Hot Mix Asphalt Characteristics with Sugar Industry Waste Materials as Mineral Filler

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Abstract. Recently, applying of the waste materials as mineral filler in hot asphalt mixture has many advantage for economic and environmental impacts and also used to improve the hot asphalt mixtures characteristics. In this research, sugar industry waste materials has been used as mineral filler to investigate the achievable prospects to improve hot asphalt mixture properties. The aim of this study is to evaluate the effect of adding Sugar Waste (SW) materials on the properties of hot mix asphalt in comparison with the State Commission of Roads and Bridges (SCRB, R9) requirements. Two groups of hot asphalt mixtures have been prepared, the first was with the Ordinary Portland Cement (OPC) as mineral filler i.e. (control mixture) and the second was prepared with SW materials (modified mixtures). These mixtures have been assessed based on different experimental tests which were Marshall Stability, Indirect Tensile Strength (ITS), Index of Retained Strength (IRS) and Long Term Aging (LTA). The results indicate that there is an improvement in the mixture properties; slight increase in Marshall Stability, an improvement in Indirect Tensile Strength, enhanced their Marshall stability after aging when tested in accordance to LTA. Furthermore, the modified mixtures comply with (SCRB, R9).

Keywords: Marshall stability, long term ageing, durability, mechanical properties

1. Introduction

Pavement is commonly constructed from hot asphalt concrete due to the durability, stability, and water resistance that can be achieved when adopted for roads construction. Asphalt mixtures are consisted of aggregates i.e. coarse, fine, and filler, asphalt cement and air voids. The durability and quality of asphalt road is affected by the amount and type of mineral filler material which is used in addition to some other parameters. Different materials are used as mineral filler such as cement, lime, limestone dust, stone dust, granite powder, and fine sand [1]. Reusing of waste material became a topic of growing importance, "The European union" keeps pushing them self in this direction and infrastructures of transportation are expected to comply with general view of recycling of waste materials and environmental compatibility [2]. Therefore, many studies have been conducted which were focussed on incorporating of waste materials in different kinds of asphalt mixtures i.e. hot, cold and warm [3–9]. Some interesting works for the waste materials as mineral filler in asphalt mixtures, Sargin et al., (2013)
[10] for example, investigated the effect of using Rice Husk Ash (RHA) as mineral filler in asphalt mix; the results of the tests showed that mixture which is containing 50% RHA and 50% Lime Stone (LS) had an appropriate Marshall Stability (MS). Sargin’s research concluded that, RHA can be used as filler in asphalt mix as an alternative of limestone mostly in areas where it ”RHA” is available. Arabani et al., (2016) [11] studied the use of different waste materials as a filler in asphalt mix. They examine several of waste materials i.e. glass powder waste, brick powder waste, RHA and stone dust as mineral filler. Marshall stability test, indirect tensile fatigue and indirect tensile stiffness modulus tests were conducted in their study. The results of these tests showed that glass powder waste and brick powder waste rise remarkably the fatigue life and the mix performance in general. As well as, they showed that there was no considerable alteration in the performance of the mix containing RHA and the control mix. Rongali et al., (2013) [12] explained the benefits of combined "plastic waste" and "fly ash" in asphalt mix. It was concluded that fly ash can be used as mineral filler in asphalt mix, and improved the properties of asphalt mix by covering fly ash with plastic waste, especially in the rutting terms. Lately, López- López, et. al., (2015) [13], discussed the probability of incorporating bottom ash that collected from thermal power plant and lime as a mineral filler in asphalt mix. The study Concentrated on the description of physical and chemical properties of Bottom Ash (BA) and on determining the mechanical characteristics of asphalt mix formed of BA or hydrated lime as mineral filler. The results of the tests that obtained in their work explained that the asphalt mix with a filler formed of 30% (HL) plus 70% (BA) achieved European specification.

In this paper, the main aim is to investigate incorporating of Sugar Waste (SW) as mineral filler in hot mix asphalt. Also, the modified mixtures will be compared by means of the mechanical and durability with the conventional hot mixtures which contains Ordinary Portland Cement (OPC) as mineral filler. Furthermore, the results will be compared with the specification requirements that is adopted by the State Commission of Roads and Bridges (SCRB R9) [14].

2. Methodology

2.1 Materials

Coarse aggregate, fine aggregate, filler and asphalt cement have been characterized using available lab tests. All these materials were compared with the SCRB R9 requirements and it comply with them.

2.1.1. Aggregate

The coarse aggregate that have been used in this research were crushed quartz which was collected from Al-Nibaee quarry, Iraq. The chemical and the physical properties of "crushed quartz" are shown in Table 1 and Table 2, respectively. The midrange was selected to prepare hot asphalt mixtures, Fig. 1, that comply with the SCRB requirement for type IIIA surface course mix with 12.5 mm max. size [14].
Table 1. Chemical properties of coarse aggregate.

| Chemical compound | Results % |
|-------------------|-----------|
| SiO₂              | 82.52     |
| SO₃               | 2.7       |
| CaO               | 5.37      |
| MgO               | 0.78      |
| Fe₂O₃             | 0.69      |
| Al₂O₃             | 0.48      |
| L.O.I             | 6.55      |

Mineral composition

Quartz 80.03  
Calcite 10.92

Table 2. Physical Properties of Coarse and Fine Aggregate.

| Property                                    | Test No. | result | SCRB requirement |
|---------------------------------------------|----------|--------|------------------|
| Soundness loss by sodium sulfate solution, %| C88      | 3.4    | 12 Max           |
| Bulk specific gravity                       | C127     | 2.610  | ......            |
| Apparent specific gravity                   | C127     | 2.6    | ......            |
| Percent wear by Los Angeles abrasion, %     | C131     | 22.7   | 30 Max           |
| The degree of crushing, %                   | D5821    | 96     | 90 Max           |
| Flat and elongated particles, %             | C4791    | 5      | 10 Max           |

Fine aggregate

| Property                                    | Test No. | result | SCRB requirement |
|---------------------------------------------|----------|--------|------------------|
| Sand equivalent, %                          | D2419    | 57     | 45 Min           |
| Apparent specific gravity                   | C128     | 2.6    | ......            |
| Angularity, %                               | C1252    | 54     | ......            |
| Bulk specific gravity                       | C128     | 2.631  | ......            |
| Clay lumps and friable particles, %         | C142     | 1.85   | 3 Max            |

Fig. 1. Selected gradation for surface course hot asphalt (Type IIIA).

2.1.2. Asphalt cement
(40–50) penetration grade asphalt cement which was collected from Al-Nasiriya Refinery was used in preparation of HMA. The physical properties is shown in Table 3.

2.1.3. Mineral filler
There are two different kinds of filler used in this research which were Ordinary Portland Cement (OPC) and Sugar Waste (SW) materials. OPC is collected from Al Kufa cement factory. Table 4 presents the
physical properties of OPC. While, SW materials which is an ash collected from Etihad Food Industries in Babylon. Table 5 shows both the physical and chemical properties of SW filler. While, Fig. 2 shows its photo.

In accordance to the selected gradation, mineral filler i.e. SW and OPC were added by 7% by total mass of aggregate.

### Table 3. 40–50 penetration grade properties.

| Property                        | Test No. | Result | SCRB Requirement |
|---------------------------------|----------|--------|------------------|
| Penetration at 25°C, 1/10 mm    | D5       | 46     | 40–50            |
| Flash point, °C                 | D92      | 273    | >232             |
| Specific gravity at 25 °C       | D70      | 1.03   | -                |
| Ductility at 25 °C, cm          | D113     | 115    | >100             |
| Solubility in trichloroethylene, % wt | D2042  | 99.31  | >99              |
| Thin-film oven residue test     | D1754    | -      | -                |
| Penetration, % of original      | D5       | 69     | >55              |
| Ductility at 25 °C, cm          | D113     | 55     | >25              |

### Table 4. Physical Properties of OPC

| Physical Properties             |         |
|---------------------------------|---------|
| Passing sieve No. 200            | 95%     |
| Specific gravity                | 3.12    |
| Specific surface area (cm²/gm)   | 4180    |

### Table 5. Chemical and Physical Properties of Sugar Waste

| Chemical Properties             | Typical Range in % |
|---------------------------------|---------------------|
| Major Elements                  |                     |
| 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                |
2.2. Testing methods

HMA specimens have been prepared according to the procedure mentioned in ASTM Designation: D1559-89 [15]. Firstly, the aggregate were separated to the selected gradation then heated up to 150°C. On the other hand, asphalt cement has been heated up to 150°C. Finally, the heated aggregates and asphalt were completely mixed at a temperature degree between 160–170°C by using a hot plate. The mixture was compacted according to the Marshall mix design method standards which state that 75 blows per each specimen face is applied by compactor hammer. Marshall Stability and flow and Indirect Tensile Strength (ITS) were conducted to investigate the mechanical properties. While, Index of Retained Strength (IRS) and Long Term Aging (LTA) have been used to evaluate the durability of the produced mixtures. Three specimens for each mix and property were prepared and tested. It is worthy to state that all the reported results were averaged to the results of three specimens.

2.2.1. Marshall Stability and flow

ASTM D6927 mentions the procedure that is used to prepare and test the specimens to specify MS and flow [15]. The resistance to plastic flow is determined by applying the load to a specimen with 4 in. (diameter) and 2.5in (height) by Marshall machine with 2 in./min rating load and at 60°C temperature up to the max. load is achieved. MS is the max. load resistance while Marshall flow is the corresponding strain values.

2.2.2. Volumetric properties

Asphalt mixtures’ bulk density was determined in accordance to ASTM D2726. Whereas, ASTM D3203 has been implemented to indicate Air Voids (AV), Voids in Mineral Aggregate (VMA) and Voids Filled with Asphalt (VFA).

2.2.3. Indirect Tensile Strength Test

ASTM D4123 test procedure was followed to indicate Indirect Tensile Strength (ITS) results. This procedure is depended on applying a compression load with a constant rate of 2 in. per min on the specimen to generate a tension area alongside the specimen’s loaded diameter. The term for the max tensile strength created can be found as:
\[ \sigma_t = \left( \frac{2 \times P_{\text{max}}}{\pi H D} \right) \]  
(1)

Where: \( \sigma_t \): ITS in KPa, \( P_{\text{max}} \): maximum applied load in KN, \( D \) and \( H \): diameter and height of specimen in m, respectively.

2.2.4. Durability
Two type testing were used to evaluate the modified and control mixtures i.e. moisture damage and long term aging. These factors are extremely affecting HMA performance in their service life.

2.2.4.1. Water Damage
Water damage have been assessed by specifying IRS which is in tern determined according to the test procedure described in ASTM D6927. This property has to comply with SCRB requirements for asphalt mixtures, must be higher than 70\%. The value of IRS test results are determined using Eq. (2). Two groups of specimens have been prepared and separated. The first set of specimens, dry specimens, represent the traditional MS procedure for preparation and testing. While wet specimens were submerged for 24 h at 60\°C then MS was conducting at 60\°C.

\[ \text{IRS} = \left( \frac{S_2}{S_1} \right) \times 100\% \]  
(2)

Where: IRS = Index of Retained Strength, \%, \( S_2 \) and \( S_1 \) are MS of the wet and dry specimens, KN, respectively.

2.2.4.2. Long term aging
Age hardening through road use can be simulated by Long Term Ageing (LTA). The prepared specimens are conditioned in an oven at 85\°C for 5 or 2 days to simulate 10 or 5 years’ age hardening in the field [16]. In this study, all the mixtures were conditioned in an oven at 85\°C for 5. Then ASTM D6927 was used to indicate MS [15].

\[ \text{LTG} = \left( \frac{\text{MS}_2}{\text{MS}_1} \right) \times 100\% \]  
(3)

Where: LTG = Long term aging, \( \text{MS}_2 \) and \( \text{MS}_1 \): MS after and before aging, respectively.

3. Results and discussion
Two asphalt concrete mixtures were prepared i.e. with OPC (traditional mineral filler) which is called OPCAC and with SW which is called SWAC. Asphalt cement contents for the two mixtures have been taken as 5\% by mass of total mix and three specimens were prepared for each test. Based on ASTM D2041 and ASTM D2726 theoretical maximum specific gravity and bulk specific gravity have been determined, respectively. While, air voids percentage have been determined according to ASTM D3203.

3.1. Influence of Sugar Waste (SW) Addition on Marshall Stability Test
The conditioning of the specimens for this test was submerged them for (30–40) min in the water bath at 60\°C. After that MS and flow have been implemented for each compacted specimen by the testing device.
MS (in KN) of HMA is the peak load that the specimen can hold when tested in Marshall device. Whereas, Marshall flow (in mm) is the strain corresponding to the maximum load. Figs. (3), (4) and (5) show the results of MS, flow and Marshall stiffness for the control and modified mixtures i.e. OPCAC and SWAC with 5% asphalt cement content (proposed optimum asphalt content in accordance to the practical experience in the local area).

As presented in Fig. 3, a slight increase in MS can be observed when OPC was replaced with SW. In Fig. 4 Marshall flow values for OPCAC and SWAC are within the range specified in the requirement. Finally, in Fig. 5 Marshall Stiffness values for SWAC are comparable with the control mixtures. A slight increase of MS results for SWAC in comparison with the control mix can be attributed to the surface area of SW which is higher than OPC. Therefore it can produce a mastic with stiffness higher than that produced from OPC.

![Figure 3. The results of MS for OPCAC and SWAC.](image1)

![Figure 4. The results of Marshall flow for OPCAC and SWAC.](image2)

![Figure 5. The results of Marshall Stiffness for OPCAC and SWAC.](image3)

3.2. Effect of incorporating of Sugar Waste on the volumetric properties of HMA

The mechanical properties and performance of HMA in the field is highly influenced by their volumetric properties. These properties were investigated by means of specifying bulk density, AV, VMA and VFA.
Figs. 6–9 display the volumetric parameters for OPCAC and SWAC. It is clearly shown that there is a little decrease in the bulk density for SWAC in comparison with the control mix. Despite, AV and VMA of the modified mixtures i.e. SWAC achieved the SCRB requirements for surface course HMA.

![Figure 6. Influence of Sugar Waste on Bulk Density.](image1)

![Figure 7. Influence of Sugar Waste on Air Voids.](image2)

![Figure 8. Influence of SW on VMA.](image3)

![Figure 9. Influence of SW on VFA.](image4)

3.3. Influence of Sugar Waste incorporating on ITS

Fig. 10 displays ITS results for OPCAC and SWAC. It can be stated that ITS for the new mixtures is higher than those of the control mixtures, Imost 17% increase in comparison with the traditional mixtures. This increase might be due to the higher stiffness of the produced mastic when using SW in comparison with OPC.

3.4. Influence of Sugar Waste addition on the durability of HMA

The durability of HMA can be characterised by indicating moisture damage and aging properties. IRS was used to indicate the earlier while LTA was used to investigate the later.
3.4.1. Water sensitivity

Fig. 11 demonstrates the results of IRS for both OPCAC and SWAC mixtures. Despite the decrease in IRS of SWAC mixtures in comparison with the control mixtures, it is still satisfying the SCRB requirements for surface course HMA.

![Figure 11. Influence of SW on Index of Retained Strength.](image)

3.4.2. Long Term Aging

The influence of aging on the performance of the control and modified mixtures was studied by means of LTA, Fig. 12 shows the result. There is an interesting results for SWAC in comparison with the control mixtures, nearly 23% rise when compared with OPCAC, which represent a very attractive finding.
4. Conclusions

Sugar industry waste materials (SW) has been proposed as an alternative to the conventional mineral filler in HMA. A detailed investigation has been implemented to compare between the novel mixtures with SW (SWAC) and mixtures with OPC as mineral filler (OPCAC). Furthermore all the results where compared with SCRB requirements which is adopted in Iraq.

Below are the main points that can be stated from this lab investigation:

1. Marshall stability of HMA increased very slightly when replacing the conventional mineral filler (OPC) with sugar waste (SW).
2. ITS results for SWAC mixtures increased more than the conventional HMA.
3. The modified mixtures i.e. with SW comply with the volumetric properties requirements.
4. By means of water sensitivity, IRS decreased for SWAC mixtures in comparison with the control mixtures. Moreover, based on LTA results, these mixtures i.e. SWAC have enhanced their mechanical properties after aging. In general, SWAC mixtures are more durable than the traditional mixtures based on the long term aging investigation.
5. Generally the modified mixtures i.e. SWAC comply with the required specification which is agreed by SCRB in Iraq.

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