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Evaluation of Cold Mix Asphalt Concrete Properties

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Abstract

Cold mix asphalt concrete is considered as a sustainable and green pavement, the aggregates and the binder can be mixed, laid, and compacted without consumption of energy. In this investigation, an attempt has been made to prepare cold mix asphalt concrete for base course construction. Two types of liquid binder, named Cationic emulsion Medium Setting CMS and Medium Curing cutback MC-250 have been implemented in preparation of Marshall specimens. Four types of additives, named Portland cement, coal fly ash, limestone dust and hydrated lime have been tried. Mixtures were subjected to aeration, then compacted. However, Specimens were subjected to curing before testing. It was concluded that mixtures with (optimum cutback content + 5% cement and 4 hours aeration and 24 hours curing at 60°C) and (optimum emulsion content +2% hydrated lime +3% cement or fly ash and 4 hours aeration at 25°C and 24 hours curing at 60°C) satisfies the volumetric and Marshall properties requirements for base course. It was recommended that increasing the aeration and curing periods is beneficial for the cold mix asphalt concrete in satisfying the specification requirements for base course.

Key Words: Cold Mix; Asphalt Concrete; Cement; Lime; Fly ash; Marshall; Aeration; Curing;

Introduction

Cold mix asphalt concrete provides a sustainable, cost-effective and energy efficiency alternative to traditional hot mixtures because no heating is required to manufacture the mixture. However, these mixtures have a comparatively low initial strength and is an evolutionary material, mainly in its early life where the initial cohesion is low and builds up slowly, [1]. An attempted has been made by [2] to evaluate the performance characteristics of cold mix asphalt using reclaimed asphalt mixture. It was observed that the reclaimed asphalt was having a positive impact on strength by 10% while it increases the crushing strength by 8.2%. The maximum stability obtained from optimum binder content was 384 kg which is a very good value for a cold mix made up of reclaimed asphalt aggregate. The flow value obtained was also 5.06 mm as observed. [3] stated that cold mix asphalt concrete mixtures are inferior regarding mechanical properties, high air voids, rain sensitivity and the long curing time needed to achieve their final strength. [4] evaluated the volumetric properties, indirect tensile stiffness modulus, repeated load axial creep and fatigue properties of the cold mixture. A target of tensile strength value of 2000 MPa was selected. It was observed that at full curing conditions, the stiffness of the cold mixes was found to be very similar to that of hot mixtures of the same penetration grade base binder. Test results also show that the addition of 1–2% cement significantly improved the mechanical performance of the mixes and significantly accelerated their strength gain. [5] studied different mechanical properties of CAM, such as unconfined compression strength (UCS), indirect tensile strength (ITS) and indirect tensile stiffness modulus (ITSM) not only in an independent way but also by giving a global approach. It was concluded that after reaching an optimal bitumen content, not all properties perform in the same way. ITS is the mechanical property which less sensitivity shows to bitumen content while ITSM and UCS perform alike and worse than ITS. [6] mentioned three reasons for the hardness of Cement Asphalt Emulsion Composites (CAEC), namely: breaking of the emulsion, water evaporation and cement hydration. They also demonstrated two possible benefits of A Novel Cold Asphalt Concrete Mixture for Heavily Trafficked Binder Course CAEC, which are the lower temperature susceptibility compared with asphalt concrete and the flexibility, which is higher than that of cement concrete. Fly ash has also been used as a replacement for conventional limestone fillers in hot rolled asphalts as reported by [7]. It was stated that as fly ash particles tend to be more spherical in shape when compared with limestone, laboratory investigations have shown that fly ashes can enhance the workability of the bituminous mixtures, which is of great benefit particularly during the compaction process. As reported by [8], when cold mixes were brought to full curing condition by oven drying at 40°C for 18–21 days (until achieving a constant weight), the samples should have undergone some level of oxidation, hence stiffening the bitumen. [9] conducted experiments to assess the mechanical properties of emulsified asphalt mixtures including 0-6% OPC which was substituted for mineral filler. Significant improvement was revealed with high percentage of OPC addition and they reported that cement-modified asphalt emulsion mixtures might be used as a structural layer. [10] investigated cold asphalt concrete binder course mixtures with cationic emulsions by means of stiffness modulus whereas water sensitivity was assessed by measuring the stiffness modulus ratio before and after sample conditioning. The results indicate that a substantial enhancement in the stiffness modulus and a considerable improvement of water sensitivity resistance is achieved by adding LJMU-A2 to the cold asphalt mixtures as a supplementary cementitious material after 2-day curing compared to that obtained with Portland cement, which occurs after 7-day curing. Cement is extensively used in cold mix asphalt and its role has been investigated in several studies. OPC can considerably develop the early stiffness, decrease the permanent deformation, and increase the durability of the mixtures. An initial study conducted by [11] demonstrated that the addition of cement to the emulsion-treated mixes resulted in acceleration of the rate of development of the resilient modulus. [12] indicated that, with 1% OPC addition, Marshall Stability of modified cold asphalt mix increased by around three times compared with un-treated mix. It was concluded that when cement was added to the aggregate at the time the asphalt emulsion was combined, the mixes cured faster, and more resilient modulus (Mr) developed rapidly.

The aim of this investigation is to evaluate the properties and suitability of cold mix asphalt concrete prepared by implementation of two types of liquid asphalt (cationic medium setting emulsion and medium curing cutback) and four types of additives, named Portland cement, coal fly ash, limestone dust and hydrated lime for base course construction using various aeration and curing periods.

Materials and Methods

The materials used in this investigation are locally available while the aggregates are usually used for pavement construction in Iraq.

Coarse and Fine Aggregates

Coarse and fine aggregates were obtained from Badra quarry, such aggregates are widely used in the middle and south parts of Iraq for asphalt pavement construction. The coarse and fine aggregates used in his work were sieved and recombined in the proper proportions to meet the requirement for base course with maximum size of 37.5 mm as per [14]. Table 1 illustrates the physical properties of aggregates. Table 2 exhibit the aggregates combined gradation implemented for base course. It can be noted that it is a dense gradation.

Table 1: Physical Properties of Aggregate

Property	ASTM, (2013) Designation	Coarse Aggregate	Fine Aggregate	SCRB, (2003) specification
Bulk specific gravity gm./cm^3	C127, C128	2.46	2.54	------
Apparent specific gravity gm./cm^3	C127, C128	2.57	2.61	------
% water absorption	C127, C128	0.96	0.74	------
Abrasion (Los Angeles)	C131	23 %	------	Max 30%
Flat and elongated particles, %	D4791	0.6%		10% Max

Table 2: Aggregate gradation with specification limits for Base course.

Standard sieves size (mm)	SCRB, (2003) Specification limits	% finer by weight
37.5	100	100
25	90-100	94
19	76-90	83
12.5	56-80	68
9.5	48-74	61
4.75	29-59	48
2.36	19-45	27
0.300	5-17	11
0.075	2-8	5

Mineral Filler

Filler is defined as aggregate, most of which passes through a 0.075 mm. sieve NO.200. Filler could be active or inert. Active filler is filler that produces hydration in the presence of water, while inert filler does not. Incorporating active fillers in cold mix asphalt concrete can show a high significant improvement in the mechanical properties. In this investigation, four types of fillers were tried which represent conventional mineral filler (limestone dust), Fly Ash, hydrated lime, and ordinary Portland Cement. Table 3 exhibit the physical properties and chemical composition of mineral filler adopted. The mineral filler implemented are 95% passing sieve No. 200.

Emulsified Asphalt

Medium Setting Cationic emulsion CMS with a residual asphalt content of 54% was obtained from local market and implemented as liquid binder. Table 4 demonstrates its properties as supplied from the manufacturer.

Table 3: Properties of mineral filler

Property	Limestone dust	Portland cement	Coal fly ash	Hydrated lime
Physical Properties				
Specific surface area (m^2/kg)	451	418	320	280
Density ($gm./cm^3$)	2.635	3.12	2.27	2.12
Chemical composition (XRF)				
SiO_2	51.392%	24.564%	57.76%	0.74%
Al_2O_3	8.285%	2.135%	19.45%	0.5%
Fe_2O_3	7.066%	1.131%	6.42%	0.19%
CaO	5.782%	60.845%	1.35%	64.23%
MgO	4.883%	1.625%	0.5%	1.17%
K_2O	3.226%	0.694%	0.5%	------
Na_2O	2.082%	1.583%	57.76%	------

Table 4: Properties of Emulsion

Property	Specification ASTM, (2013)	Limits	Test Results
Emulsified asphalt type	D2397	Rapid, medium, slow setting	Medium setting CMS
Color appearance	---	----	Dark brown liquid
Residue by Evaporation %	D6934	Min. 40	54
Specific gravity, $gm./cm^3$	D70	---------	1.04
Penetration (mm)	D5	100-250	219
Ductility (cm)	D113	Min. 40	46
Viscosity, rotational paddle viscometer 50	D7226	110-990	348
Solubility in Trichloroethylene (%)	D2042	Min. 97.5	97.7
Emulsified asphalt / job aggregate coating practice	D244	Good, fair, poor	Fair
Evaluating Aggregate Coating	D6998	Uniform	Uniformly and thoroughly coated

Cutback Asphalt

Medium Curing cutback asphalt MC250 was supplied from AL Dora refinery. The properties as supplied by the refinery are given in Table 5.

Preparation of Cold Mix Asphalt Concrete Mixtures

Coarse and fine aggregates were air dried at 40°C for 24 hours, then were separated to different sizes and stored. Aggregates were recombined, and the filler was added to meet the overall aggregates gradation requirement for base course as per SCRB, (2003) specification requirements. Liquid asphalt (cutback or emulsion) was added to the combined aggregates to achieve the desired amount and mixed thoroughly at laboratory environment of 30 ± 1 °C using mechanical mixer for two minutes until all aggregate particles were coated with thin film of liquid asphalt. The range of liquid asphalt implemented was (4 - 8) % with 0.5 % increment.

Table 5: Physical Properties of Cutback	
Grade	MC 250
Viscosity(cst.) @ 60°C	250-500
Flash point(COC) °C (min)	66
Water %V(max)	0.2
Distillate %of total Distilled	
TO 225 °C (max)	10
TO 260 °C(max)	15-55
TO 315 °C (max)	60-87
Residue from distillation to 360 °C %V(min)	67
Tests on Residue from distillation	
Penetration @25 °C (100g.5sec.0.1mm)	120-250
Ductility @25 °C (cm)(min)	100
Solubility in Trichloro ethylene % wt. (min)	99

The cold mixture was subjected to aeration at (25 or 60)°C for the specified periods listed in Table 6. Figure 1 exhibit the aeration process. Such aeration was required to lose part of the excess water in the emulsion or volatiles in the cutback.

Similar procedure was reported by [15, 16]. After the aeration, Marshall Size specimens were prepared in accordance with ASTM D1559, (2013) using 75 blows of Marshall hammer on each face of the specimen for asphalt base course. Specimens were subjected to curing for 24 hours at 60°C environment using an oven. Such curing was required to increase the cohesion and viscosity of the binder as suggested by [17, 18]. The optimum asphalt content for each mixture was determined based on the maximum stability and density and 4.5% of air voids as recommended by SCRB, (2003). A total of 13 cold asphalt concrete mixtures have been prepared with various percentages of binder and filler content and aeration and curing conditions as demonstrated in Table 6. Figure 2 exhibit part of the prepared specimens while, Figure 3 shows the curing process. Three specimens for each mixture were prepared and tested and the average value was considered.

Table 6: Cold Mixtures Designation

Designation	Details	Aeration	Curing
CM-1	Cold Mix, 5% Limestone dust + MC-250	4 hours @ 60°C	24 hours @ 60°C
CM-2	Cold Mix, 5% cement + MC-250	2 hours @ 25°C	24 hours @ 60°C
CM-3	Cold Mix, 5% cement + MC-250	4 hours @ 60°C	24 hours @ 60°C
CM-4	Cold Mix, 5% Hydrated lime + MC-250	4 hours @ 60°C	24 hours @ 60°C
CM-5	Cold Mix, 5% fly ash + MC-250	4 hours @ 60°C	24 hours @ 60°C
CM-6	Cold Mix, 2% Hydrated lime + 3% fly ash + MC-250	4 hours @ 60°C	24 hours @ 60°C
CM-7	Cold Mix, 2% Hydrated lime + 3% cement + MC-250	4 hours @ 60°C	24 hours @ 60°C
CM-8	Cold Mix, 5% Limestone dust + CMS	4 hours @ 60°C	24 hours @ 60°C
CM-9	Cold Mix, 5% Hydrated Lime + CMS	4 hours @ 60°C	24 hours @ 60°C
CM-10	Cold Mix, 5% cement + CMS	4 hours @ 60°C	24 hours @ 60°C
CM-11	Cold Mix, 5% fly ash + CMS	4 hours @ 60°C	24 hours @ 60°C
CM-12	Cold Mix, 2% Hydrated lime + 3% fly ash + CMS	4 hours @ 25°C	24 hours @ 60°C
CM-13	Cold Mix, 2% Hydrated lime + 3% cement + CMS	4 hours @ 25°C	24 hours @ 60°C

Figure 1: Aeration Techniques Adopted for Cold Mix Asphalt Concrete

Figure 2: Part of the prepared specimens

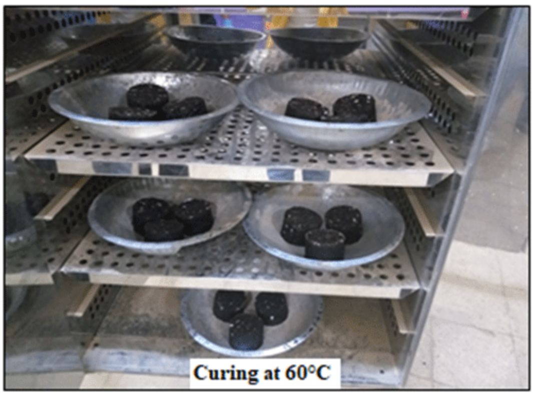

Figure 3: Curing of cold mix asphalt concrete

Results and Discussions

As demonstrated in Table 7, the optimum asphalt content is obtained based on maximum stability, maximum density, and average air voids of 4.5 %. However, the requirements for a suitable cold mix asphalt concrete are a minimum Marshall stability of 5 kN, average voids content of 4.5%, and a range of flow value (2-4) mm as recommended by SCRB, (2003). It can be observed that implementing Portland cement as a filler is effective when more aeration period of 4 hours and aeration temperature of 60°C were allowed when comparing CM-2 with CM-3 mixtures. The higher aeration temperature will allow more water to evaporate from the air-dried aggregates and support the hydration of cement. This was further supported by the higher volume of voids filled with asphalt of 71% for CM-3 mixture and lower voids in the mixture as compared to CM-2 mixture.

Table 7: Marshall and Volumetric Properties of Cold Mix Asphalt Concrete

Designation	% Asphalt	Density gm/cm^3	Stability kN	Flow mm	AV %	VFA %	VMA %
CM-1	5.46	2.310	2.75	5.4	5.4	65.5	15.1
CM-2	5.1	2.310	2.1	3.52	5.75	62	14.9
CM-3	5.18	2.344	5.0	3.56	4	71	13.65
CM-4	5.6	2.304	4.5	5.1	4.5	68	15.1
CM-5	5.13	2.322	4.54	5.11	5	66	14.42
CM-6	4.67	2.342	4.0	5.54	4.5	69.5	13.35
CM-7	5.43	2.328	2.56	6.5	4.3	69	14.35
CM-8	5.8	2.302	2.9	6.4	4.5	69	15.5
CM-9	5.86	2.304	3.1	6.58	4.6	73	15.58
CM-10	5.63	2.333	4.85	5.98	4.53	68.5	14.61
CM-11	5.66	2.335	4.1	6.15	4.4	77	14
CM-12	8.1	2.330	9.6	4.51	4.54	72.5	16.54
CM-13	7.95	2.331	10.4	4.2	4.4	73	16.52

When the cationic emulsion was implemented as a binder, the addition of 5% of Portland cement was effective to a large extent but it was felt that more curing time is required as exhibited in CM-10 mixture. This agreed with the work reported by Fang et al. (2015). When hydrated lime and fly ash were added as in CM-12 mixture, lime was able to absorb the water from the emulsion for hydration and increase the Marshall stability to 9.6 kN and reduces the flow to 4.5 mm when compared to CM-11 mixture without lime. On the other hand, when both hydrated lime and Portland cement were implemented in the aggregate-emulsion mixture, a significant increase in the stability of 10.4 kN could be observed.

It can be concluded that the mixtures of designations (CM-3, CM12, and CM-13) are satisfying the SCRB (2003) requirements for base course construction. It was felt that other mixtures (CM-4, CM-5, CM-10) may satisfy the requirements if more aeration and curing periods are allowed. Similar recommendations were reported by Serfass et al., (2004).

Conclusions

Based on the limitations of materials and testing program, the following conclusions may be drawn.

1- Implementing Portland cement as a filler in the aggregate-cutback cold mix is effective when more aeration period of 4 hours and aeration temperature of 60 °C were allowed.

2- Higher aeration temperature has exhibited higher volume of voids filled with asphalt of 71% for CM-3 mixture.

3- When hydrated lime and fly ash were added to the aggregate-emulsion mixture, lime was able to increase the Marshall stability to 9.6 kN and reduces the flow to 4.5 mm.

4- When both hydrated lime and Portland cement were implemented in the aggregate-emulsion mixture, a significant increase in the stability of 10.4 kN could be observed.

5- Mixtures of designations (CM-3, CM12, and CM-13) are satisfying the SCRB (2003) requirements for base course construction.

6- It is recommended to allow more aeration and curing periods for cold mix asphalt concrete to satisfy the specification requirements for base course.

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