Cold Asphalt Mixtures Characteristics with Cement and Sugar Industry Waste Material as Mineral Filler

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Abstract. Cold mix asphalt is bituminous material that produced at ambient temperatures. Many advantages can be obtained from cold mix asphalt especially, economic and environmental aspects this come from no need to heat of aggregate and bitumen for purpose the production and laying mix which are remain necessary demand to hot mix asphalt production. However, cold mix asphalt show inferior performance at early life and high porosity. This lab investigation focuses on improving the Cold Bitumen Emulsion Mixtures (CBEMs) containing 2% ordinary Portland cement (OPC) by adding Sugar industry Waste (SW) with different percentages i.e. 2, 4, 6 by total mass of aggregate. The optimum SW content was selected based on Indirect Tensile Strength (ITS) test which was 4%. ITS for the modified mix increased significantly to more than 55% and 32% in comparison with the untreated mixtures and CAEM with 2% OPC, respectively. On the other hand, the results of tests for Marshall Stability (MS), Marshall flow (MF) and index of retained strength (IRS) tests were encouraged. The value of MS and MF for mixtures with 4% SW increased about 140% and 38% respectively while, IRS improved about 45% in comparison with untreated mix. Finally, this research has gave highly improved cold bituminous emulsion mixtures (CBEMs) with SW in addition to environmental and economic benefits.

Keywords: by product materials, cold emulsion mixtures, indirect tensile strength, waste materials.

1. Introduction
Cold-mix asphalt is an asphaltic material that is mixed at ambient temperatures [1-5]. Particularly when compare the engineering properties for cold bituminous emulsion mixtures (CBEMs) with hot-mix asphalt (HMA) it will give important benefits because CBEMs do not need to heat it through the production and laying process. Consequently, new pavement produces more cost effective and less environmental effect. However, comparably between CBEMs and conventional hot mix asphalt, CBEMs will offer weak early strength and raise in porosity [6], [7]. The disadvantages that mentioned it can be attributed to the presence of water in the mixture [8]. So their uses are very limited due to the long period needed for such materials to arrive on their full strength after paving. In addition, at early age these mixes are very highly sensitive to rainfall [9]. Consequently, cold mix asphalt has seldom been used as structural layer for heavy-duty pavements [10]. Previously, many studies were conducted to improve the performance of CAEMs using hydraulic binder i.e. lime, cement… etc [11]. OPC largely improves the early mechanical properties when adding (1-2) % by total mass of aggregate [12]. Several experiences have been conducted to use waste and by-product materials as replacement of cement.

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because they are not costly to improve CBEM mechanical properties in addition economic and environmental benefits [13].
In this study conventional mineral filler was replaced with Sugar Industry Waste Materials. Therefore, the aim from this study is investigating about possibility improve mechanical properties and moisture damages of CBEMs after adding sugar industry waste.

2. MATERIALS

2.1. Aggregate
The materials which were used in this research are the same that was functioned to produce conventional Hot Asphalt Mixtures (HMA) in Iraq. The aggregates were divided into two groups according to the particle size and conformed with the "general specification for roads and bridges" (SCRB, 2007) [14], section R9/3 as illustrated in Table 1 and Figure 1. A crushed coarse aggregate, which was collected from Al-Nibaie quarry, was used in this work, while a sand collected from local quarry in Al- Najaf city. A summary of their physical properties is presented in Table 2.

| Sieve opening size, mm | 25 | 19 | 12.5 | 9.5 | 4.75 | 2.36 | 0.3 | 0.075 |
|------------------------|----|----|------|-----|------|------|-----|-------|
| Specification limits, % passing | 100 | 90-100 | 76-90 | 56-80 | 35-65 | 23-49 | 5-19 | 3-9   |
| Mid-limit gradation specifications, % passing | 100 | 95 | 83 | 68 | 50 | 36 | 12 | 6     |

Figure 1. Gradations of aggregate that are used in the work.
Table 2. Aggregate Physical properties.

| Aggregate type  | Property                  | Result |
|-----------------|---------------------------|--------|
| Mineral filler  | Particle specific gravity | 2.71   |
| Fine aggregate  | Apparent specific gravity | 2.72   |
|                 | Bulk specific gravity     | 2.69   |
|                 | Water absorption, %       | 1.60   |
| Coarse aggregate| Apparent specific gravity | 2.82   |
|                 | Bulk specific gravity     | 2.78   |
|                 | Water absorption, %       | 0.61   |

2.2. Filler
Three types of materials were used as filler in this lab investigation which were, sand dust, OPC, and Sugar Industry Waste (SW). OPC was supplied by AL-Kufa Cement factory and added as a replacement to filler with different percentages i.e. 0, 2, 4 and 6% by total mass of aggregate. Physical and Chemical characteristics of OPC are displayed in Table 3.

Table 3. OPC Physical and Chemical characteristics.

| Physical Properties |                        |
|---------------------|------------------------|
| Specific surface area (m²/kg) | 418 |
| Density (gm./cm³)    | 3.12                   |
| Passing sieve No.200 | 95%                    |

| XRF Results          |                        |
|----------------------|------------------------|
| CaO                  | 60.845%                |
| SiO₂                 | 24.564%                |
| Al₂O₃                | 2.135%                 |
| MgO                  | 1.625%                 |
| Na₂O                 | 1.583%                 |
| Fe₂O₃                | 1.131%                 |
| K₂O                  | 0.694%                 |

*The tests of OPC were conducted at Kufa Cement factory in Najaf city
On the other hand, Sugar waste was supplied from Etihad Company for food industries in Babylon and considers as by product material of sugar manufacture. In this research (SW) was partially replaced with (OPC) by different percentages of total mass of aggregate. Sugar Waste Chemical properties are displayed in Table 4 and its photo is shown in Figure 2.

2.3. Bitumen Emulsion
All CBEMs specimens were prepared using K3-60 Cationic emulsified asphalt because it has high stability and high adhesion (Nikolaides, 1994 [15] and Thanaya, 2003 [16]). The properties of this asphalt emulsion are exhibit in Table 5.
Table 4. Chemical and Physical Properties of (SW).

| Chemical Properties | (SW) |
|---------------------|------|
| Oxides              |      |
| SiO₂                | 19.8%|
| Al₂O₃               | 3.2% |
| Fe₂O₃               | 2.5% |
| CaO                 | 71.6 %|
| SO₃                 | 1.1 %|
| MgO                 | 1.8% |

| Physical Properties  |      |
|----------------------|------|
| Specific surface area, (cm²/gm) | 4796 |

*The tests of SW were conducted at Kufa Cement factory in Najaf city.

Figure 2. Sugar Industry waste that are used in this work.

Table 5. Asphalt Emulsion Properties.

| K3-60 asphalt emulsion properties | Value |
|-----------------------------------|-------|
| Residual bitumen penetration, 1/10 mm | 100   |
| Residue by distillation, %         | 60    |
| Appearance                         | Black to dark brown liquid |
| Relative Density at 15 °C, g/cm³   | 1.05  |

3. CBEMs’ Design Procedure and Preparation

Depending on asphalt institute design procedure MS-14 [17], Cold Bitumen Emulsion Mixtures (CBEMs) specimens were designated and this design way includes the following steps; determination of aggregate gradation, definition of initial residual bitumen content (IRBC) and initial emulsion content (IEC), and determination of pre-mixing water content (PMWC). Accordingly, IEC= 12%, PMWC= 3%.
To prepare CAEM, firstly weighing (1000 gm) from the require gradation of CBEM Specimen with different percentages of filler type according to Table (1) and incorporate shown in Figure 3, then was placed it in the mixing machine shown in Figure 4. Pre-wetting water content (3 % by weight of aggregate) were added to the aggregate and filler material and mixed for one minute at slow speed. Then bitumen emulsion (12 % by weight of aggregate) was gradually added at high speed for 30 minute and the mixing process was persisted for 1.5 minute. As a result the total time of mixing for both pre-wetting water content and bitumen emulsion equal to 3 minutes. After that the mixture was placed in the mold with hand blows process by spatula; (10 blows in the center and 15 blows in the edges). Finally, the mold that contain mixture put under standard Marshall Hammer (impact compactor) as illustrated in Figure 5 and compaction process was applied with number of blows equal to 75 blows to each face of the specimens.

Figure 3. Specimen of 1000 gm From gradation aggregate.

Figure 4. Mixing Machine.

Figure 5. Standard Marsha Hammer.
4. Testing

4.1. Indirect Tensile Strength (ITS) Test
The method that was depended to conduct Indirect Tensile Strength (ITS) test is based on ASTM D 4123 (ASTM Standards, 2004) [18]. The aim of experimental test is to investigate the tensile, or splitting, strength of a cylindrical specimen and this achieve when apply compression load diametrically on specimen with a constant rate of 50.8 mm/min using steel strip on the specimen top and bottom to procreate tension zone which passing through the center of its loaded. The value of the maximum tensile strength calculated as below:

\[
\sigma_t = \frac{2 \times P_{\text{max}}}{\pi H D}
\]  

Where:
\[
\begin{align*}
\sigma_t & = \text{indirect tensile strength, KPa;} \\
P_{\text{max}} & = \text{ultimate applied load, KN;} \\
H & = \text{specimen height, m;} \\
D & = \text{specimen diameter, m.}
\end{align*}
\]

ITS test for CBEM specimen is conducted after the sample was compacted, and placed in the mold for 24 hour at laboratory temperature i.e. 40 °C, then curd in the oven, as shown in Figure 6, at 40 °C for 24 hours after extracting it from mold by machine as displayed in Figure 7. Finally the next day the test of (ITS) was implemented by Marshall apparatus as presented in Figure 8.

![Figure 6. The Heating oven.](image)

4.2. Marshall Stability and Flow (MS & MF) Test
Marshall stability value is the maximum force that is recorded during the compression load. The test of stability for CBEMs was conducted on the sample which had been modified and the control after prepare and compact it and this accomplished by using the apparatus of Marshall Stability that Hot Mix Asphalt (HMA) was depended it in the test as shown in Figure 9. The samples was treated with the following circumstance; (24 hours placed in the mold at lab temperature 40 °C). Then the sample was left at lab temperature for 5 days after extracting it from mold. In the sixth day the test is made but before that put in the oven at least for 2 hours at 40 °C.

Marshall Flow is the depth of the plastic flow resistance to bituminous mixtures specimens that is loaded on the lateral surface by means of the Marshall apparatus too. The test was conducted based on ASTM D 1559-76 and AASHTO T 245-97. The Marshall Flow Value is the deformation recorded at maximum load at constant rate 50.8mm (2 in) per min that apply synchronization with Marshall Stability Test and this occur when holding the sleeve
firmly against the upper segment of the breaking head then the flow meter was zeroed and the test will begin.
The test was performed only on dry samples group which were next referred to them in Index of Retained Strength (IRS) test and at the same curing.

**Figure 7.** Specimen Extraction Machine.  
**Figure 8.** Marshall Apparatus for (ITS) Test.  
**Figure 9.** Marshall Apparatus for (MS & MF) test.
4.3. Index of Retained Strength (IRS) Test
Moisture susceptibility for both control and improved CBEMs was investigated by indicating IRS based on ASTM D 1075 [18]. Two groups of samples were made and distinct. After the preparation and compaction all samples. Take the first group which are dry samples and placed in the mold for 24 hours at lab temperature (40 ºC). Then the sample was remained at lab temperature (40 ºC) for 5 days after extracting it from mold. In the sixth day the test is made but before that put the sample in the oven at least for 2 hours at 40 ºC. The second group which represent wet samples were cured as following: 24 hours in the mold at lab temperature (40 ºC). Then, extracting the specimens from mold and placed it at lab temperature i.e. 40 ºC for 4 days, then put it in the water bath at 40 ºC for 24 hours as shown in Figure 10. Finally, the samples were take out from water bath and tested at the same temperature. The value of IRS can be determined in accordance to the below equation:

\[ IRS = \frac{S_2}{S_1} \times 100\% \]  

Where:
IRS = Index of Retained Strength, %
S_1 = Marshall Stability of dry mix, KPa
S_2 = Marshall Stability of wet specimens, KPa

5. Results and Discussions

5.1. Effect of OPC Addition on ITS Results
ITS test was used to measure asphalt mixtures ability to resist tensile cracks failure. Figure 11 offer results addition (OPC) on (ITS) for Cold Bitumen Emulsion Mixture samples that prepared with various percentages; 2%, 4%, 6% by mass of aggregate (1000gm for each sample) as substitution to mineral filler that passes from sieve no.200 (size 0.075mm).

Addition of OPC to the mixture increases (ITS) as shown in Figure 11. The (ITS) value of control mixture that contain only 6% of materials mineral filler was 69.19 Kpa, and can be seen that (ITS) increased largely when added OPC with the above mentioned percentages. So the increment percentages are as following: 17.4%, 38.9% and 50.4% respectively in comparison with untreated mixtures.

This clear improvement on (ITS) interrupt the role of cement in Cold Bitumen Emulsion Mixture in enhance its mechanical properties as mineral filler.
5.2. Effect of Sugar Industry Waste addition on ITS Results
ITS was adopted to indicate the optimum content of Sugar Industry Waste. So the results that obtained in Figure 12 were made for four percentages of this waste: 0%, 2%, 4%, 6% by total weight which added as filler with constant percentage of 2% OPC for all sample.

Figure 12 shows the results of ITS test values for cold mixtures with different percentage of Sugar Industry Waste. There is gradually increase of ITS value with increasing of Sugar Industry Waste percentage; but it decrease after 4%. As a result the optimum content of Sugar Industry Waste can be adopted to be 4% by total weight of aggregate. The increment percentage for the mixtures with 4% Sugar Industry Waste was over than 55% and 32% as comparable with the control mixtures (which mean mix containing only dust as filler that passes from sieve no.200) and the cold mixtures containing 2% OPC respectively. Due to this results values of (ITS) that obtained from mixtures containing 2%OPC+4%SW higher of all until 6% OPC. So the sugar waste is a very promising finds from mechanical, environmental and economic aspects which consider advantage of using Cold Bitumen
Emulsion Mixtures. Finally, based on these results, the optimum content of Sugar Waste use in this study can be undertaken to be 4% by total mass of aggregate.

5.3. Influence of (SW) Addition on Marshall Stability and Flow
The results of Marshall stability for Cold Bitumen Emulsion Mixtures (CBEMs) shown in Figure 13 signified great increment in percentages between mix with 6% dust (materials that passing sieve no.200) and mix with (4%SW+2%OPC) of total weight which equal to 140%, furthermore there is a little increment between mix contains (4%SW+2%OPC) and mix with (2%OPC+4%dust) and equal more 9%. Also, Figure 14 shows decline in flow values and this considers improvement in flow property. When compare mix that consist of (4%SW+2%OPC) with untreated (mix contain material passing sieve no.200) and mix with (2%OPC+4%dust). The proportions were more 38% and 27% respectively. As a result the mix which consist of (4%SW+2%OPC) by the total weight of aggregate can be consider as optimum percentage for utilizing it to improve CBEMs.

![Figure 13. Marshall Stability Values Vs different percentages of filler (Dust of Aggregate, OPC, SW) on (CBEM).](image1)

![Figure 14. Marshall Flow Values Vs different percentages of filler (Dust, OPC, SW) on (CBEM).](image2)
5.4. Effect of (SW) on IRS
Test results of retained strength test that determine in term Marshall Stability tests in both condition: dry and soaked on water as sketch in Figure 15, have shown increasing in values gradually, so may be seen when compare mix contained (2%OPC+4%SW) with untreated CBEM (contain only materials passing sieve no.200) (IRS) increases around 45%. Moreover, there is increase too, between mixes contain (2%OPC+4%SW) and (2OPC%+4%dust) by total weight of mix and it around 30%. This increase which obtained from mentioned results especially from (2%OPC+4%SW) can be contributed to accelerate of hydration process that result from water presence on CBEMs.

![Figure 15. Index Retained Strength Values Vs different percentages of filler (Dust of Aggregate, OPC, SW) on (CBEM).](image)

6. Conclusion
In accordance to the lab investigation results, the following conclusions can be reported:

1. When use OPC in Cold Bitumen Emulsion Mixtures (CBEMs) with different percentages: 2, 4, and 6 by mass of aggregate, the indirect tensile strength increases significantly as following: 17.4%, 38.9% and 50.4% respectively in comparison with untreated mixture.
2. By using Sugar Waste as filler with 2, 4, 6% by mass of aggregate as replacement substitute of OPC the mechanical properties in term indirect tensile strength and Marshall stability of mixture was improved.
3. The optimum content of sugar waste can be adopted as 4% which is corresponding to the optimum ITS.
4. It can be noted that Sugar Waste at 4% partially replacement of OPC by mass of aggregate improves the ITS, and MS of cold mix asphalt in comparison with untreated mixtures as follows: 55 and 140 %, respectively. Also flow value is reduced around 38%.
5. Optimum content of sugar waste that corresponding indirect tensile strength was higher than the value of indirect tensile strength with 6%OPC and this is good for environmental and economic considerations to replace it with the Sugar Waste.
6. Through the results of index retained strength which is measurement of damage moisture for Cold Bitumen Emulsion Mixtures (CBEMs) by adopting optimum Sugar Waste (4%) there was enhancement equal to 45% in comparison with untreated mixtures this mean hydraulic products react with the Sugar Waste with the presence of water.

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