Kerbala Journal for Engineering Science

https://kjes.uokerbala.edu.iq/

Cracking Evaluation of Semi-Flexible Mixture Comparison Sustainable Modified Cementitious Grout

Karrar Muhsin ALBusaisi [a]*, Shakir Al-Busaltan [a], Mustafa Amoori Kadhim [a]

[a] Department of Civil Engineering, College of Engineering, University of Kerbala, Karbala, Iraq.

* Corresponding author, Email: kararmohsin@gmail.com

Received: 26 September 2021; Revised: 11 November 2021; Accepted: 22 November 2021

Abstract:

Semi-flexible pavement (SFP) get high importance in recent years due to its high traffic load capacity. Its strength, rutting resistance, and component structure have been explored comprehensively in think. In any case, understanding its cracking execution and instrument is restricted. To this end, this paper assesses the cracking execution of the SFP mixture by utilizing the indirect tensile strength test (ITS). Both ITS monotonic and tensile strength ratio TSR tests are utilized to characterize the cracking resistance of SFP mixtures with several kinds of grout materials. Ordinary Portland Cement (OPC), silica fume (SF), palm frond waste ash (PFWA), superplasticizer (SP), and water are all used in a sustainable modified grout which incorporate w-LDPE (waste-low density polyethene) modified asphalt binder. ITS comes about to appear that the addition of 10% PFWA is the best grout content to be used for cracking resistance for SFP. The cracking resistance of sustainable modified cementitious grout and modified asphalt binder used for SFP is profoundly influenced by grout ingredient sorts, dosage and properties.

Keywords: cracking; indirect tensile strength; tensile strength ratio; modified asphalt binder; palm frond waste ash.

1. Introduction

The common concept of semi-flexible asphalt (SFP) material is a jointless wearing course composed of an open-graded asphalt mixture with (25-35)% air voids filled with extraordinary cement grouting material with flow time (11-16) sec [1-3]. Its rutting resistance is predominant to dense-graded asphalt concretes. At the same time, it can support heavy-loaded activity. With the increment of traffic flow and traffic loads, it is promising for SFP to apply in overwhelming load pavements, intersections, transport stops and other uncommon segments. However, cracking is the most issue that ruins the promotion and application of SFP. Even though numerous examinations have been performed on the visible properties of SFP [4-6].

Grout materials used to prepare the grout for injection into the porous asphalt layer influenced grout fluidity; superplasticizers have the greatest effect on grout fluidity. Based on Sulphonated Naphthalene Formulation, the superplasticizer carboxylic or polymers have high effectiveness in causing high fluidity by depressing cementitious particles [7]. Furthermore, grout fluidity is highly affected by water content, which influences strength properties.

As a modified grout in this study, a blend of OPC, water, superplasticizer with partial replacement of OPC with SF and palm frond waste ash (PFWA) was suggested. The incorporating of PFWA was due to its economic, environmentally friendly, and resource conversation issues [8]. The availability of PFWA in Arab countries regions like Iraq and Saudi Arabia. For example, pruning the 12 million palm trees grown in the Kingdom yields approximately 360,000 tons of date palm trees each year. According to a report issued by the King Abdulaziz City for Science and Technology Saudi [9]. Similarly, in Iraq, there is about 17036560 palm trees in 2019 according to the Ministry of Planning Central Statistical Organization [10].

Therefore, this study aims to find the effect of the use of this modified grout in SFP to reduce the pavements cracking which is one of the deformations of the primary pavement.

2. Experimental work

2.1 Materials

Materials that are used to prepare sustainable modified grout and porous asphalt layer are listed below:

2.1.1 Ordinary Portland Cement (OPC)

OPC that is used in this study is (CEM I 42.5R), according to Iraqi specification No: 5/1984 type I [11], that produced at the Kerbala cement plant. The chemical and physical properties are shown in Table (2).

Table 1 Physical and chemical properties of OPC

Physical		
Property	**Results**	**Requirement**
Fineness (m^2/Kg)	338	250
Density (gm/cm^3)	2.05	Not specified
Initial Setting Time (min)	145	≥ 45
Final Setting Time (hr.)	3.17	≤ 10
Expansion (mm)	1	≤ 10
Chemical		
SiO_2	19.94	Not specified
Al_2O_3	4.57	Not specified
Fe_2O_3	4.85	Not specified
CaO	61.14	Not specified
MgO	3.15	$\leq 5\%$
SO_3	2.26	$C_3A \leq 5$ % $SO_3 \leq 2.5$ % C_3A more than 5 % $SO_3 \leq 2.8$ %
Na_2O_3	0.23	Not specified
K_2O	0.53	Not specified
Chloride	0.017	Not specified
L.O. I	2.93	≤ 4.0 %
Eq. Alkalies	0.56	< 0.6 % for low alkalies
I.R	1.04	≤ 1.5 %
L.S.F	0.9503	0.66 % - 1.02 %
SM	2.13	Not specified
AM	0.94	Not specified
C_3A	3.98	3.5 %>

2.1.2 Silica Fume (SF)

The silica fume used in this study was a fine powder known as micro silica produced by the CONMIX company, and it is a by-product material of the smelting processes used in the silicon and ferrosilicon industries [12]. The chemical and physical properties of SF are shown in Table (3).

Table 2 Chemical and physical properties of SF

Physical properties		
Properties		**value**
Surface area (m^2/kg)		18100
Density		700 (kg/m^3)
Chemical properties		
Chemical composition		value
NaO	Sodium	1.537
MgO	Magnesium	0.434
Al_2O_3	Aluminum	0.095
SiO_2	Silicon	92.04
Cl_2O	Chlorine	0.002
K_2O	Potassium	1.885
CaO	Calcium	3.037
TiO_2	Titanium	0.003
MnO	Manganese	0.147

Fe_2O_3	Iron	0.449
Co_2	Cobalt	0.008
CuO	Copper	0.018
ZnO	Zinc	0.178
SrO	Strontium	0.019
Y2O3	Yttrium	0.004
BaO	Barium	0.059

2.1.3 Palm Frond Waste Ash (PFWA)

Because PFWA is not yet available as a product, a process for producing it in a heat recovery power plant was designed to stimulate its production. Preparing PFWA entails gathering palm fronds from Karbala orchards after they have fallen in the autumn season. Then, in order to reduce the volume, burn it in an open area. The produced ash is ground and sieved on #200 mesh. Finally, the ash is re-burned in the furnace at 900 0 C to achieve the required chemical properties for use as PFWA.

Table 3 The chemical component of PFWA

Chemical properties	
Oxide (%)	**value**
CaO	13.93
SiO2	38.87
Al2O3	2.03
Fe2O3	3.12
SO3	2.87
MgO	10.2
Na2O	3.93
K2O	7.32
Loss on ignition	9.43

2.1.4 Superplasticizer (SP)

LYKSOR company "Nano flow 5500" supplied superplasticizer, hydroxylamine compound with organic amine and Hydroxyl, its effect fluidity of grout and get more cement strength due to its high water reducer, which is confirmed to ASTM C494-15 type G [13]. The recommended dosage is 0.5-2 percent of the cement's weight [14]. The technical properties are shown in table 4.

Table 4 Technical properties of LYKSOR SP [14].

Colour	Colourless to light yellow liquid
Water content	10-15%
Structure Formula	$C_9H_{21}NO_3$
Smelling	Very light ammoniac odour
Physical form (25 ºC)	Liquid
Molecular Point	163.22
Freezing Point	3-8ºC
Boiling Point	104-107ºC
Flash Point	Min. 154ºC on a dry base
Specific Gravity (25/4ºC)	1.027
Viscosity	400-500_{cps}
TIPA Content	85% Min.
MIPA and DIPA content	3% Max.

2.1.5 Water

The used water in this study is tap water.

2.1.6 Aggregate Gradation

The aggregate used in design OGFC in this study is crushed limestone, supplied from Kerbala quarries, the physical properties of this aggregate are shown in table 5 below. To achieve 25-35% air voids, the aggregate gradation used is according to [15]. The aggregate gradation is shown in figure 2. The test method is according to the American Society for Testing and Materials (ASTM), using the gradation suggested by ASTM D7064 [16].

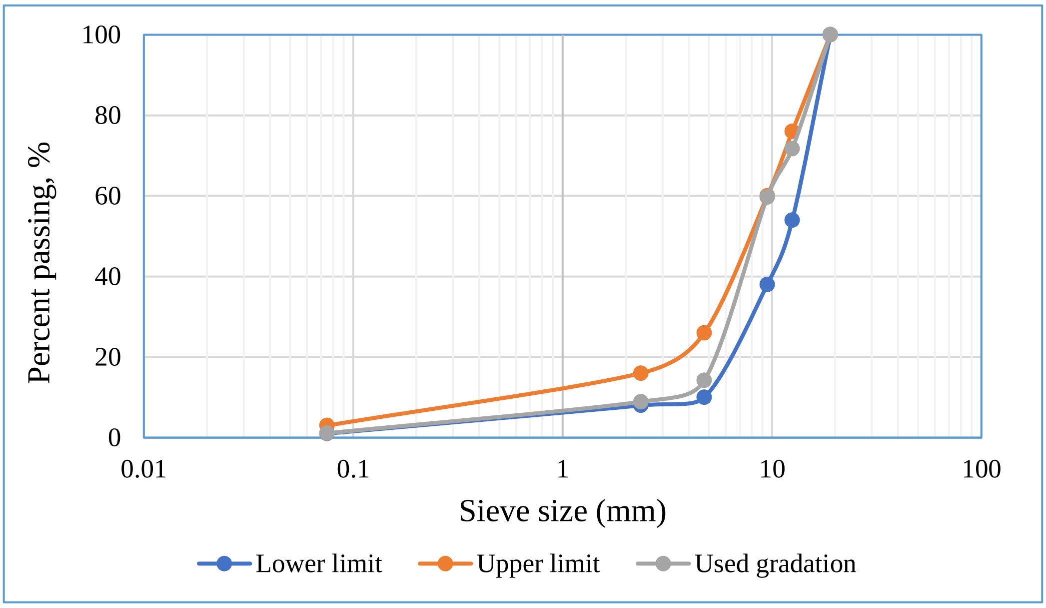

Figure 1 Particle size distribution of aggregate gradation

ISSN: 2709-6718

2.1.7 Neat and modified bitumen

The Al-Nassria refinery supplies neat bitumen with penetration grades ranging from 40 to 50, which is used in the preparation of HMA. Table 5 below shows the physical properties.

Table 5 Physical properties of neat bitumen

Property	Specification	Amount
Penetration, 25℃, 0.1mm	ASTM D5-D5M [17]	43
Softening point, ℃	ASTM D36-95 [18]	49
Ductility, 25℃, cm	ASTM D113-07 [19]	132
Flash point, ℃	ASTM D92-05 [20]	355
Specific gravity	ASTM D70-09 [21]	1.03
Loss on heat		
Penetration aging index (PAI)	ASTM D1754/D1754M [22]	0.74
Softening point index (SPI)	[23]	4.7

To improve bitumen penetration waste low-density polyethylene were added.

Waste-Low-Density Polyethylene (w-LDPE)

Because of its availability and low cost, w-LDPE is the polyethylene (PE) type suggested for use in bitumen modification. However, due to the unstable crystallize nature and non-polar non-aromatic characteristics, it becomes almost completely immiscible with asphalt; therefore, the use of chemically grafted PE and/or chlorination processing may help to improve the compatibility between PE and asphalt [24]. Table 6 shows the physical properties of w-LDPE collected from a small refinery in Kerbala as recycled material of plastic water tank.

Table 6 Physical properties of w-LDPE

Properties	Amount
Density (g/cm^3)	0.91
Tensile strength (MPa)	8.5
Tensile elongation (%)	>350
Melting temperature (◦C)	110
Flexural modulus (MPa)	7.2
Hardness shore D	45

According to [25], w-LDPE is the best-achieved bitumen modification for that use of 3% of w-LDPE used in this study.

2.2 Methods

The procedure that followed is divided into three stages. The first stage is to prepare the porous asphalt layer with 30% air voids as a middle value of the required air voids of 25 to 35%. The second stage involves preparing cementitious grout with a fluidity range of 11 to 16 seconds. The cementitious grout has PFWA percent as cement replacement at 5, 10, and 15%, and the SF percent as cement replacement at 5%, as determined by previous research [26, 27]. The prepared cementitious grout is then injected into the prepared porous asphalt in the third stage. Table 7 depicts the injected cementitious grout into PA.

Table 7 Injected cementitious grout matrix

Mix.	OPC %	SF %	PFWA %	SP %	W/B %	Flow time, sec
M0P	4 % asphalt , 30 % air void , 20 blows each face					
M0C	95	5	0	2	40	11
M1	90	5	5	2	42	12
M2	85	5	10	2	46	13
M3	80	5	15	2	50	13

2.3 Preparation of porous asphalt mixture

PA was prepared using the steps outlined below.

- Modified bitumen is prepared by adding 3 percent w-LDPE to the shear mixture to ensure homogeneous addition.
- Preparation of aggregate gradation according to [15], weighted according to marshal mould and heated to ensure good interlock with heated asphalt.
- To ensure that the asphalt-covered aggregate is close, combine the heated asphalt and aggregate in the mixture.
- The mixture was moulded into a marshal mould and then subjected to 20 blows to each face by a marshal hummer.
- After allowing the specimens to cool, they are ready for grout injection.

2.4 Preparation of grouts

The steps of preparing the cementitious grout materials are illustrated as follows:

- Add SP to the water and mix them well to ensure the homogenous and ensure SP is activated to add the dry materials.

- Adding the dry materials to water while the mixing device is operated to ensure the homogenous paste and prevent the balling phenomenon.
- The prepared mix is subjected to a flow time test.
- The produced grout is cast into the cubic mould with 50 x 50 x 50 mm or beam (200 x 50 x 50 mm).
- The specimens are moulded after one or two days, depending on their hardening, and the early curing temperature when the specimens are in the mould is kept at 20 °C by a heater fan device, in accordance with ASTM C 109/C 109M [28]. According to ASTM C 109/C 109M [28], the specimens matured in water at 20 °C, and the curing temperature was controlled by a heater.

2.5 Preparation of Semi-Flexible Mixtures

Following the preparation of the HMA with 30% air voids, the specimens were wrapped in transparent plastic tape in preparation for grout injection into the HMA with a vibration device to ensure that the grout got into the HMA's air voids.

3. Experimental work

3.1 Volumetric Properties of HMA and SFP

The following equations were used to calculate volumetric properties in accordance with MS-2 [29] and ASTM D2041[30].

$$Gmb= WV* \gamma W \quad (1)$$

$$Gmm= AA+D-E \quad (2)$$

$$AV=100*(1-(GmbGmm)) \quad (3)$$

$$VMA=100*(Gmb* PSGsb) \quad (4)$$

$$VFA=100*(VMA-AVVMA) \quad (5)$$

Where**:**

Gmb = Bulk specific gravity of asphalt mixture

Gmm = Theoretical maximum specific gravity of asphalt mixture

Gsb = Bulk specific gravity of aggregate

W = Weight of Marshall sample

V = Volume of Marshall sample

ɣw = Density of water

Ps = Percentage of aggregate in the total mixture

A = Mass of specimen in air, gm

D = Mass of a container filled with water, gm

E = Mass of container filled with sample and water, gm

Density**,** air voids, VMA and VFA are the volumetric properties of the SFP mixture. Densities are decreased with curing time development due to the evaporation of the water from Cementous grout which leads to weight decrease which causes the density decrease due to their positive relationship this agree with [31] as shown in figure (7). AV increase with curing time development due to the water evaporation which leaves air void instead of it, as shown in figure (8). VMA increase with curing time development due to an increase of air void due to their positive relationship as shown in figure (9). VFA decrease with the development of curing time because of an increase of VMA as mentioned above as shown in figure (10).

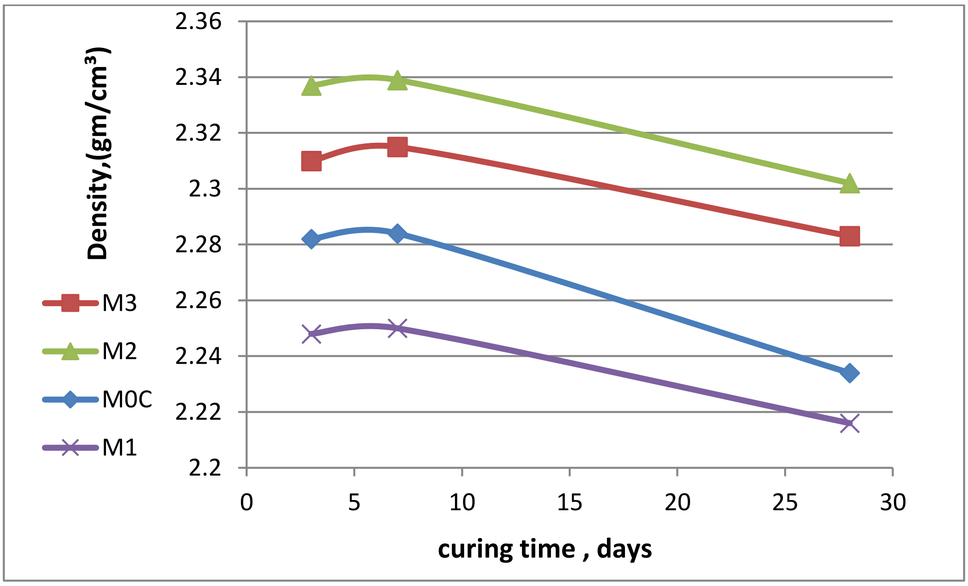

Figure 2 density change with curing time for SFP

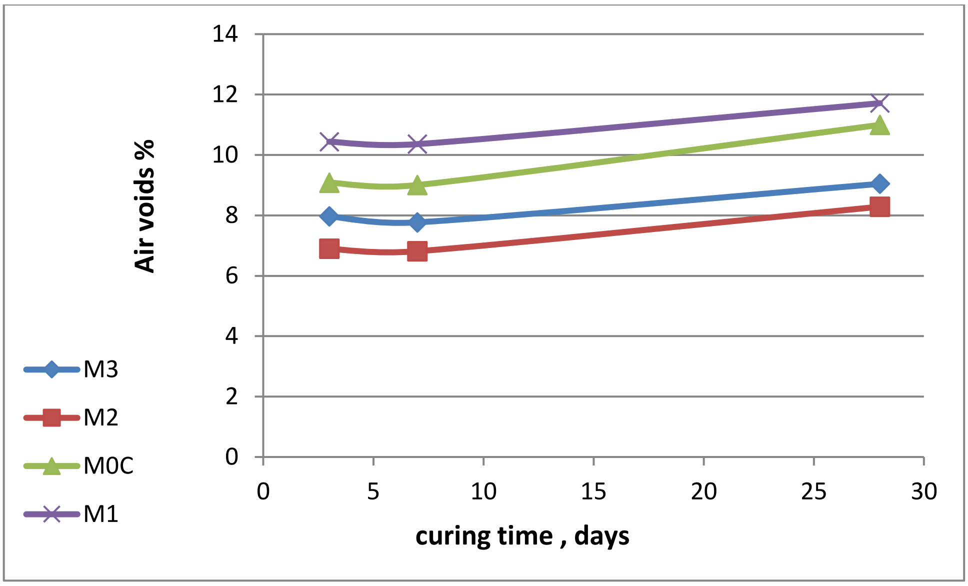

Figure 3 AV change with curing time for SFP

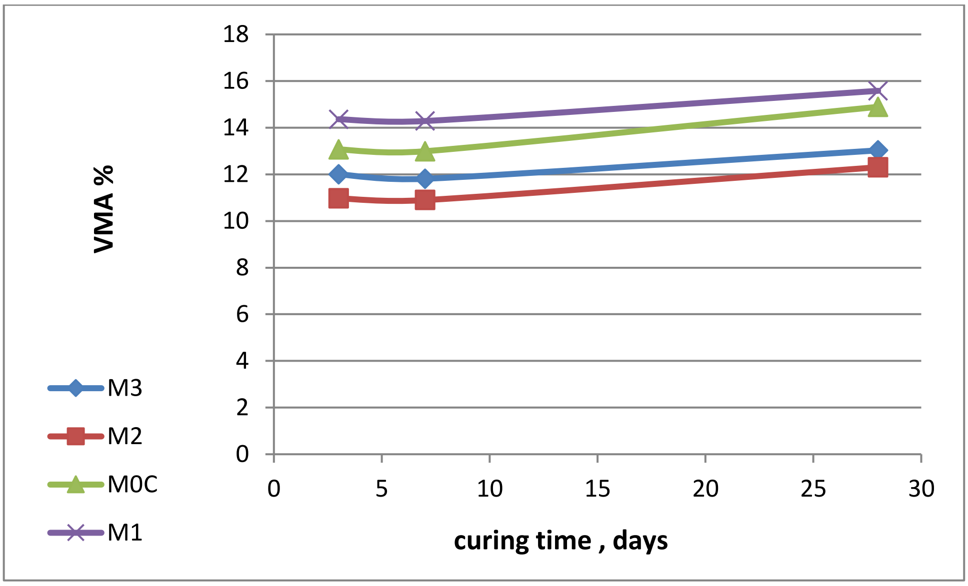

Figure 4 VMA change with curing time for SFP

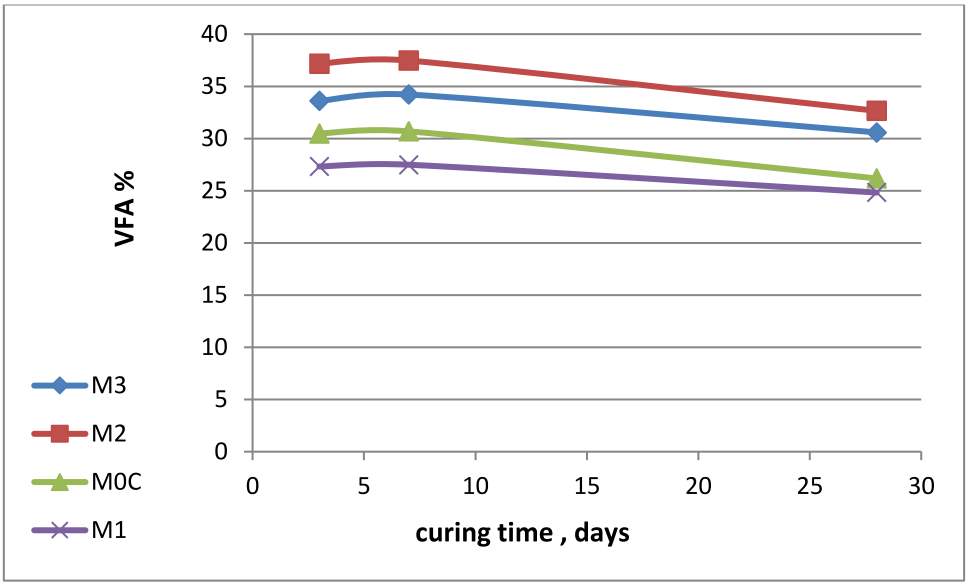

Figure 5 VFA change with curing time for SFP

2.7 Mechanical properties of HMA and SFP

The mechanical properties that indicated pavement cracking in this study were indirect tensile strength (ITS) and tensile strength ratio (TSR).

2.8 Indirect Tensile Strength (ITS)

The indication of tensile crack failure resistance of asphalt mixture at intermediate pavement temperature was determined in this test. The ITS is determined by loading a cylindrical specimen across its vertical diametral plane at a predetermined rate of deformation and temperature. The peak load at failure is measured and used to calculate the specimen's ITS strength. This test is according to ASTM D6931[32]. Equation (6) calculates the ITS strength of specimens.

$$\mathbf{ITS} = \frac{\mathbf{2000*P}}{\boldsymbol{\pi}\,\mathbf{t\,D}} \qquad \textbf{(6)}$$

Where**:**

ITS = Indirect tensile strength, KPa

P = Maximum load, N

t = Specimen height immediately before test, mm

D = Specimen diameter, mm

The results were achieved from ITS for 3,7 and 28 days. For 28 days, the results show the lowest value in normal porous asphalt and increase with SFP highest value with M2 in injected grout as result below for grout. The strength increases with time due to cementitious hydration action complete with time due to maturation in humidity. The wide difference between normal porous asphalt mix and SFP is shown the enhance this mixture type in tensile strength this agree with [27] as shown below.

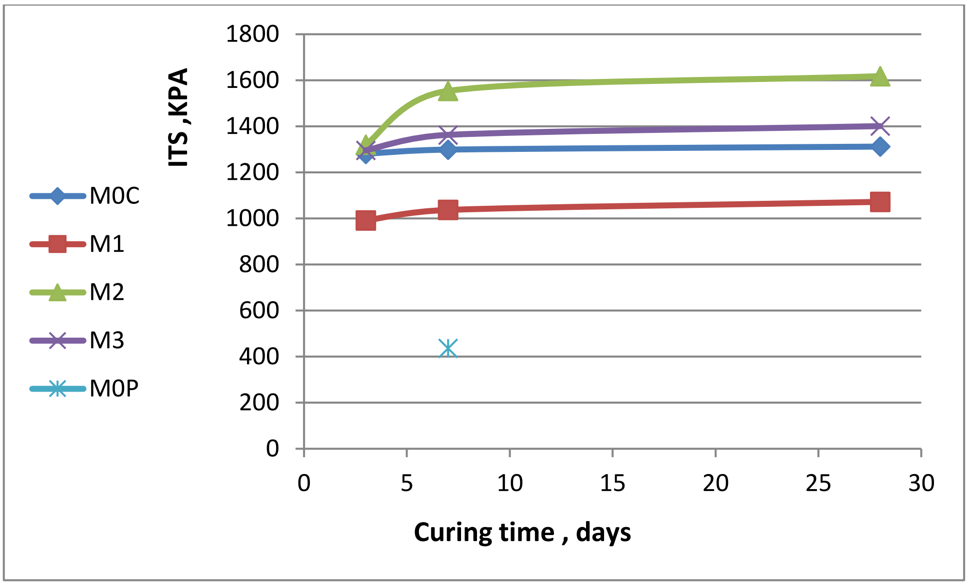

Figure 6 un aged ITS for SFP

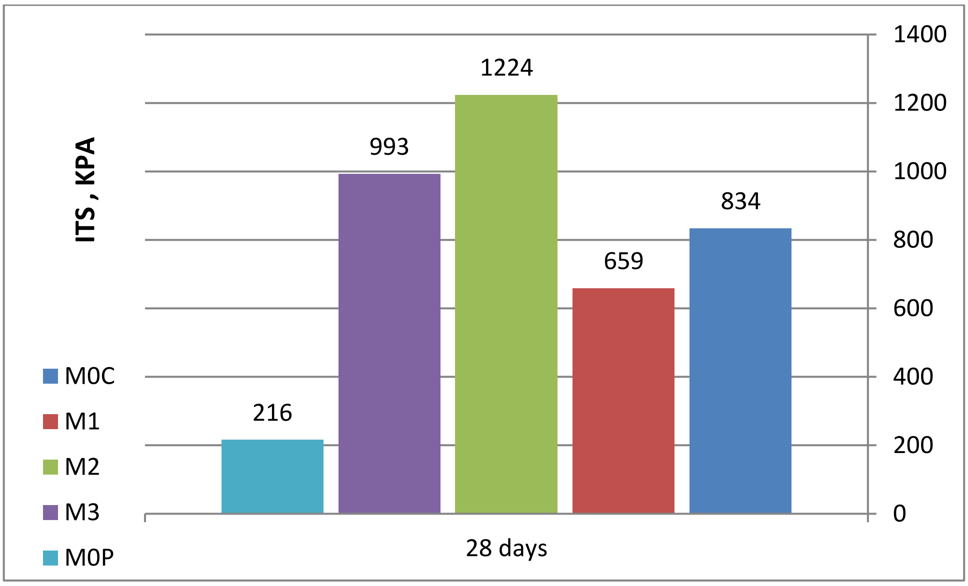

Figure 7 aged ITS for 28 days SFP

As shown in the Figures above, the ITS is decreased with 5 % PFWA replacement, then increased with 10%, after that returned to decrease when PFWA increased to15 %. At 5 %, the SCM effect is still low and the pozzolanic activity is still low and uncompleted. The improvement in strength at 10 % could be due to the denser microstructure of mortar, caused by the PFWA effect. Additionally, the increase in strength of grout with 10% PFWA may be attributed to the continuous formation of additional calcium silicate hydrate (C–S–H) upon the reaction of reactive silica of pozzolan and calcium hydroxide (CH) produced by the cement hydration. This provides additional strength particularly at later ages, as confirmed by a previous study [33]. At 15 % of PFWA level, the strength decreases due to the presence of interconnected micropores that cause weak microstructure than 10 % without these pores, as suggested by a previous study [8], and agreed with others [34].

2.9 Tensile Strength Ratio TSR

TSR test indicated permanent failure due to moisture, a major reason for the permanent failure of the asphalt pavement layer is moisture [35].

The moisture in the pavement cause stripping of the aggregate from the asphalt due to the asphalt films weakening [36].

TSR is measured by ITS aged and unaged at 28 days for SFP. Aged specimens prepared according to ASTM D4867/D4867M [37] . ITS aged requirements are shown in table (8). TSR can be calculated according to equation (3-11). TSR should be more than 70 % according to Iraqi specification GSRB/R9 [38].

$$TSR = Stm/Std \qquad (7)$$

Where:

TSR = Tensile strength ratio, %

Stm = Average tensile strength of the moisture (conditioned subset), kPa

Std = Average tensile strength of the moisture unconditioned subset, kPa

Table 8 ITS Aged Requirement.

Item	**Range**
No. of required specimens	3
Rate of loading, mm/min	50 ± 5
Device accuracy	Min. 50 N
Test temperature, ºC	25 ± 1
Specimen diameters, mm	101.6
Thickness specimen, mm	63.5 ± 2.5
Compaction (Marshall Hammer)	20 blow each face
Unconditioned specimen protocol	2 hr. in oven-dry @ 25 ºC after 28 days
Conditioned specimen protocol	*24 hr. in a water bath at 60 ± 1 ºC + 1 hr. in a water bath at 25 ± 1 ºC*

IS proportional to ITS in 28 days curing time for a conditional and unconditional specimen of SFP. 10 percent PFWA is the highest value then, and 15 percent PFWA meets Iraqi specification

GSRB/R9 required it's not less than 70 percent, as shown below. The control mix and 5 percent PFWA do not meet it.

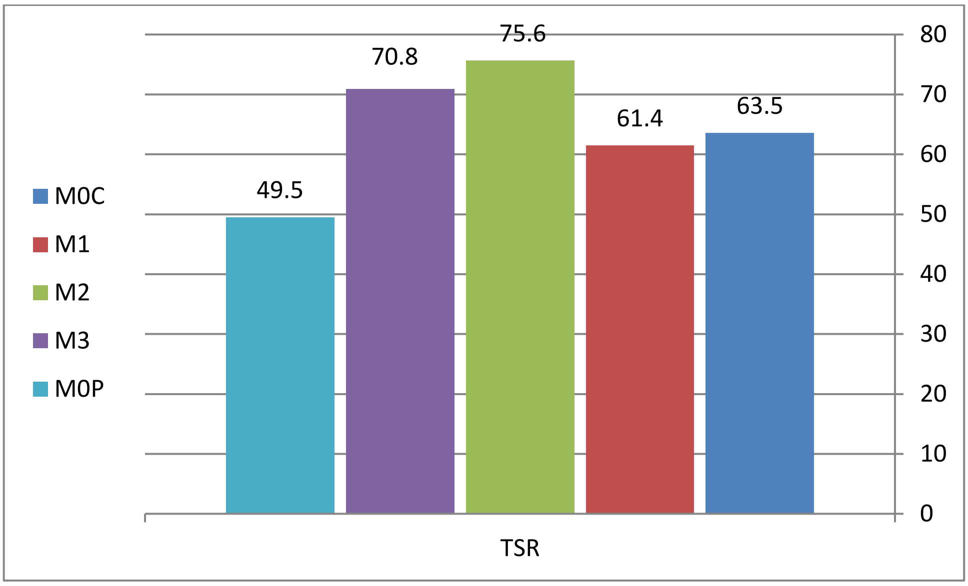

Figure 8 TSR test

4. Conclusions

The goal of this study was to cauterize the volumetric and mechanical properties of SFP using a sustainable approach by replacing a portion of OPC with PFWA; the main conclusion is shown below:

1. The ITS of the SFP increased with higher values than the ITS of the traditional porous asphalt mixture.
2. Volumetric properties indicate that 10% PFWA cement replacement is the appropriate percentage of replacement.
3. Its highest value was achieved with a 10% PFWA cement replacement, resulting in the lowest cracking deformation, whereas the traditional porous asphalt mixture had the highest cracking deformation under load.
4. TSR testing revealed that 10% PFWA replacement provided the best crack resistance, followed by 15% PFWA replacement; these two met the Iraqi specification GSRB/R9 requirement of not less than 70% PFWA replacement, while control mix and 5% PFWA did not.

Acknowledgement

This work was completed with the assistance of the highway research facility staff at the College of Kerbala and the wrker that offers assistance in the supply of materials, which is then acknowledged and thanked.

References

[1] Afonso, M.L., et al., Development of a semi-flexible heavy duty pavement surfacing incorporating recycled and waste aggregates–Preliminary study. 2016. 102: p. 155-161.

[2] Oliveira, M., et al., Modulation of pentylenetetrazol-induced seizures by prostaglandin E2 receptors. 2008. 152(4): p. 1110-1118.

[3] Zoorob, S., K. Hassan, and A. Setyawan, Cold mix, cold laid semi-flexible grouted macadams, mix design and properties, in Performance of Bituminous and Hydraulic Materials in Pavements. 2017, Routledge. p. 105-112.

[4] Ding, Q.J., et al. The performance analysis of semi-flexible pavement by the volume parameter of matrix asphalt mixture. in Advanced Materials Research. 2011. Trans Tech Publ.

[5] Ling, T.-Q., et al., The Application of Semi-Flexible Pavement on Heavy Traffic Roads. 2009. 2(5).

[6] Cai, X., et al., Damage analysis of semi-flexible pavement material under axial compression test based on acoustic emission technique. 2020. 239: p. 117773.

[7] Koting, S., H. Mahmud, and M.R. Karim. Influence of superplasticizer type and dosage on the workability and strength of cementitious grout for semi-flexible pavement application. in Proceedings of the Eastern Asia Society for Transportation Studies Vol. 6 (The 7th International Conference of Eastern Asia Society for Transportation Studies, 2007). 2007. Eastern Asia Society for Transportation Studies.

[8] Alrshoudi, F., M.J.A.J.f.S. Alshannag, and Engineering, Suitability of Palm Frond Waste Ash as a Supplementary Cementitious Material. 2020. 45(10): p.7974-7967 .

[9] Al-Juruf, R., et al., Development of heat insulating materials using date palm leaves. 1988. 11(3): p. 158-164.

[10] The Central Statistical Organization Iraq CSO, T.I.M.o.P., 2019, 2019.

[11] specification, I., Iraqi specification No. 5 (1984), "Portland cement" the Central Agency for Standardization and Quality Control. 1984.

[12] Hlail, S.H., S. Al-Busaltan, and A.M. Shaban. Durability Evaluation: Sustainable Semi-flexible Pavement Mixtures. in IOP Conference Series: Materials Science and Engineering. 2021. IOP Publishing.

[13] ASTM, ASTM Standard Specification for Chemical Admixtures for Concrete. 2015.

[14] LYKSOR, 2016.

[15] Anderton, G.L., Engineering properties of resin modified pavement (RMP) for mechanistic design. 2000, Engineer Research and Development Center Vicksburg Ms Geotechnical Lab.

[16] ASTM, ASTM D7964 Standard Practice for Open-Graded Friction Course (OGFC) Mix Design. American Aociety for Testing Material. West Conshohocken, PA, United States. 2013.
[17] ASTM ,ASTM D5-D5M - 13 'Standard test method for penetration of bituminous materials'. 2013.
[18] ASTM, ASTM D 36 – 95 (Reapproved 2000) 'Standard test method for softening point of bitumen (ring-and-ball apparatus)'. 2009.
[19] ASTM, ASTM D 113 - 07 'Standard test method for ductility of bituminous materials'. 2007.
[20] ASTM, ASTM D92-05 'Standard Test Method for Flash and Fire Points by Cleveland Open Cup Tester'. 2005.
[21] ASTM, ASTM D70 - 09'Standard Test Method for Density of Semi-Solid Bituminous Materials (Pycnometer Method)'. 2009.
[22] ASTM, ASTM D1754/D1754M − 09 (Reapproved 2014) 'Standard test method for effects of heat and air on asphaltic materials (Thin-Film Oven Test)'. 2014.
[23] Zhang, H., et al., Physical, rheological and chemical characterization of aging behaviors of thermochromic asphalt binder. 2018. 211: p. 850-858.
[24] Polacco, G., et al., Asphalt modification with different polyethylene-based polymers. 2005. 41(12): p. 2831-2844.
[25] AL-YASARY, R., CHARACTERIZING OF MODIFIED OPEN GRADE FRICTION COURSE WITH SUSTAINABLE MATERIALS. 2020.
[26] Ajileye, F.V.J.G.J.o.R.I.E., Investigations on microsilica (silica fume) as partial cement replacement in concrete. 2012. 12(1-E.(
[27] Koting, S., et al., Effects of using silica fume and polycarboxylate-type superplasticizer on physical properties of cementitious grout mixtures for semiflexible pavement surfacing. 2014. 2014.
[28] ASTM, ASTM C 109/C 109M Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using-2in. or-50] mm] Cube Specimens). 2005.
[29] Institute, A.I.J.A., MS-2 asphalt mix design methods. 2014, Lexington Kentucky, USA.
[30] ASTM, ASTM Standard Test Method for Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures. D2041, American Aociety for Testing Material. West Conshohocken, PA, United States . 2015.
[31] Pei, J., et al., Design and performance validation of high-performance cement paste as a grouting material for semi-flexible pavement. 2016. 126: p. 206-217.

[32] ASTM, ASTM Standard Test Method for Indirect Tensile (IDT) Strength of Bituminous Mixtures. D6931, American Aociety for Testing Material. West Conshohocken, PA, United States . 2012.

[33] Mardani-Aghabaglou, A., et al., Comparison of fly ash, silica fume and metakaolin from mechanical properties and durability performance of mortar mixtures view point. 2014. 70: p. 17-25.

[34] Zhang, J., et al., Formulation and performance comparison of grouting materials for semi-flexible pavement. 2016. 115: p. 582-592.

[35] Sengoz, B., E.J.B. Agar, and environment, Effect of asphalt film thickness on the moisture sensitivity characteristics of hot-mix asphalt. 2007. 42(10): p. 3621-3628.

[36] Tandon, V., N. Vemuri, and S. Nazarian. Evaluation of environmental conditioning system for predicting moisture susceptibility of asphalt concrete mixtures. in Transportation Research Board, 75th Annual Meeting, Washington DC. 1996.

[37] ASTM, ASTM Standard Test Method for Effect of Moisture on Asphalt Concrete Paving Mixtures. D4867/D4867M, American Aociety for Testing Material. West Conshohocken, PA, United States . 2014.

[38] GSRB, GSRB General Specifications for Roads and Bridges, SECTION R9. Iraq . 2003.

تقييم التشققات للخلطه الشبه المرنه بإستخدام المواد المستدامه فى تكوين الحقين الاسمنتى

الخلاصة: *الخليط شبه المرن عبارة عن تكوين خليط إسفلتى مسامى مع فراغات هوائية (25-35)٪ وحقين أسمنتى يملأ الفراغات للحصول على الصفات شبه المرنة اللازمة لاستخداماته. يحتوى الحقين الأسمنتى بشكل عام على الأسمنت والماء ، ويمكن إضافة المواد الأسمنتية التى تضيف للحصول على خصائص أفضل لهذا الحقين. فى هذا البحث تم استخدام المواد المستدامة لتعزيز خصائص الحقين. من ناحية أخرى ، أدى استخدام المواد المعاد تدويرها إلى تقليل التلوث البيئى. كان الرماد المستدام الذى استخدم فى هذه الدراسة هو رماد نفايات سعف النخيل (PFWA) ، حيث قام بجمع سعف النخيل الذى سقط فى الخريف ثم حرقه فى درجة الحرارة العادية ثم جمع النتيجة لحرقه عند 900 درجة مئوية للحصول على الخصائص البوزولانية. لضرورة الحصول على تفاعل كيميائى مع المواد الأسمنتية الأخرى. تم تعبئة الملاط الناتج فى خليط الإسفلت المسامى ثم أجريت الاختبارات المعملية للحصول على خليط شبه مرن وتقييم العينات فى الخواص المستهدفة. فى هذا البحث تقييم التشققات هو المطلوب لذلك أقيمت الفحوصات الخاصه ب هذا المجال.*