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Characterizing the properties of sustainable semi-flexible pavement produced with polymer modified bitumen

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ABSTRACT

Semi-Flexible Pavement (SFP) is a composite type of pavement produced by manufacturing of porous asphalt mixes using open graded aggregate gradation to create 20-35% of voids filled with grout (cement paste, cement mortar, etc.….). The resulting pavement has the flexibility of asphalt pavement and some strength of concrete pavement. The current study focused on investigation of using widely available (in Iraq) waste material namely Rice Husk Ash (RHA) to replace the Ordinary Portland Cement (OPC) partially in grout, also, using Polymer Modified Bitumen (PMB) to develop Open-Graded Asphalt (OGA) pavement without using cellulous fibre. The study focused on assessment of mechanical properties of the obtained SFP mixes with and without PMB. The results of study showed that using of PMB increased the Marshall Stability up to 100% and indirect tensile strength up to 50%. The Marshall Retained Stability gave about 90% which is quite higher the minimum required limit (70%). The results also revealed that RHA can be used as replacement for the OPC in SFP mixes. All investigated percentages showed satisfactory mechanical properties.

Keywords: Grout, Hot mix asphalt, Hexamine, Novolac, Rice husk ash, SFP

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1. Introduction

The commons majors' two types of pavements are flexible and rigid pavement. Each type of these pavements has advantages and disadvantages. For example, flexible pavement has relatively lower initial cost and provides less roughness, but it may suffer severe distresses such as rutting and fatigue cracking especially due to the rapid increase in traffic volume and load during the last decades. On the other hand, the rigid pavement can withstand heavy traffic load but it has relatively higher initial cost and it may show more roughness and noise due to existing of transverse joints and consequently less riding comfort [1-4]. The Semi Flexible Pavement (SFP) can be considered hybrid pavement type provides comfort riding (less roughness) due to the constructions of SFP without joint, provides higher stability and strength compared with flexible pavement and less stresses due to volumetric changes compared with rigid pavement [5].

The SFP is produced by grouting the Open-Graded Asphalt (OGA) pavement with a suitable cementations material [6, 7]. The design of SFP is slightly differ than that OGA used as wearing layer to promote drainage in pavement; since, it requires an air voids ranging (20-35) %. These air voids in usual cases can produce several distresses such as moisture damaged, and fatigue and low temperature cracking. However, these voids are reduced to normal range (3-5%) after filling it with flow able grouting material. The reduction of air voids to less than the minimum acceptable limit (20%) may lead to prevent the grouting material to penetrate the OGA and consequently produces unsatisfactory properties of SFP [8-10]. Although several methods and standards were adopted to design SFP, the Marshall method [11] is one of common these methods used to design and produce OGA mixes for SFP. The main steps of design involves several stages as: firstly, selecting the raw materials such as aggregate, binder, cellulous fibre and/or polymer to produce satisfactory OGA; secondly, test the permeability of the mix and drained down of binder; and finally, determining the optimum binder content to satisfy the volumetric and mechanical requirement for adopted mix [12, 13]. The using of cellulous fibre or polymer is necessary to control the drain out of binder resulting from the using of very small quantity of fine aggregate in OGA. The proportion of fibre is usually between 0.2%- 0.5% of the total mix according to ASTM D7064 [14]. On the other hand using higher asphalt content may affect the permeability and air voids of mix due to creating thick film of asphalt around the aggregate particles.

The conventional grouting material used to fill the air voids in OGA to produce SFP is the cement paste. However, this cement paste usually differs than the conventional paste, since the fluidity, workability and strength of it are an important characteristic which need to be checked to obtain satisfactory SFP mixes. The fluidity of the grout is usually tested by flow cone method [15], according to this method and as mentioned by previous researchers the flow time is should be within 10 - 16 second. The flow time of more than 16 seconds may lead to not filling the gaps in OGA due to high fluidity of grouting material; while the flow time less than 10 seconds may lead to difficulty in penetrating the grout material to air voids in OGA [6, 16, 17].

Several studies were conducted to assess the properties and performance of SFP. These studies were pointed out some important finding. From these findings were that the SFP can significantly have less moisture susceptibility and consequently less particles separation and moisture damage. The tensile strength of SFP cab be increased by about 20% compare to that of conventional Hot Mix Asphalt (HMA) [7]. SFP can produce high strength and stability and higher resistance to permanent deformation (rutting) under higher temperature and traffic load compared with conventional HMA [9, 18, 19]. SFP can show a good fatigue life and low temperature cracks resistance comparing with conventional flexible pavement due to the flexibility of grouting material at low temperature [1, 20, 21]. Recent study [20] showed that, the retained Marshall stability and tensile strength ratio for the grouted OGA were higher than that of the dense graded HMA by 4.8% and 5.6% respectively. Also, it showed that the dynamic stability of dense graded HMA is about 40 % of the grouted OGA.

The current research aims to produce SFP mixes using Polymer Modified Bitumen (PMB) to strength the structure of OGA pavement instead of using cellulous fibre. Also, the experimental program involved testing the use of waste material (Rice Husk Ash – RHA) as partially replacement for the OPC used for producing cement paste which is finally used as grout for OGA pavement.

2. Design of semi-flexible pavements

The production of semi flexible pavements (SFPs) consists of two stages:

In the first stage, porous asphalt (open-graded) mixture is constructed with 20% -35% of air voids. The second stage consists of pouring the grouts (i.e., cement mortar or cement paste) inside the mixtures and then mixture is cured in a certain amount of time that depends on grout composition and thickness of asphalt mixture. In following sections, the steps and experimental tests regarding the design of open- graded asphalt mixture and filling grout have been discussed thoroughly.

3. Materials and design of open-graded asphalt mix

3.1 Aggregates

The aggregate material used in this research were crushed aggregate(coarse) from badrah quarry in Al-Kut city and crushed sand (fine aggregate) brought from hot mix plant of stat corporation of highways and bridges at Al-Diwaniyah city. All mixtures incorporated OPC as mineral filler. The properties of the course and fine aggregates and mineral filler were evaluated according to ASTM D 7064 [22] and the obtained results were compared with Iraqi specifications for roads and bridges. Table 1 presents the selected Physical Properties of aggregates.

Table 1. Physical properties of the aggregate used

Property	Course Aggregate	Fine Aggregate
Bulk Specific Gravity	2.63	2.642
Apparent Specific Gravity	2.66	2.674
Percent Water Absorption	53	67%

3.2 Asphalt cement

In the first phase of this study, the 40-50 penetration grade bitumen was used as conventional binder to produce the control mix. While in the second stage, PMB was produced by adding Novolac (phenol formaldehyde) and hexamine as cross-linking agent to pure binder. Novolac and hexamine were added as 4% and 0.4 % respectively by the weight of bitumen, these percentages were adopted according to previous study by the first author [23]. The preliminarily properties of conventional (pure) and PMB binders were adopted as presented in previous mentioned study.

3.3 Open-graded asphalt design

In this research, Marshall Design method was used to design the HMA. According to ASTM D7064 the gradation of open graded mixture was produced with 82.5 % of coarse aggregates and 14.5% of fine aggregates with 3% of Portland cement filler, where the mid-range of specification was selected as shown in Figure 1. The optimum bitumen content was determined as 3.5 %. In the hot mix porous asphalts, mixing was conducted at 170 C, whilst the compaction temperature was fixed at 150 C. Samples Preparation, mixing process and compaction process are shown in Figures 2 and 3. The obtained void contents of the various compacted asphalt spacemen revealed that all the skeletons produced had porosity values in the range from 28% to 33%, which was deemed within the acceptable limits for this investigation.

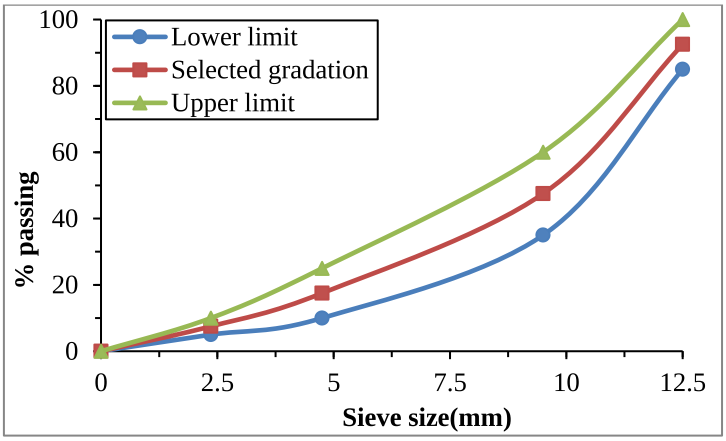

Figure 1. Gradation of open graded mixture according to ASTM D 7064-08

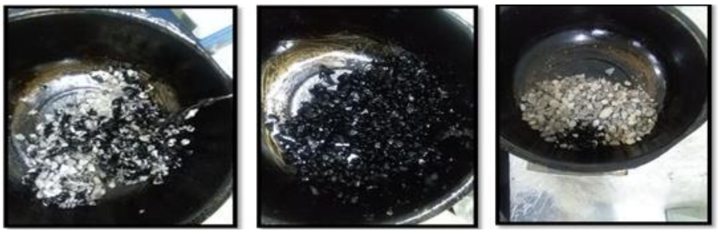

Figure 2. Preparation and mixing of samples.

Figure 3. Compaction of samples

3.4 Grouts formulations

The grouting materials used in this research were OPC RHA and water. The RHA was prepared in two stages of burring, the first stage involved burning the waste products of rice in open space and the second stages involved burning this material again in oven with temperature of 700 ^{0}C for 2 hours as recommended in literature[24]. Water was added for the materials to convert them to flowable materials, the quantity of water was determined by flow time test according to ASTM C939-10 [15]. The fluidity of various grouts can be determined using a standard flow cone as shown in Figure 4.

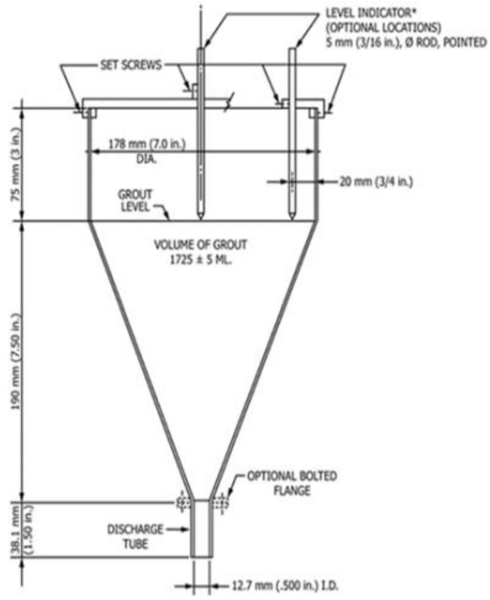

Figure 4. Standard flow cone

3.5 Adding the mortar (grout) to samples

Two types of grouts were used, namely cement paste and cement with RHA, which were mixed in certain proportions with water to form grouts. Different percentages of RHA were used to replace the OPC to produce grouting material as follow:

1. 100% OPC and 0 RHA
2. 90% OPC and 10% RHA.
3. 80% OPC 20% of RHA.
4. 70% OPC 30% of RHA.

After finding the required water quantity according to flow cone test, the water is added to each proportion above then grout is added to samples of OGA on vibrated table to simulate the adding grout in field with vibratory roller. The samples are left to cure for period of (3-4) days then the required tests were performed. Figure 5 shows the stages of Adding grout to samples.

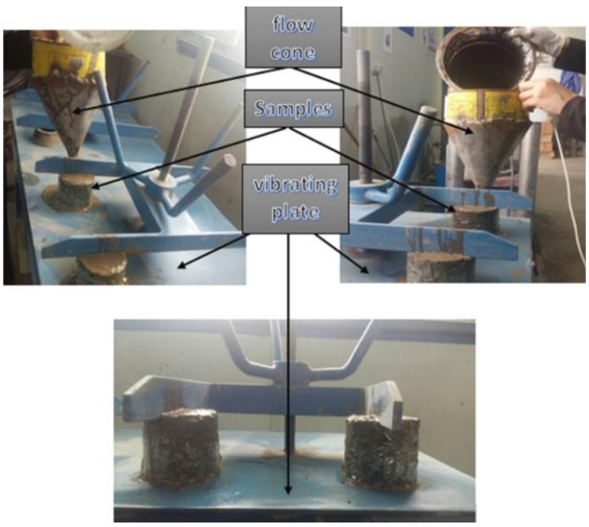

Figure 5. Stages of adding the mortar (grout) to samples

4. Results and discussion

4.1 Test results of standard flow of grout

The flow cone test was conducted according to ASTM C939-10 for the four proportions of grout materials adopted in this research to determine the follow time for each proportion to satisfy the requirement of SFP. The results of flow time were presented in Tables 2, 3, 4 and 5. Three percentages of water were adopted to select the Optimum Water Content (OWC) required for each type of grout; accordingly, the OWC was selected as shown in Table 6.

Table 2. Trail blends to determining OWC for the grout with 100% OPC

Blend No.	% Water	% Cement	% Ash	Time of efflux	Test method
1	35%	100%	0%	11.22sec	ASTM C939
2	33%	100%	0%	10.17sec	
3	32%	100%	0%	10.01sec	

Table 3. Trail blends to determining OWC for the grout with 90% OPC and 10%RHA

Blend No.	% Water	% Cement	% Ash	Time of efflux	Test method
1	36%	90%	10%	12.14 sec	ASTM C939
2	35%	90%	10%	11.11sec	
3	34%	90%	10%	10.16 sec	

Table 4. Trail blends to determining OWC for the grout with 80% OPC and 20% RHA

Blend No.	% Water	% Cement	% Ash	Time of efflux	Test method
1	39%	80%	20%	12.21 sec	ASTM C939
2	38%	80%	20%	11.66sec	
3	37%	80%	20%	10.20sec	

Table 5. Trail blends to determining OWC for the grout with 70% OPC and 30% RHA

Blend No.	% Water	% Cement	% Ash	Time of efflux	Test method
1	38%	70 %	30%	14.64sec	ASTM C939
2	40%	70 %	30%	13.31sec	
3	42%	70 %	30%	11.14sec	

Table 6. Optimum Water Content (OWC)

% No.	% OWC	% Cement	% Ash	Time of efflux	Test method
1	35%	100%	0%	11.22sec	ASTM C939
2	36%	90%	10%	12.14 sec	
3	39%	80%	20%	12.21 sec	
4	38%	70 %	30%	14.64sec	

4.2 Results of marshall stability

Figure 6 presents the results of the Marshall Stability test for OGA and two types of the SFP mixes. The results revealed that the SFP can give superior stability compared with the OGA. Also, it showed the PMB binder significantly improve the strength of the specimens in case of OGA and SFP. This response may be related to the increase in viscosity of binder and that leads to more adhesion between aggregate particles. The Marshall stability increases approximately by 100% during using PMB binder for SFP mixes and by 65% for OGA mixes. This is mainly due to strengthen the structure of OGA mixes. It was noticed that with the increasing of percentage of replacement of OPC with RHA, the Marshall stability slightly decreased. This may be related to that the RHA is absorbing some binder which might lead to less coating of aggregate particles and more voids. It was observed during the test that with increasing the percentage of RHA, the coating is slightly decreased especially for specimens produced with pure binder. However, all SFP specimens produced with PMB binder gave satisfactory Marshall Stability and quite higher than the minimum limit (8 kN) for SCRB [25].

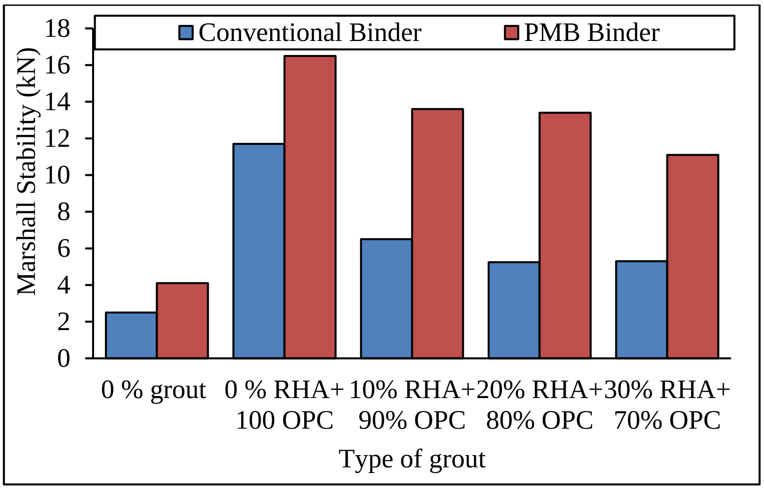

Figure 6. Marshall Stability test results

4.3 Test results of retained stability

The Marshall retained stability test was conducted according to ASTM D 1075 [26], two sets of samples were prepared for each mix. First set represents the condition samples and second set represents the unconditions samples. The Marshall retained stability was calculated by dividing the Marshall stability value for condition sample on the Marshall stability value for uncondition sample. The results Marshall retained stability is presented in Figure 7. Significant increasing in Marshall retained stability values were observed for SFP mixes compared with OGA mixes. All specimens for SFP mixes showed high values for Marshall retained stability and which is significantly higher than the minimum required limit (70 %) according to SCRB. There is no significant can be noticed for Marshall stability values of pure and PMB samples because it is calculated as a percentage for condition and unconditions samples for each type. Therefore, even the of Marshall retained stability is approximately similar but the Marshall values for PMB samples (for condition samples) are significantly higher than that of pure binder as shown in Figure 8.

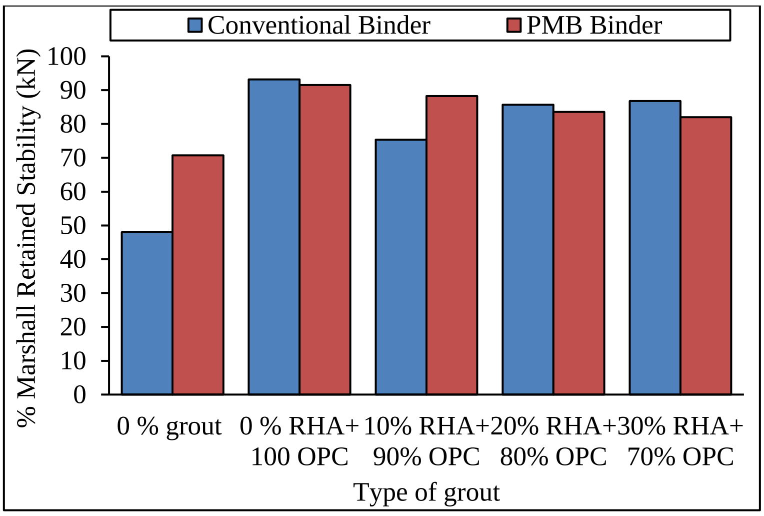

Figure 7. % Marshall retained stability test results

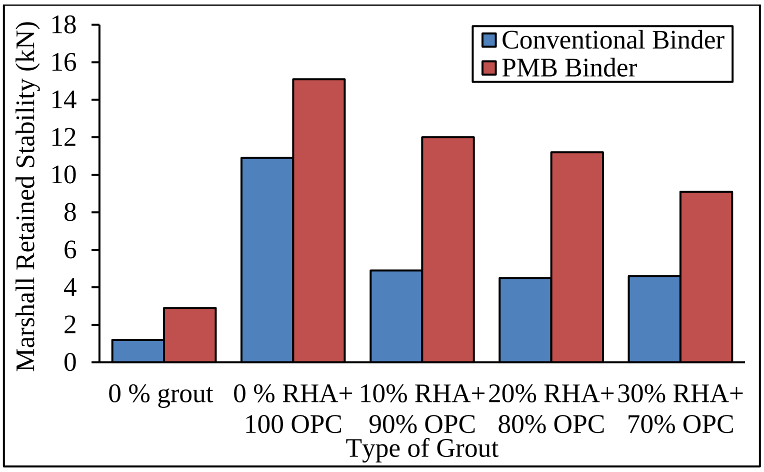

Figure 8. Marshall retained stability test results (condition samples)

4.4 Results of indirect tensile strength (ITS)

The ITS test was carried out according to modified Lottman AASHTO T 283. Figure 9 presents the results of ITS for all mixes with PMB binder and pure binder for SFP and OGA for condition and uncondition samples. The OGA showed very low ITS values for PMB and pure binder samples due to high air voids which makes them non-structural courses. The SFP mixes showed significantly increasing in ITS values especially for specimens produced with PMB binder. This is mainly due to filling the air voids with grout which make these voids not connected, the filling of these voids with grout increases the sample integrity of structure of specimen. The using of PMB binder can increase the ITS values for SFP up to 50% compared with that produced with pure binder. The PMB binder promotes more adhesion between the components of SFP mixes. Although, the using of RHA relatively decreases the ITS for SFP mixes compare to that produced with OPC only, however, it is still showing high values. The replacing the OPC with 30% RHA is only reducing the ITS value by about 20-25%. The ITS values for SFP with grout has 30% RHA is comparable for that of the conventional HMA.

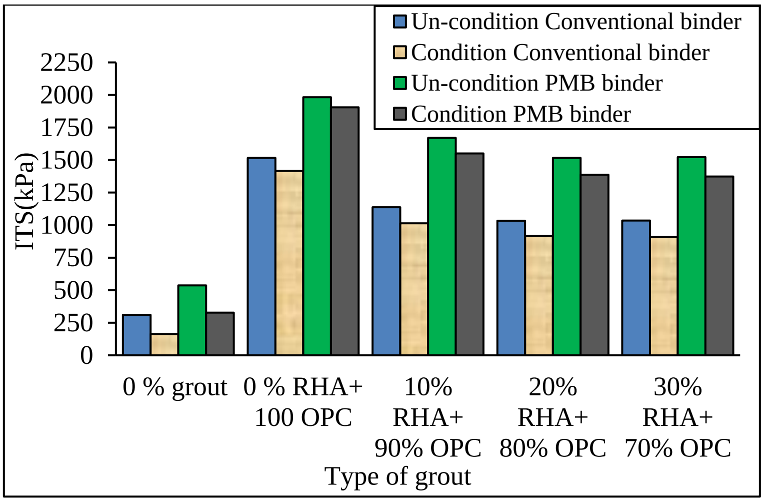

Figure 9. Results of Indirect Tensile Strength test

4.5 Results of tensile strength ratio (TSR)

The % TSR were calculated by dividing the ITS results for condition specimens on that of uncondition specimens. Figure 10 illustrates the results of the TSR for the SFP mixes with deferent percentages of types of grout. As expected, the TSR value is significantly improved by adding grout to OGA to produce SFP. All results of TSR for SFP mix were about 90% which is good value compared with minimum limit (80 %) suggested in designing HMA according to superpave method, on the contrary with that of OGA mixes. Filling the voids in OGA is significantly reduces moisture susceptibility of the SFP mixes due to preventing the air and moisture to entering the pavement course. The using of PMB binder can increase the film thickness around the aggregate particles and consequently improved the resistance of mix to moisture

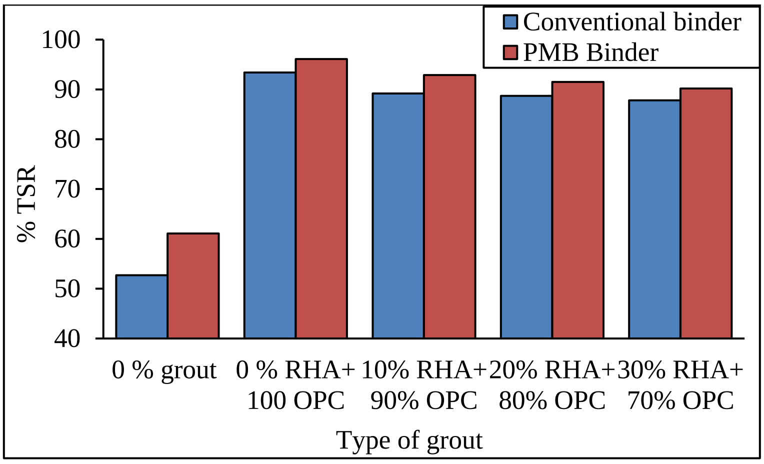

Figure 10. Result of TSR values for mixes with different grout types

5. Summary and conclusions

The current article presents an experimental investigation to produce SFP with different types of grouts and different types of binders. These grout types included OPC and RHA mixed with appropriate percentages of water. While, the binder's types involved conventional and PMB binder. The following conclusions were drawn from the results.

1- The results of experimental investigation showed that the grouting of OGA to produce SFP is significantly improved the mechanical properties of pavement.
2- The PMB binder can significantly improve the properties of OGA and SFP mixes.
3- The RHA can replace the OPC in grout with all percentages investigated in this research. This replacement reduces the cost of raw materials and in addition to better management of the solid waste. Although, some mechanical properties decrease with increase RHA replacement, however, these properties remain satisfactory for the standard requirement.
4- The Marshall stability increases approximately by 100% during using PMB binder for SFP mixes and by 65% for OGA mixes. The using of PMB binder can increase the ITS values for SFP up to 50% compared with that produced with pure binder.

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