, RMS, and double punch test results showed that the additional of hydrated lime and fly ash can improve the water sensitivity for cold bitumen emulsion mixture. In spite of the use of fly ash give good resistance to moisture, but the use of hydrated lime is the superior.
2) The additional of fly ash as a replacement to limestone dust decreased the marshall stability, indirect tensile strength, and compressive strength as the content was increased. Also, need to more curing protocol to satisfy the specification. In addition, using of fly ash gives a high degree of coating and good workability.
3) In contrast, the additional of hydrated lime as a replacement to limestone dust increased the marshall stability, indirect tensile strength, and compressive strength as the content was increased especially with 2% contained.
4) Using of Superpave gyratory compactor specimens for CRM can give better behavior than samples compacted by using Marshall hammer, as well as, give less air voids content than those with Marshall compactor.

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