Dense Grade Surface Course Cold Asphalt Emulsion Mixture Properties Containing Cement and Wheat Straw Ash (WSA)

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Abstract. Hot mix asphalt (HMA) can be replaced by cold bitumen emulsion mixtures (CBEMs), which are more environmentally friendly, less expensive, and use less energy. However, traditional CBEM has some drawbacks, primarily because it takes a while to reach its peak performance and is more susceptible to water damage. This paper talks about the test results of research that looked into and tried to make a new dense grade CBEM with a waste biomass material called wheat straw ash (WSA), made when the wheat straw is burned. The new (CBEM) was compared to a reference standard cold mix and to hot mix asphalt. The Marshall test and the indirect tensile strength test were used to measure the mechanical properties of the mixtures. The durability was tested by seeing how it reacted to water and how long it lasted. The outcomes demonstrated that CBEMs constructed using regular Portland cement (OPC) has superior mechanical characteristics, and then WSA could replace some OPC without compromising the gains. According to the results, the new CBEMs with WSA performed significantly better than the older CBEMs with OPC. The sensitivity to water also considerably improved when WSA was utilized. This study paves the way for creating novel, highly mechanically efficient CBEMs manufactured from biomass ash.

Keywords: Cold bitumen emulsion mixture; dense grade; indirect tensile strength; wheat straw ash (WSA); ordinary Portland cement (OPC).

1. INTRODUCTION

In contrast to conventional hot mix asphalt (HMA), cold bituminous emulsion mixtures (CBEMs) can be produced using environmentally friendly methods that lower CO_2 emissions while conserving energy [1]. These mixes, however, need more time to dry and are more susceptible to water damage due to their low initial strength [2-8]. In order to overcome their flaws and use their obvious advantages, much study has been done to establish the advantages and disadvantages of CBEMs [3,9]. Numerous studies have been conducted on the effectiveness of ordinary Portland cement (OPC), typically used in CBEMs to compensate for their weak early strength [5]. In order to manage how bitumen emulsions (BEs) break, to make mixtures stronger and stiffer early in the production process, and to reduce the amount of water released when the emulsion breaks, researchers have looked at adding OPC to bitumen emulsions (BEs) [10]. Others have demonstrated that including cement can reduce the mix's sensitivity to water, which facilitates the development of the mix's mechanical properties over time [11]. OPC interacts with the water in the emulsion, changing its continuous phase and hastening the emulsion's disintegration [12]. Researchers have also discovered that OPC improves the adhesion of the binder to the aggregate and lessens the undesirable effects of free water in mixes. This occurs due to the cement's increased coalescence rate, which results in a thicker binder when the cement is wet [3].

Using pozzolanic materials to construct roadways has various benefits, especially in CBEMs. According to [4], the cement and water in the CBEM harden the pozzolanic filler. According to [13], this material raises the ITS, moisture resistance, and Marshall Stability to acceptable values for cold recycled pavements. Rice husk ash was employed by [14] to enhance the mechanical characteristics of CBEM. In this work, CBEMs were made using wheat straw ash (WSA) rather than OPC as filler. Thus, this study aimed to describe the mechanical and long-term characteristics of CBEMs that contained either all or a portion of WSA. WSA is a waste product created by burning wheat straw that is removed following wheat harvest. The primary Objectives of this study are:

- To promote using (CAEMs) as an alternative to conventional hot mix asphalt in the construction of highways and roads for various reasons, including ease of production, cost-effectiveness, and environmental tolerance.
- To study strategies for increasing the efficiency of CAEMs in specific mixes with suitable gradation selection and using OPC and WSA as fillers.

2. MATERIALS

Materials like aggregate, cement, and bitumen emulsion used in this study are often used to pave asphalt roads in southern and central Iraq.

2.1 Aggregates

According to particle size, the aggregates are divided into coarse and fine aggregates; the coarse material utilized in the project is crushed aggregate from the Al-Nibaie quarry, and the fine aggregate comes from the city of Najaf. The aggregates undergo routine testing to determine their physical qualities; the findings are described in Table 1. In line with the British standard, Table 2 displays the selected gradation and specification limitations [15].

Table 1: Physical characteristics of mineral filler and coarse and fine aggregate.

Material	**Property**	**Value**
Coarse aggregate	Bulk specific gravity	2.78
	Apparent specific gravity	2.82
	Water absorption, %	0.61
Fine aggregate	Bulk specific gravity	2.69
	Apparent specific gravity	2.73
	Water absorption, %	1.60
Mineral filler	Particle specific gravity	2.71

Table 2: Selected surface course gradation [15].

Sieve opening size (mm)	**Limits specification of passing (%)**	**Mid-limit gradation specifications, passing (%)**
20	100	100
14	95-100	97.5
10	70-90	80
6.3	45-65	55
4	-	-
2	19-37	28
1	10-30	20
0.063(filler)	3-8	5.5

2.2 Bitumen Emulsion

In this research, all CBEM samples are made with cationic ally emulsified asphalt. Table 3 shows the properties of the used bitumen emulsion.

Table 3: Properties of Bitumen emulsion [16].

Bitumen emulsion	
The Properties	The Values
Residue by distillation, %	60.0
Relative Density at. 15 ºC, g/cm^3	1.050
Appearance.	Dark brown to black liquid
Residual bitumen penetration, 1/10 mm	100.0

2.3 Conventional Mineral Filler (CMF)

The residual powder from the aggregate crushing operation was used to make the conventional mineral filler. CMF filler was made from the components that passed through sieve No. 200.

2.4 Ordinary Portland Cement (OPC)

Ordinary Portland cement was provided in this study from the Kufa Cement Lab. Using the OPC as filler with a ratio (2%) of the total weight aggregate (1000 gm) in this study, the physical and chemical properties shown in Table 4.

Table 4: Analysis of XRF for OPC and physical properties.

Physical Property	
Specific Surface area (m^2/kg)	418
Density (gm/cm^3)	3.12
Chemical Composition (XRF)	
CaO	60.845%
K_2O	0.694%
MgO	1.625%
Na_2O	1.583%
SiO_2	24.564%
Al_2O_3	2.135%
Fe_2O_3	1.131%

2.5 Wheat Straw Ash (WSA)

This material was bought as sticks from the local market and then washed with a water well to remove impurities and mud. It was burned in a large container exposed to the air to turn it into charred sticks and then burned again in an electric incineration oven at a temperature of 700° C for 2 hrs [17]. Then grind the product with the grinding device shown in the picture so that the grains of this substance pass through a sieve (No.200). The chemical composition of WSA is shown in Table 5.

Table 5: Chemical composition for WSA [17].

Compounds	Values (%)
Na_2O	1.67
Al_2O_3	0.94
CaO	3.23
MgO	1.85
SiO_2	73.4
K_2O	9.45
MnO	0.02
P_2O_5	1.28
TiO_2	1.90
Fe_2O_3	1.17

3. MIXTURE DESIGN

3.1 Identifying the Initial Bitumen Emulsion Content (IBEC)

The empirical Equation proposed by MS-14 (Asphalt Institute, 1989) was utilized to calculate the initial residual bitumen content (P) for constructing CBEMs. The following is this Equation:

$$P = 0.7\,(0.05\,A + 0.1\,B + 0.5\,C) \tag{1}$$

Where:
P = is the percentage of emulsified asphalt in weight, depending on the weight of the dry aggregate،
A = percentage of material retained on a 4.75 mm sieve،
B = % of aggregate passing a 4.75 mm sieve and remaining on a sieve (No200).
C =stands for the percentage of aggregate passing sieve (No200).

The chosen aggregate gradation, which is displayed in Table 2, was used to calculate the values for (A), (B), and (C). For a dense grade, the values of (A, B, and C) were discovered to be (55, 39.5, and 5.5%). An emulsion is created by combining water and small drops of bitumen. Divide (P) by the proportion of the residual bitumen content in the emulsion to get the value of IEC (Initial Emulsion Content). The amount of residual bitumen in the emulsion can be calculated by heating it until all of the water has evaporated, then dividing the result by the total amount of emulsion using the formula below:

$$IEC = P/X \tag{2}$$

Where:
IEC = is the initial emulsion content by mass of dry aggregate %.
P = stands for Percent by Weight of Asphalt Emulsion based on Weight of Graded Mineral Aggregate.
X = is the residual bitumen percentage in the emulsion.

By the chosen grade and after using Equation (1), the initial residual bitumen content was (6.615%) by aggregate mass. The utilized emulsion had 60%. IEC equals 6.615 / 0.6 = 11.025% by aggregate mass.

3.2 Determination of Optimum Emulsion Content (OEC)

Additional sets of samples were created with different amounts of (BEC) by Initial Residual Bitumen Content utilizing the optimal pre-wetting water content (OPWC) previously stated (IEC). For five sets of combination specimens, the IEC defined, and its value obtained following Section 4 are utilized as a median value, two points below and two points above the (IEC). The suggested interval steps are 0.5% [18]. The two specimens in each set are represented. The best Indirect Tensile Strength Test result-based emulsion content was selected after specimens were produced and examined at each level. Figure 1 shows the Determination of optimum emulsion content.

3.3 Determination of Pre-Mixing Water Content

The pre-mixing water quantity largely controls the coating degree of the aggregate and bitumen emulsion, especially when the aggregate gradation has a high proportion of filler. According to reports, the optimum bituminous coating on aggregate may be produced when the mixture is neither stiff nor sloppy. Different pre-mixing water contents were integrated, namely (3-6%) by mass of aggregate with Initial Emulsion Content (IEC), computed from equations (1) and (2), to mention the lowest pre-mixing water content with adequate coating. In preparation for CBEMs, 4% pre-mixing water (40 grams) by aggregate mass was chosen based on visual inspection [18].

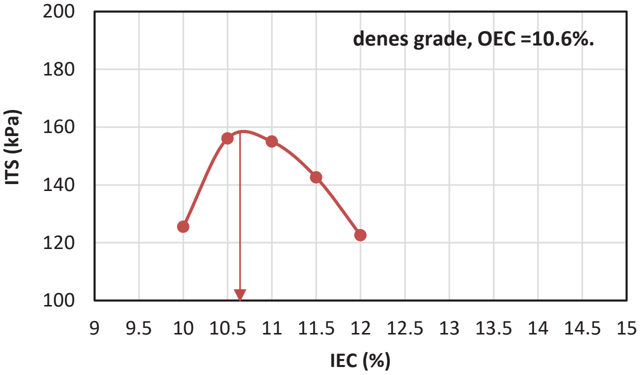

Figure 1: Determination (OEC).

3.4 Preparation of Cold Asphalt Emulsion Mixtures (CAEMS)

CAEM specimens were combined employing the mixing process. The filler and aggregate materials were combined for one minute slowly with pre-wetting water content (4% from aggregate mass). Asphalt emulsion was added slowly during the next minute of mixing at the same speed. This process was repeated for another minute at high speed, for 3 minutes of mixing. The mixture was then blown by hand into the mold, ten times in the middle and fifteen times on the ends. Also, each side of the samples got 75 hits from a Marshall hammer.

3.5 HAM Mixture Design

The traditional Marshall method was chosen to prepare HAM samples in this study. As mentioned previously, the materials used in the preparation are asphalt of the type (40-50). As for the aggregate, it used the same gradation for the surface layer, as shown in Table 2. As for the type of filler, mineral filler was used to produce samples. As a result, the optimum asphalt content (OAC) was (5.1%) of the aggregate mass.

3.6 Determining the Optimal WSA Concentration

WSA was applied to cold bitumen emulsion mixtures containing 2% OPC at concentrations of 2, 4, 6, 8, and 10% by total aggregate weight as filler. The specimens were prepared and evaluated to determine indirect tensile strength values. ITS was adopted to denote the optimal WSA content. The outcomes are depicted in Figure 2. Figure 2 displays the ITS values for cold mixtures with various WSA percentages. It is evident that when the percentage of WAS grew, the mixture's indirect tensile strength increased dramatically. This increase was abrupt until the WSA percentage reached 4%.

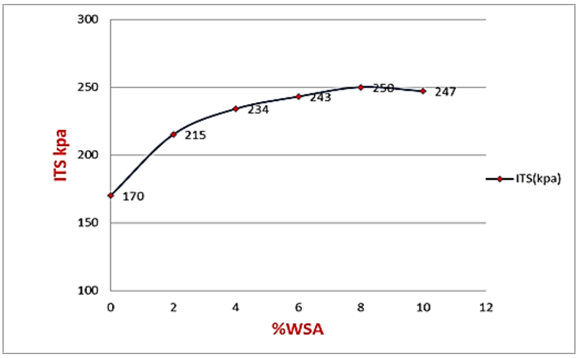

Figure 2: Optimum % WAS.

4. TESTING PROGRAM

4.1 The Marshall Stability (MS) Test

The Marshall stability apparatus is used to test the stability of (CBEMs) in a similar way that it is used to test the stability of (HMA). Following preparation and compacting, the sample is changed to be tested for curing (24 hours in a mold at 30°C). After that, the samples are left at 30°C for seven days and tested in the Marshall apparatus. According to [19].

4.2 The Indirect Tensile Strength Test

The (ITS) test was performed using the technique specified by ASTM D 4123. (ASTM Standards, 2004) [20] The experimental approach for determining a cylindrical specimen's tensile or splitting strength is based on loading the specimen diametrically in compression at a constant rate of 50.8 mm/min (2 in/min) to establish a tension zone along the loaded diameter of the specimen. The greatest achievable tensile strength can be expressed as follows:

$$\mathrm{ITS} = 2\,\mathrm{P}/\pi.\mathrm{D}.\mathrm{T} \tag{3}$$

Where:
ITS = Indirect tensile strength, kPa.
P = maximum load, kN.
T = Height of specimen immediately before test, m.
D = diameter of specimen, m.

The indirect tensile strength test for CBEM specimens follows sample compaction and curing testing (24 hours in the mold at 30 degrees Celsius). Placed at (30°C) laboratory temperature for (7) days according to the specified test age before executing the (ITS) test using Marshall Equipment.

4.3 Index of Retained Strength Test

The (IRS) measures how much the CAEMs have been damaged by water. According to ASTM D 1075 [21], "Effect of Water on Cohesion of Compacted Bituminous Mixtures," this test was done. Using indirect tensile strength (ITS), this study determined the asphalt mixtures' retained strength index. For this test, two independent sets of samples were created. Following preparation and compaction, the first batch of dry samples was placed in the mold for 24 hours at (30°C) lab temperature. They were then stored at this temperature for the previous seven days while being subjected to an indirect tensile strength test. The second set of samples was wet and subjected to the identical circumstances as the first set, with the exception that after being taken out of the mold, the samples were left at room temperature (30°C) for four days before being placed in a water bath at (40 °C) for three days. Indirect tensile strength testing (ITS) was conducted on the samples after they were taken out of the water bath and kept at room temperature (30°C). Using the following Equation, one can determine the value of the index of maintained strength (ASTM D 1075).

$$\mathrm{ITSR} = \mathrm{STa} \,/\, \mathrm{STb} \tag{4}$$

Where:
ITSR = Ratio of (ITS), %.
STb= value of (ITS) before aging, kPa.
STa = value of (ITS) after aging, kPa.

4.4 Aging Test

The term "aging" can describe how bitumen binders and mixtures change throughout construction and their service life in terms of their rheological characteristics [22]. Bitumen typically ages in two stages: short-term aging, which is brought on by heating the binder during production and construction, and long-term aging, which takes place as a result of oxidation during the period of the pavement's service life. Short-term aging is not a concern for CBEMs because no heat is required in their production. The Strategy Highway Research programmer (SHRP) A003A's long-term oven aging method was utilized in this study to assess long-term aging for the new asphalt mixture. Curing compacted specimens at 85°C for 2 or 5 days simulates bitumen aging in the field for 5 to 10 years [23]. This method simulates bitumen aging in the field throughout 5 to 10 years by curing compacted specimens at 85°C for 2 to 5 days [23].

5. RESULTS AND DISCUSSION

5.1 Effects of OPC and WSA Addition on the Results of Indirect Tensile Strength after 7 Days

The Indirect Tensile Strength (ITS) test is crucial for determining the tensile strength of a cylindrical specimen when applied to cold bituminous emulsion mixtures. The influence of adding OPC with WSA on ITS with age is seen in Table 6.

Table 6: Indirect tensile strength (ITS) in (7 days) age.

Symbols	**ITS (kPa)**	
CBEM (mineral filler) Control	165	**159**
	153	
CBEM(2%opc)	173	**170**
	167	
CBEM (2%opc+%WSA)	236	**234**
	232	
HAM	1012	**1022**
	1032	

It also shows that the mixture with (2%OPC+4%WSA) has increased in ITS (47%) compared to the control. CBEM with 2% OPC+4% WSA showed an insignificant drop in ITS. The pozzolanic property of the WSA in the presence of OPC and the hydraulic propriety of the OPC itself is after insignificant changes in ITS. Finally, the obtained ITS still needed to be comparable to HMA. Therefore, there is still a strong need for further development of CBEM's crack resistance.

4.2 Effects of Adding OPC, WSA on Marshall Stability

Marshall Stability is essential to asphalt mixture performance in surface course design. It can withstand shoving and rutting and provide sufficient stiffness under traffic [14]. Figure 3 shows (MS) values for cold mixtures. Marshall's mixture stability rose considerably when OPC and WSA were added to be more than hot asphalt mixture outcomes.

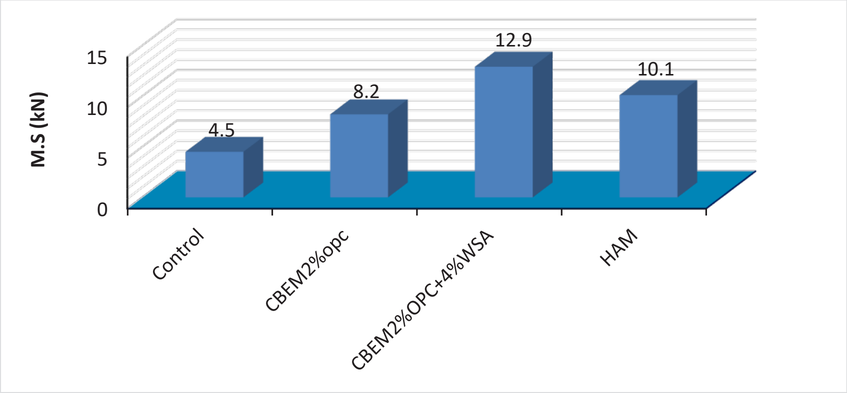

Figure 3: Marshall Stability.

4.3 Effect of Adding OPC, WSA on (IRS)

In order to evaluate the moisture damage to the CBEMs, the Index of Retained Strength, also known as water sensitivity, is used. Figure 4 displays the ITS for these mixtures both before and after exposure to water.

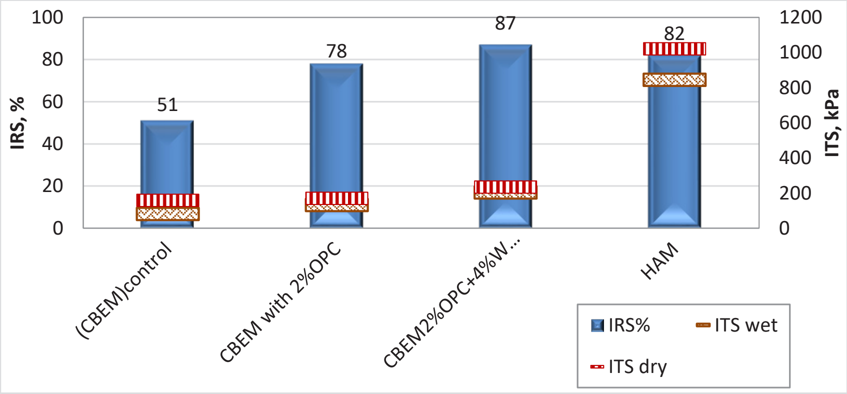

Figure 4: Index of retained strength.

Actually, in Figure 4, the IRS equals (51%) for the control, which is very low if compared with the hot asphalt mixture (HAM) was equal (82%). However, when adding (2%OPC), the IRS results became the same level as (HAM). Also, the mixture with (2%OPC+4%WSA) was the best result when using (OPC+WSA).

4.4 Effect of Adding OPC, WSA on Aging Test

Both samples from the conditioned and unconditioned groups were used in these group experiments. The samples in the first group underwent standard curing in a lab setting. To imitate the age-hardening effects of medicine, the samples in the second group underwent oven curing at 85C for two days. Then, using ASTM D6931 at 25°C (ITSR), the indirect tensile strength (ITS) was assessed for both groups of samples to determine the hardening aging in terms of ITS. Aging effects were calculated using Equation (5) and the indirect tensile strength ratio. The result is shown in Figure 5.

$$\mathrm{ITSR} = \frac{S_{Ta}}{S_{Tb}} \quad (5)$$

ITSR = Ratio of (ITS), %.
S_{Tb}= Value of (ITS) before aging, kPa.
S_{Ta}= Value of (ITS) after aging, kPa.

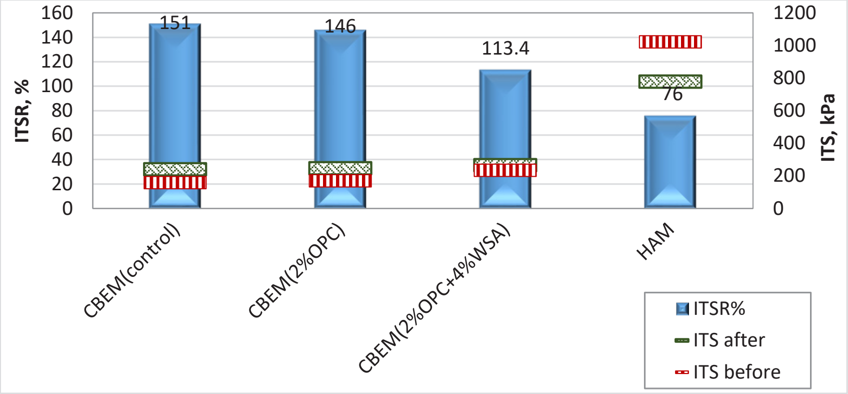

Figure 5: Aging test.

From the above, it is clear that the cold asphalt mixtures (CAM) achieve an increase in (ITS) with age. This is due to the growing of the mixture and the evaporation of quantities of the mixture water, unlike the hot asphalt mixtures (HAM).

12. CONCLUSIONS

This study was involved in the effect of adding (OPC and WSA) on the performance of cold asphalt emulsion mixtures in surface course. From this study, we can say the following:

- Because of the pozzolanic qualities of WSA, it is possible to replace most of the OPC with WSA. Replacing the CMF with OPC and WSA makes it possible to produce CBEMs that match specification criteria.
- When OPC or OPC with WSA as a filler is used in place of CMF, early cracking resistance can be remarkably improved. When OPC substitutes WSA for CMF, indirect tensile strength is increased by 47%. Nevertheless, it accounts for 19.1% of the outcome obtained in the hot mixture.
- Marshall Stability of CBEMs increased significantly when adding OPC and WSA to be more than hot asphalt mixtures results.
- Conventional CBEM is very easy to damage by water. This problem is solved by adding OPC or OPC with WSA. When a small amount of OPC is added to WSA, it is more resistant to water damage than OPC alone.
- In the (Aging long-term) test, it was noted that the performance of the cold asphalt mixture increased due to the curing and evaporation of the mixture water due to the heat, in contrast to the hot asphalt mixture, which showed a decline in the results.

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