Laboratory investigation on the properties of asphalt concrete mixture with GGBFS as filler

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Abstract. Consuming of by product materials in build manufacture such as making of hot asphalt mixtures introduces worthy interest on the way of ecological, economic standpoint. Accordingly, in this experimenter research, it was scrupulous for using Ground Granulated Blast Furnace Slag (GGBFS) in state traditional metal filler in hot asphalt mixtures. The mechanical characteristic was rating by lineal Marshall Stability & Indirect Tensile Strength tests. However, moisture harm and long-range aging were investigated by locate Index of retained Strength (IRS) & Mean Marshall Stability Ratio (MMSR), respectively. The empirical outcomes have presented a considerable refinement in the mechanical properties and a fundamental promotion in durability of the generated mixtures i.e. Asphalt Concrete Mixtures with GGBFS as a mineral filler (GGBFSAC) in rapprochement with the control mixtures that were infectious by ordinary Portland cement (OPC) as a mineral filler (OPCAC). As an outcome of this research, GGBFS can be united in state classical mineral filler in asphalt concrete mixtures especially in region where there is large GGBFS waste.

Keywords. Ground Granulated Blast Furnace Slag, OPC, durability, filler

1. Introduction

Asphalt concrete common applications in pavement as a result of its excellent service achievement, resistance and water impedance, are mostly a base, binder or surface course contain graded aggregate caught simultaneously by asphalt cement [1, 2]. Asphalt cement is the classical binder applied in build highways and road. Whereas, the aggregate particles work as the constitutional skeleton of the pavement which may represents about 90% of the volume of Hot Mix Asphalt (HMA) [3]. Additionally, filler materials resort to solidify the asphalt cement. Many materials like cement, limestone dust, lime, fine sand and rise husk ash normally applied as metal filler in HMA. As popular that lime, limestone dust and cement are costly and applied effectively for else aims. However, ash fine, sand and GGBFS passing 0.075 mm sieve magnitude are suitable as mineral filler.

The benefit from using the waste fine particles as filler in HMA were inspected by several investigators. Phosphate garbage filler [4], Jordanian oil shale fly ash [5], bag house fines [6], municipal solid waste incineration ash [7], and waste lime [8] were inspected as filler. It was stated that these garbage materials may be applied in asphalt concrete mixtures without any major decline in its effectiveness.

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Several studies have been conducted to improve the performance of cold asphalt emulsion mixtures by using different waste materials such as (but not limited to) GGBFS, fly ash, paper sludge ash …etc [9-11].

Many studies proves that effective mineral filler will react with asphalt cement to modify the produced mastic [12]. Also, addition of mineral filler can improve the elastic modulus of HMA. But, high amount of filler might be increase the demand of asphalt cement [13, 14].

GGBFS (Ground Granulated Blast Furnace Slag) is produced from the ferrous making manufacture. GGBFS was gained by mashing the muffle molten runny iron brusqueness. GGBFS is a granulated item that has so restricted crystal fashioning, with quite cementitious characteristic when take place cement fineness. About 2.2 million tons of GGBFS are generated per year in the UK and applied as texture aggregates or like a cementitious binder in the shape of ground granulated blast furnace slag (GGBFS). The BF slag is shaped in an uninterrupted operation by the incorporation of limestone (and/or dolomite) and other inflow with the dust from the carbon origin (coke) and the non- mineral combination of the iron ore. The slag buoys on the face of the slushy iron and is then pulled off and pliable to phlegmatic to produce a semi-dense pored crystal item (lightweight aggregate) recognized as air cooled breath oven slag.

It has two ingredient; 80-100% interactive elements fundamentally from the galenites ($2CaO.Al2O_3.SiO_2$) and akermanite ($2CaO.MgO.2SiO_2$), whereas the non-reactive elements are the crystalline metals gehlenite, akermanite, diopside ($2CaO.MgO.2SiO_2$) and merwinite ($3Cao.MgO.2SiO_2$).

The popular pozzolanic elements from biomass and manufacture by output such as RHA, fly ash and GGBFS are turn into effective areas of research due to the favourable ecological effects in increment to the economic matter [8].

For the time being, there is a growing benefit in the profiteering of garbage elements that is one of the fundamental goal sketches for the environmentally cordial operations. In the situation of build manufacture, there was a growing proclivity to the evolution and consuming of garbage as additional binding material. The popular pozzolanic elements from biomass and industry by products is attractive to many researchers due to the encouraging economic and environmental effects [15-17].

In this research, GGBFS has been used as mineral filler in HMA to inspect the durability and mechanical properties of the produced mixtures. To achieve this aim two types of mixtures have been prepared i.e. with GGBS and OPC and compared with the standards which are adopted by the State Commission of Roads and Bridges (SCRB/R9) 2003 [18].

2. Methodology

2.1 Selected Materials

2.1.1 Aggregates

Crushed quartz which was collected from Al-Nibaa Quarry was used as coarse aggregate. Tables 1 and 2 show the chemical and physical properties, respectively. While natural sand was used as fine aggregate. In accordance to (SCRB/R9) 2003 [18], type III surface course gradation with 12.5 mm maximum size was adopted, Fig. 1.

2.1.2 Asphalt cement

40-50 penetration grade asphalt cement collected from local refinery was used as a binder. Its physical properties are presented in Table 3.

2.1.3 Filler

Conventional mineral filler (OPC) and GGBFA were used as mineral filler to produce the traditional and modified HMAs. Table 4 presents the physical properties of OPC.

On the other hand, GGBFS that can be generated from the iron making industry under organised process by means of temperature and duration or to get iron sections. Table 5 shows the physical properties of GGBFS. The specific gravity of the used GGBFS is 2.2, while Fig. 2 displays the used GGBFS material photo. The produced mixtures are nominated as OPCAC and GGBFSAC.

2.2 Test Methods

2.2.1 Marshall Stability and flow

ASTM D6927 has been adopted to test the specimens for specify MS and flow. From this test MS represent the maximum load reistance to the plastic flow while the flow corresponds to the strain value at the maximum load record.

2.2.2 Volumetric properties

ASTM D2726 has been adopted to determine the dry bulk density. While, ASTM D3203 was followed to determine Air Voids (AV), Voids Filled with Asphalt (VFA) and Voids in Mineral Aggregate (VMA).

2.2.3 Indirect tensile strength test

ASTM D4123 was conducted to indicate the Indirect Tensile Strength (ITS) [19]. The maximum tensile strength (σ_t) determined in accordance to Eq. (1).

$$\sigma_t = \frac{2 \times P_{max}}{\pi\, H\, D} \quad (1)$$

Where: P_{max} , H and D are the maximum applied load (kN), the specimen height (m) and specimen diameter (m), respectively.

2.2.4 Durability

2.2.4.1 Water damage

Water sensitivity for treated and untreated mixtures was evaluated by determine the Index of Retained Strength (IRS). ASTM D 6927 was used to determine IRS which is adopted by SCRB specifications and its recommend that its value must be more than 70% for surface course mixtures. Two set of samples are needed, the first set represent the standard samples (dry samples) i.e. without curing. While the other set (wet samples) was immersed for 24 hours at 60ºC before testing for MS at 60°C, Eq. (2).

$$IRS = \frac{S_2}{S_1} \times 100\% \quad (2)$$

Where: IRS = Index of Retained Strength, %

S_1= Marshall Stability of the dry specimens, kN.

S_2= Marshall Stability of the wet specimens, kN.

2.2.4.2 Long-term aging

The Strategy Highway Research Program (SHRP) A-003A has been adopted in this study to evaluate the Long Term Ageing (LTA). This procedure recommend that curing of the samples for 2 or 5 days at 85°C represent age hardening in the field for 5 or 10 years, respectively [20]. The later was conducted in this study to evaluate age hardening after 10 years. MS results were indicated and Mean Marshall Stability Ratio (MMSR) was calculated, which is the ratio between MS after and before ageing.

3. Results and discussion

First, the optimum binder content for OPCAC and GGBFSAC mixtures were determined in accordance to Marshall mix design method (ASTM D6927). Five binder contents were selected with 0.5% increment i.e. 4, 4.5, 5, 5.5 and 6%, by mass of aggregate. ASTM D2726 and ASTM D2041 were adopted to indicate the bulk specific gravity and theoretical maximum specific gravity. On the other hand, ASTM D3203 have been followed to determine percent air voids. afterwards, Marshall Stability test were implemented for each sample by Marshall apparatus. Accordingly, the optimum binder content for the two types of mixtures were determined and nominated as 5.5% by mass of aggregate.

3.1 Influence of GGBFS on Marshall Test Results

Figs. 3–5 show Marshall test results for the two types of mixtures i.e. OPCAC and GGBFSAC. Also, the requirements in accordance to SCRB Standards are presented in in these figures. As shown in Fig 3, there is a significant enhancement in MS when OPC has been replaced by GGBFS, as the increment is about 40% in comparison with the control mixtures. The same enhancement was observed in Marshall Stiffness results that is shown in Fig. 5. It is worthy to say that both of these mixtures comply with SCRB specifications.

This enhancement in MS of GGBFSAC mixtures can be attributed to the reinforcing of the binder by GGBFS particles and increasing the stiffness and cohesion of the new mastic.

3.2 Influence of GGBFS on the volumetric properties

Figs. 6–9 show these parameters for OPCAC and GGBFSAC. it can be indicated the specific gravity of GGBFSAC mixtures were improved in comparison with the control mixtures. Also, air voids and VMA remain comply with the Iraqi specifications. This performance can be attributed to the increment of the stiffness of the binder when adding GGBFS particles.

3.3 Influence of GGBFS on Indirect Tensile Strength

ITS results for the two mixtures (OPCAC and GGGBFSAC) are presented in Fig. 10. GGBFSAC has higher value in comparison with OPCAC, almost 11% increment can be observed.

3.4 Influence of GGBFS on the durability of asphalt mixtures

3.4.1 Moisture damage

Fig. 11 shows IRS results for treated and untreated mixtures. A significant improvement was reported when traditional mineral filler was replaced with GGBFS as IRS increased from 73% to 88%.

3.4.2 Long term aging

Long Term Aging results are shown in Fig. 12 for OPCAC and GGBFSAC. A significant improvement is observed when using GGBFS as filler because MS after aging increased by 28% in comparison with OPCAC mixtures. However there is a considerable increase in the results for OPCAC mixtures with and without aging (MMSR=129%).

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Table 1. Selected coarse aggregate Chemical composition.

Chemical compound	Results, %
SiO_2	82.52
MgO	0.78
SO_3	2.7
Fe_2O_3	0.69
Al_2O_3	0.48
CaO	5.37
L.O.I.	6.55
Mineral composition	
Quartz	80.03
Calcite	10.92

Table 2. Physical properties of aggregates

Property	ASTM Designation	Test results	SCRB specifications
Coarse aggregate			
Apparent specific gravity	C 127	2.695	….
Bulk specific gravity	C 127	2.64	….
Percent wear by Los Angeles abrasion , %	C131	22.7	30 Max.
Flat and elongated particles ,%	C 4791	5	10 Max.
Soundness loss by sodium sulphate solution,%	C88	3.4	12 Max.
Degree of crushing, %	D5821	96	90 Min.
Fine aggregate			
Apparent specific gravity	C127	2.701	….
Bulk specific gravity	C127	2.67	….
Clay lumps and friable particles, %	C142	1.85	3 Max.
Angularity ,%	C1252	54	….

Table 3. Asphalt cement properties

Property	Portland Cement
Specific gravity (ASTMC188-95)	3.05
Passing sieve No. 200, (%)	94.76

Table 4. Portland cement physical properties

Property	ASTM Designation	Test Results	Requirements
Penetration at 25 ºC, 0.10 mm	D5	46	40-50
Ductility at 25 ºC , cm	D113	115	>100
Specific gravity at 25 ºC	D70	1.03	------
Solubility in trichloroethylene, % wt	D2042	99.31	>99
Flash point , ºC	D92	273	>232
Residue from thin –film oven test	D1754		
-Ductility at 25 ºC, cm	D113	55	>25
- Retained penetration , % of original	D5	69	>55

Table 5. GGBFS properties

S. NO	Property	Result
1	Specific Gravity	2.2
2	Bulk density	570kg/m^3
3	Size	75µ
4	Surface area	200m^2/kg
5	SiO_2	(90-96)%
6	Al_2O_3	(0.5-0.8)%

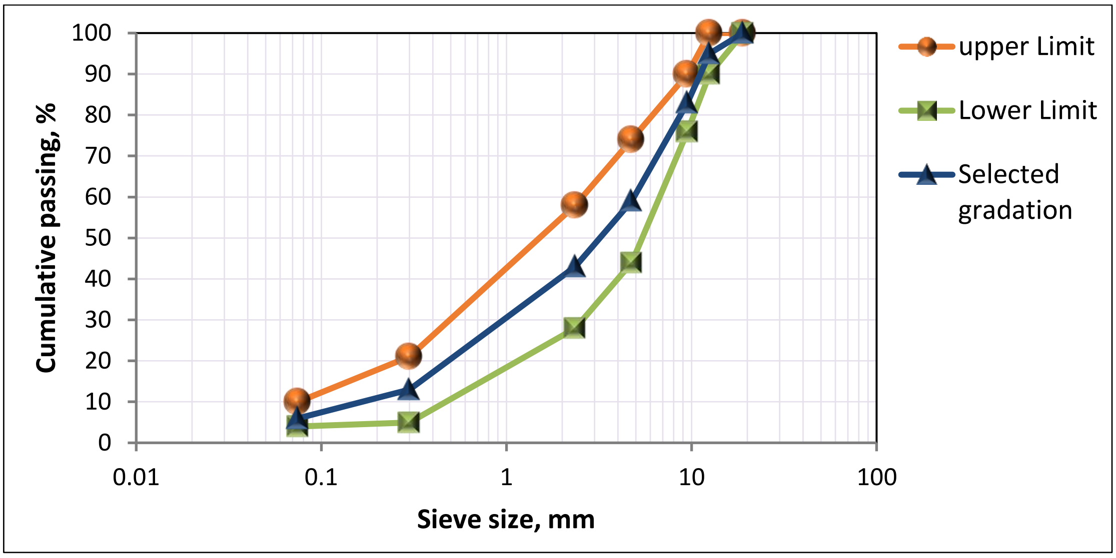

Figure 1. Type IIIA surface course hot asphalt gradation

Figure 2. GGBFS material photo

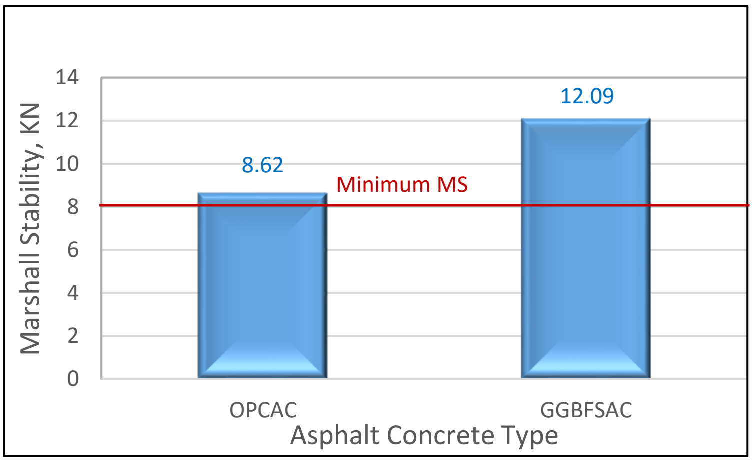

Figure 3. Marshall Stability results for treated and untreated mixtures

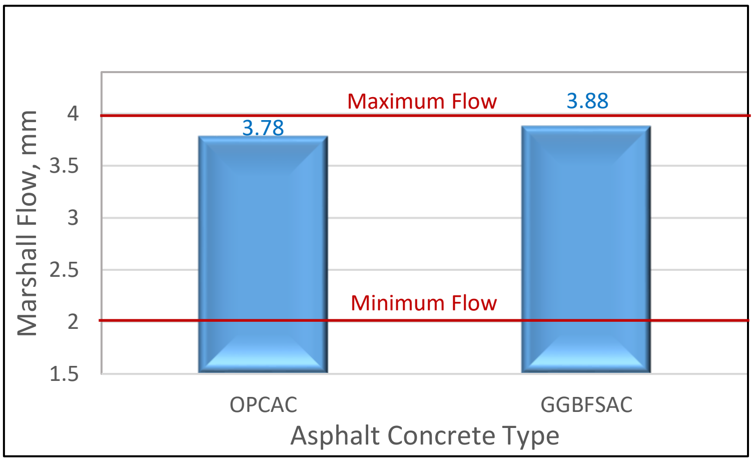

Figure 4. Marshall Flow results for treated and untreated mixtures

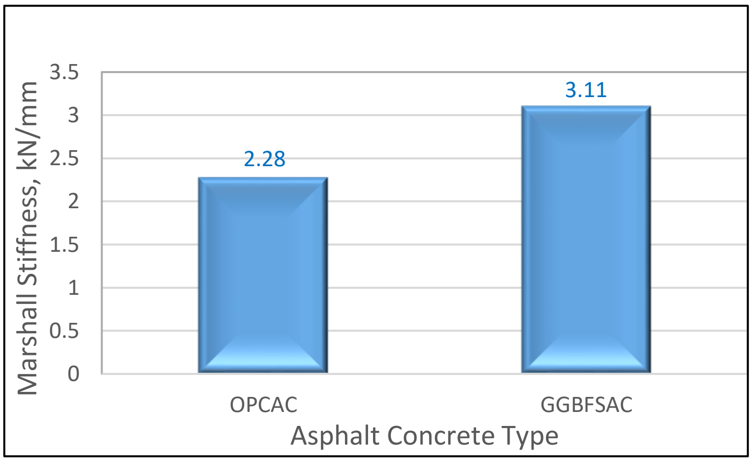

Figure 5. Marshall Stiffness results for treated and untreated mixtures

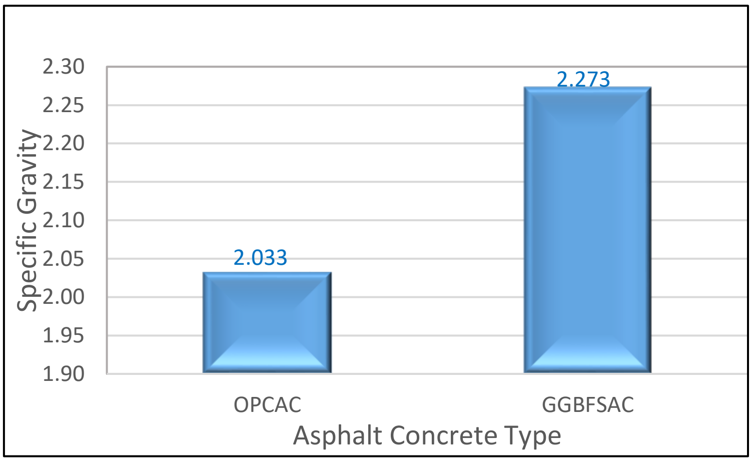

Figure 6. Specific Gravity results for treated and untreated mixtures

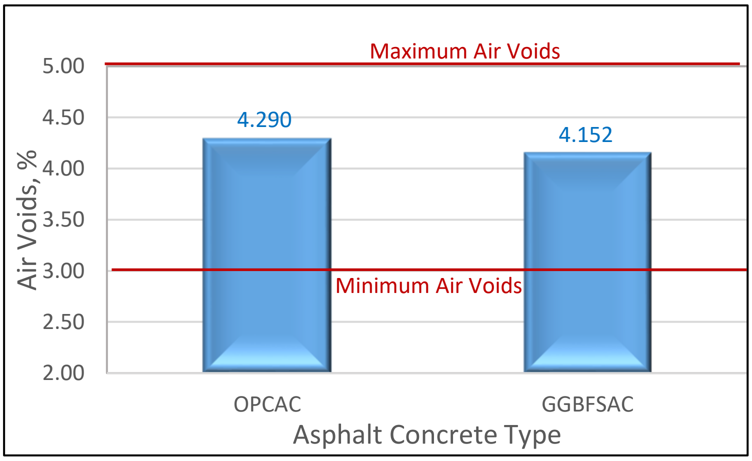

Figure 7. Air Void results for treated and untreated mixtures

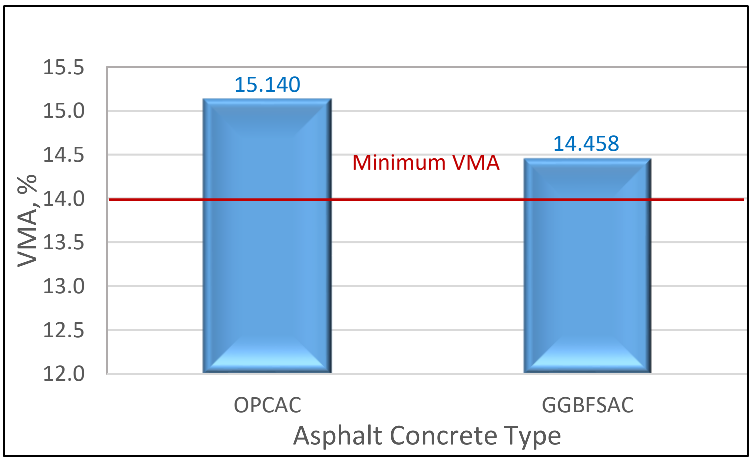

Figure 8. Voids in Mineral Aggregate for treated and untreated mixtures

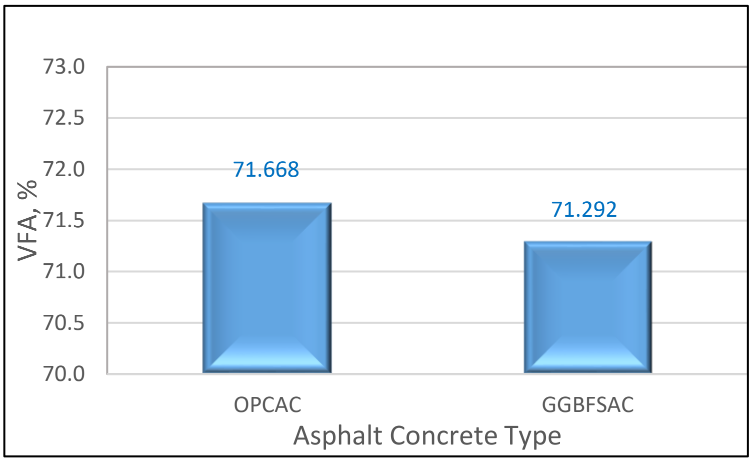

Figure 9. Voids Filled with Asphalt for treated and untreated mixtures

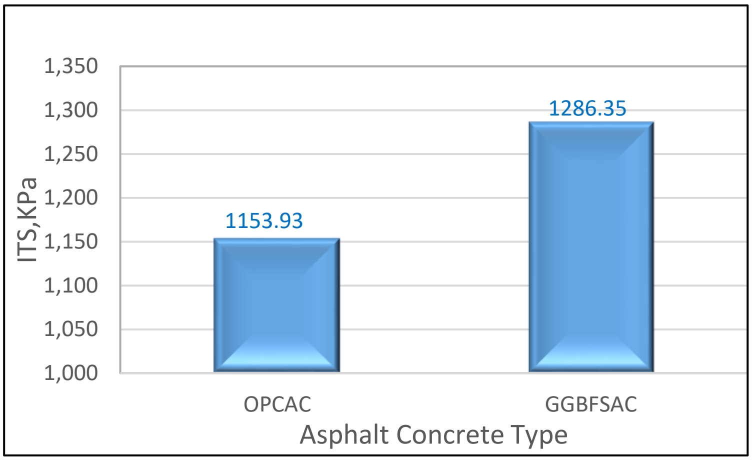

Figure 10. Indirect Tensile Strength results for treated and untreated mixtures

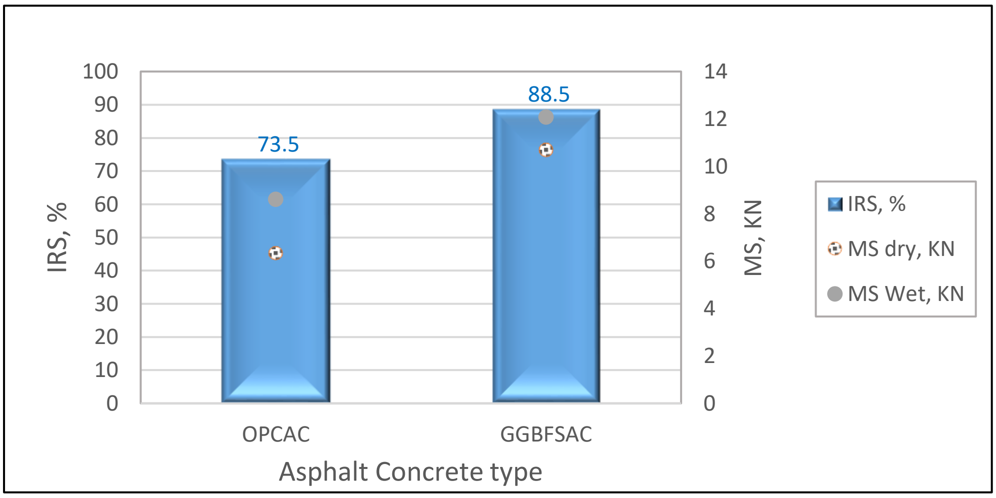

Figure 11. Index of Retained Strength for treated and untreated mixtures

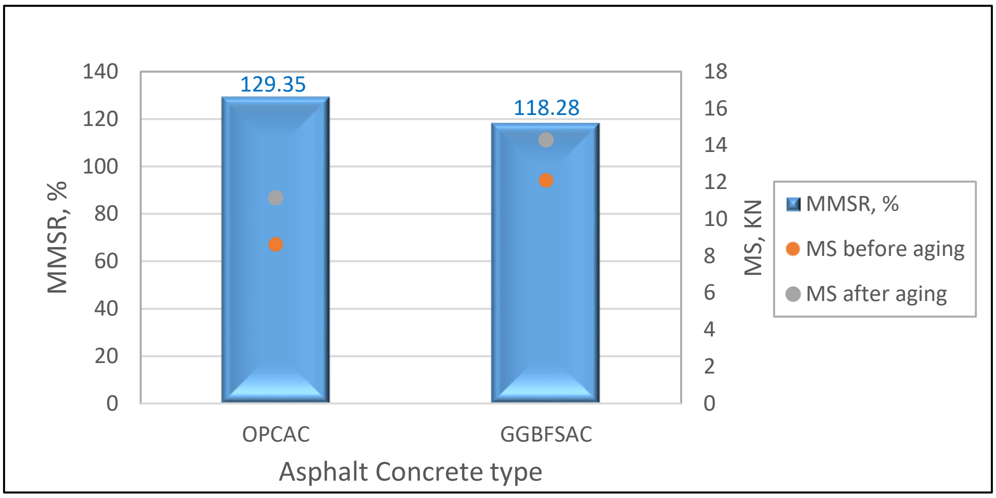

Figure 12. Effect of long-term aging on treated and untreated mixtures

4. Conclusions

Ground Granulated Blast Furnace Slag (GGBFS), which is generated from iron making industry has been used in this study as a replacement to the conventional mineral filler i.e. OPC to produce the novel hot mixture. The mechanical properties for GGBFSAC and OPCAC were evaluated by Marshall stability and indirect tensile strength tests. Water sensitivity and long term aging were used to assess the durability of the produced mixtures. Marshall stability of GGBFSAC improved substantially in comparison with OPCAC. Which is increased about 40% more than those for the control mixtures. Also, GGBFSAC mixtures implement better than the traditional hot mixtures by means of ITS results. Although there is a decrease in air voids of GGBFSAC mixtures, the results fulfil the Iraqi specifications for surface course mixtures. On the other hand, IRS increased for GGBFSAC mixtures in comparison with control mixtures and there mechanical properties were increased after aging.

5. References

[1] Uzun, I. and Terzi, S. (2012). "Evaluation of andesite waste as mineral filler in asphaltic concrete mixture." Construction and Building Materials, 31:284-8.
[2] Yilmaz, M., Kök, B. and Kuloglu, N. (2011). "Effects of using asphaltite as filler on mechanical properties of hot mix asphalt." Construction and Building Materials, 25:4279-86.
[3] Read, J. and Whiteoak, D. (2003). "The Shell Bitumen Handbook." 1 Heron Quay , London: Thomas Telford Publishing.
[4] Katamine, N. (2000). "Phosphate waste in mixtures to improve their deformation." Journal of Transportation Engineering, 126:382-9.
[5] Ibrahim, A. and Abdullah, A. (2005). "Effect of Jordanian oil shale fly ash on asphalt mixes." Journal of Materials in Civil Engineering, 17:553-9.
[6] Deng-Fong, L., Jyh-Dong, L. and Shun-Hsing, C. (2006). "The application of baghouse fines in Taiwan." Journal of Resources Conservation and Recycling, 46:281-301.
[7] Yongjie, X., Haobo, H., Shujing, Z. and Jin, Z. (2009). "Utilization of municipal solid waste incineration ash in stone mastic asphalt mixture: pavement performance and environmental impact." Journal of Construction and Building Materials, 23:989-96.
[8] Hwang, S., Park, H. and Rhee, S. (2008). "A study on engineering characteristics of asphalt concrete using filler with recycled waste lime." Journal of Waste Management, 28:191-9.
[9] Al-Hdabi, A., Al Nageim, H., Ruddock, F. & Seton, L. 2013. A novel Cold Rolled Asphalt mixtures for heavy trafficked surface course. Journal of Construction and Building Materials, 49, 598–603.

[10] Al-Hdabi, A., Al Nageim, H., & Seton, L. 2014. Superior cold rolled asphalt mixtures using supplementary cementations materials. Journal of Construction and Building Materials, 64, 95–102.
[11] Dulaimi, A., Al Nageim, H., Ruddock, F. & Seton, L. 2016. New developments with Cold Asphalt Concrete Binder Course Mixtures Containing Binary Blended Cementitous Filler (BBCF), 124, 414–423.
[12] Anderson, D. "Guidelines for use of dust in hot mix asphalt concrete mixtures." Proceeding Association of Asphalt Paving Technologists, 1987. Association of Asphalt Paving Technologists, 492-516.
[13] Elliot, R., Ford, M., Ghanim, M. and Tu, Y. (1991). "Effect of aggregate gradation variation on asphalt concrete mix properties." Transportation Research Record. Washington, D.C.: National Research Council.
[14] Kandhal, P., Lynn, C. and Parker, F. (1998). "Characterization tests for mineral fillers related to performance of asphalt paving mixtures." In: 98-2, R. N. (ed.) National Centre for Asphalt Technology.
[15] Givi, A., Rashid, S., Aziz, F. and Salleh, M. (2010). "Assessment of the effects of rice husk ash particle size on strength, water permeability and workability of binary blended concrete." Journal of Construction and Building Materials, 24:2145-50.
[16] Chindaprasirt, P. and Rukzon, S. (2008). "Strength, porosity and corrosion resistance of ternary blend Portland cement, rice husk ash and fly ash mortar." Constr Build Mater, 22(8):1601-6.
[17] Bhanumathidas, N. and Mehta, P. (2004). "Concrete mixtures made with ternary blended cements containing fly ash and rice husk ash." International conference proceeding seventh CANMET-Chennai, . India.
[18] State Commission of Roads and Bridges (SCRB/R9) (2003). "General Specification for Roads and Bridges." Republic of Iraq, Ministry of Housing and Construction, Department of Planning and Studies, Baghdad.
[19] ASTM Standards (2004). "Roads and Paving Materials. Annual Book of the American Society for Testing and Materials Standards, Section 4, Vol. 03-04.". Washinton, USA.
[20] KLIEWER, J., BELL, C. and SOSNOVSKE, D. (1995). "Investigation of the Relationship Between Field Performance and Laboratory Ageing Properties of Asphalt Mixtures (SHRPA - 003A), Engineering Properties of Asphalt Mixtures and the Relationship to their Performance, ASTM STP 1265Gerals A.". Philadelphia: Hubber and Dale S. Decker, Eds. American Society for Testing and Materials.