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Cracking Evaluation of Semi-Flexible Pavement Mixture Comparison Bitumen Emulsion Modified Grout

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Abstract:

Due to its excellent load bearing capability, semi-flexible pavement (SFP) has received a lot of attention in recent years. Its strength, rutting resistance, and constituent composition are all thoroughly investigated during examinations. However, there is a lack of knowledge on its cracking capability and mechanism. An indirect tensile strength test (ITS) and a tensile strength ratio (TSR) are used to assess the cracking ability of SFP mixtures in this paper. When a porous asphalt skeleton is filled with cement-based grouting material, semi-flexible pavement (SFP) has been found to operate effectively in the severely loaded roadway and airport pavement construction. The results showed that the ITS is high for the mixtures without emulsion, and when to increase emulsion the ITS decrease. The highest values for ITS are for the mixture without emulsion (M1) while the lowest values for ITS are for mixtures containing 60% EM. Moreover, the addition emulsion to the mixture improved TSR and using 60% emulsion give the high for TSR.

Keywords: emulsion; semi-flexible pavement; silica fume; indirect tensile strength; tensile strength ratio.

1. Introduction

Semi flexible pavement (SFP) is a high-performance cement mortar (CM)-packed porous asphalt mixture with 25 to 35% air void content. SFP is characterized by its lack of joints, great strength, impermeability, endurance, and fuel resistance, all of which are benefits. SFP can also be used to construct and reconstruct high-traffic regions including manufacturing floor, bus stations, parking lots, loading platforms, and other high-traffic spaces [1, 2]. The first country to study and use semiflexible materials was France [3]. After then, semiflexible pavements in the United Kingdom, the United States, and the former Soviet Union were investigated, and their high-temperature stability was confirmed [4, 5]. Researchers have conducted many reports on the efficiency of semiflexible materials. Using cyclic wheel load testing, the effects of various parameters on damage were investigated, and a connection between loading times and damage was established. [2].

Furthermore, there are still questions about the SFP mixture's cracking resistance [2]. Thermal stress and traffic loads have been proposed as two variables that can cause fractures in asphalt pavement. In the case of SFP, the brittleness of cement must be taken into account when determining if it would raise the cracking hazards of such an unconventional asphalt mix. Cohesion (asphalt-asphalt) and adhesion (asphalt-aggregate) failures are the two most common types of asphalt mixture failures. SFP is more complex than a standard asphalt mixture since it contains additional sub-components [6]

SFP's durability and compressive strength were examined in relation to gradation. SFP strength has been shown to be influenced by increased air voids in the asphalt mix skeleton. This study looked into grouting material, asphalt mixed matrix, and SFP mixture properties [7]. The compressive strength, resiliency modulus, and rutting resistance of the asphalt mixture skeleton were all enhanced by using cementitious grouting materials. [8]. Hou et al., [9] examined the mechanical characteristics and long-term durability of SFP and traditional asphalt mixtures. In low-temperature bending tests, SFP exhibited a lower cracking resistance than standard asphalt mixtures; this is related to the cement paste's brittleness. The causes of cracks in semiflexible paving materials can be categorized into three categories: Fatigue cracking occurs as a result of traffic load. The two types of temperature contraction are temperature cracking and dry contraction. Temperature and humidity variations induce cracking, and semi-rigid foundation cracking reflection cracks [10].

Even though SFP cracking resistance must be fully examined, and the cracking process well understood to better support the use of SFP in the field, only a few research concentrating on these issues have been undertaken, as mentioned above. Relevant issues to it have not been thoroughly investigated which factors influence SFP cracking performance [6].

2. Experimental work

2.1 Materials

Ordinary Portland cement OPC (CEM I 42.5R) was utilized in this investigation, and it meets the Iraqi standard No: 5/1984 type I. Karbala Cement Plant produced OPC. Table 1 lists the chemical and physical properties of this type of cement.

Table 1 The physical and chemical properties of OPC

Physical properties	
Specific Surface Area(m^2\kg)	410
Density (gm.\cm^2)	2.987
Chemical properties	
SiO_2	18.1
Al_2O_3	3.05
Fe_2O_3	5.45
CaO	62
MgO	1.38
K_2O	0.760
Na_2O	1.714

CONMIX Company provided the silica fume (SF). Silica Fume (SF), also known as condensed silica fume or micro silica, is a fine powder having a high concentration of amorphous silicon dioxide [11]. The smelting of silicon and ferrosilicon produces this material as a by-product [12]. Table 2 lists the chemical and physical properties of SF.

Table 2 the physical and chemical properties of SF

Physical properties			Specification, ASTM C1240
Surface area (m^2/kg)		18100	15000
Density		700 (kg/m^3)	-
Chemical properties			Specification, ASTM C1240
NaO		1.534	-
MgO		0.432	-
Al_2O_3		0.091	-
SiO_2		92.05	>85%
Cl_2O		0.001	-
K_2O		1.886	-
CaO		3.035	-
TiO_2		0.002	-
MnO		0.149	-
Fe_2O_3		0.448	-
Co_2		0.006	-
CuO		0.017	-
ZnO		0.179	-
SrO		0.016	-
Y2O3		0.005	-
BaO		0.057	-
LOI		0.01	<6%
moisture		0.05	<3%

The LYKSOR Company (under the trade name Nano-Flow 5500) supplied a superplasticizer (SP). Nano-Flow 5500 is a polycarboxylate-based high-range water reducer/super-plasticizer chemical additive designed for the creation of very flowable concretes or self-compacting concrete. According to ASTM C494, the superplasticizer used is Type G—Water reducing, retarding admixtures and high range. The properties of the Superplasticizer are listed in Table 3.

Table 3 Properties of super-plasticizer

Property	value	specification
Colour and form	Yellowish-liquid	-
Chemical base	Polycarboxylate	-
Density (kg/lt)	1.06	1.05-1.09 (at+20^0 C)
Chloride ion content	0.05	Max 0.1% - Chloride free acc.to EN 934-2)
Alkali content	3%	Max.5%
Ph	4	3-7
Conformity	-	ASTMC494 Table 1

The Fosroc Company supplied the asphalt emulsion (under the trade name Nitoproof 10). Table 4 summarizes the Nitoproof 10 properties given by the manufacture [13].

Table 4 Asphalt emulsion's properties

Property	Standard ASTM	Limits	Results
Emulsion type	D2397[14]	Rapid, medium and slow-setting	Medium-setting (CMS)
Color appearances			Dark brown liquid
Residue by evaporation, %	D6934[15]	Min. 57	60
Specific gravity, gm/cm^3	D70[16]	-------	1.03
Penetration, mm	D5[17]	100-250	235
Ductility, cm	D113[18]	Min. 40	44
Viscosity, rotational paddle viscometer 50 °C, mPa.s	D7226[19]	110-990	225
Freezing	D6929[20]	Homogenous, broken	Homogenous
Solubility in trichloroethylene, %	D2042[21]	Min. 97.5	97.8
Emulsified asphalt/job aggregate coating practice	D244[22]	Good, fair, poor	Good
Miscibility	D6999[23]	-------	Non-miscible
Aggregate coating	D6998[24]	-------	Uniformly-thoroughly coated

Crushed Limestone aggregates, which were supplied from Karbala quarries, were used in the design of the OGFC asphalt mixture. The middle gradation with 19 mm NMAS was used, gradation limits were suggested by [25], to keep the amount of air voids in the porous mixture within the allowed range of (25-35%), and to guarantee that the grout penetrates the porous mixture.

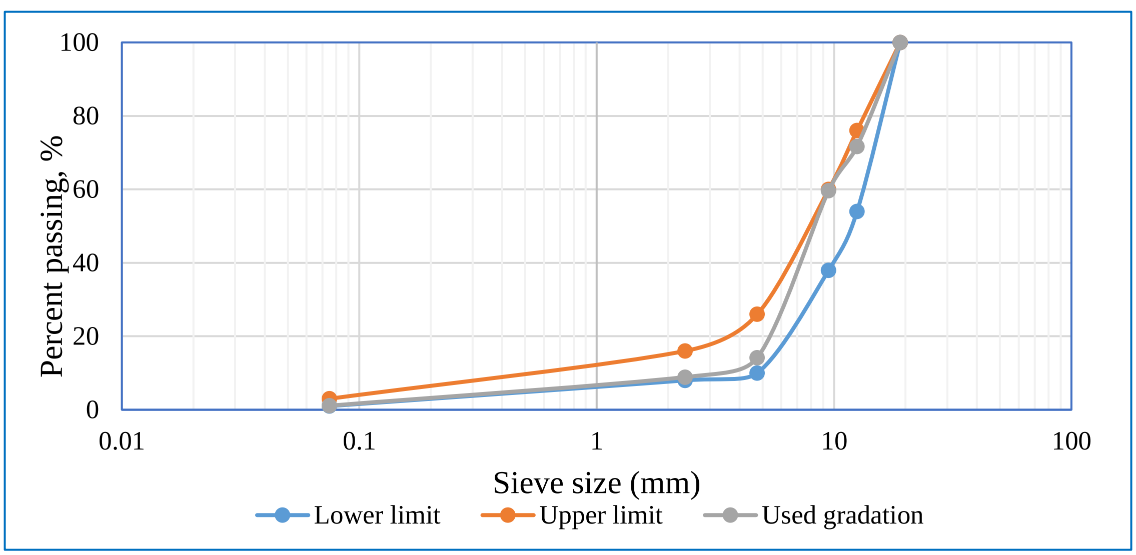

Figure 1 the aggregate gradation's particle size distribution

This study combined the use of two types of fillers: conventional mineral filler (CMF) and hydrated lime (HL). Table 5 demonstrate the fillers' chemical and physical properties.

Table 5 The physical and chemical properties of the fillers used are listed below

Chemical properties		
Oxide/property	***Concentration/amount***	
	CMF	***HL***
SiO_2	81.891	0.881
Al_2O_3	3.780	-----
Fe_2O_3	1.922	2.240
CaO	7.371	90.591
MgO	3.450	3.611
K_2O	0.732	0.570
Na_2O	0.193	1.011
Physical properties		
Density (g/cm3)	2.651	2.302
Surface area (m2/Kg)	224	1241

2.2 Methods

The design of this mixture is in three stages: the first stage is to design cementitious grout materials, the second stage design porous asphalt mixtures using modified asphalt (W-LDPE) by 3%, and finally injecting the cementitious grout materials into the porous asphalt (PA) specimens. Table 7 shows the matrix used in designing cementitious grout.

Table 7 Matrix of cementitious grout

Mix	**OPC%**	**S.F%**	**EM%**	**W\B**	**S.P%**
M1	95	5	0	0.4	2
M2	75	5	20	0.4	2
M3	55	5	40	0.4	2
M4	35	5	60	0.4	2

2.3 Tests Methods and Conditions

The indirect tensile strength test is one of the more accurate methods for determining the strength of asphalt mixtures under load. According to the AASHTO T283 [26], SFP mixes were tested at ages of 3, 7, and 28 days at 25 ^{o}C, 2 hr. in oven-dry. TSR is a measure of how durable something is. One of the most difficult problems with asphalt surfaces is moisture damage. The approach outlined in AASHTO-T283 [27] can be used to obtain TSR. For 24 hours, the conditioned samples are submerged in a water bath at 60°C. Finally, before testing, the specimens are put in a water bath at 25°C for 2 hours. In this test, the tensile strength ratio (TSR) of conditioned samples to unconditioned samples was measured by ITS at age 28 days.

3. Results and Discussion

3.1 Result of Volumetric Properties

Figure 2 shows the density of the semi-flexible mixture. The density of all mixtures decreases as curing time increased because cementitious grout materials contain a large amount of water in addition to the superplasticizer, as the curing age increases, the amount of water evaporates, leaving air voids, resulting in a decrease in density. In addition, shrinkage occurs in the grout due to OPC shrinkage [28]. The density decrease with the increased emulsion; this is mostly since the water in asphalt emulsion facilitates the backing at first but as its content increases. The mixture after curing becomes more void-filled, lowering the density.

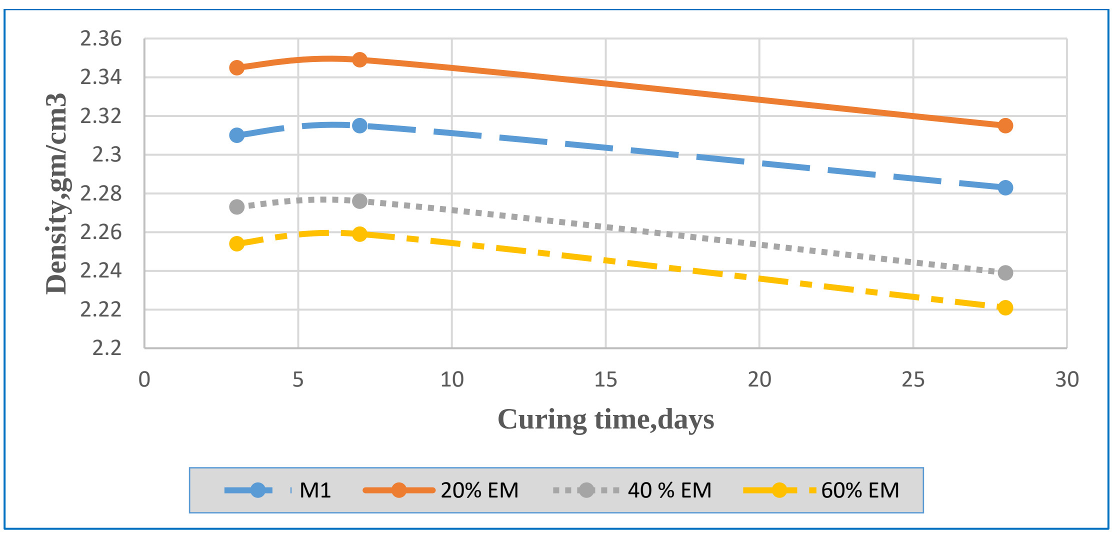

Figure 2 Density vs. curing time of SFP

Figure 3 shows that the air void of SFP mixtures. The increase of the curing age leads to an increased content of air voids. Air voids and density have an inverse relationship, as the increase in air voids leads to a decrease in density with increasing curing age, and for the same reason referred to in the decrease in density. Compared to previous studies, the air voids obtained 5.1 % in An et al., [29], 4.8% in Hou et al., [30] and between 3.1-3.5% in Husain et al. [31].

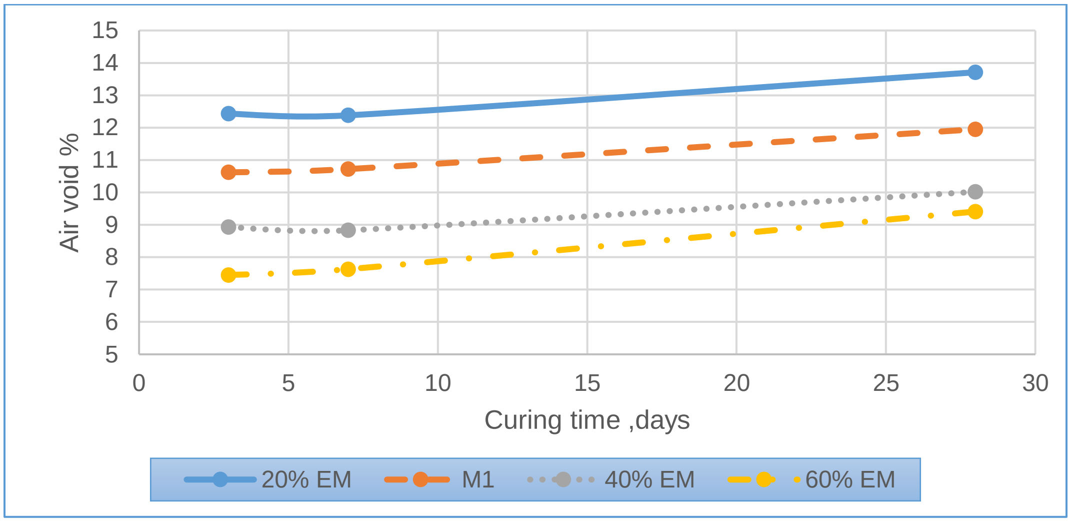

Figure 3 Air voids vs. curing time of SFP

The result of the VMA shows in Figure 4. The figure shows that the voids in mineral aggregate (VMA) of all mixture increases with the curing age increased; there is a direct relationship between the air voids and the VMA, as the increase in the air voids leads to an increase in the VMA and for the same reason mentioned in the density.

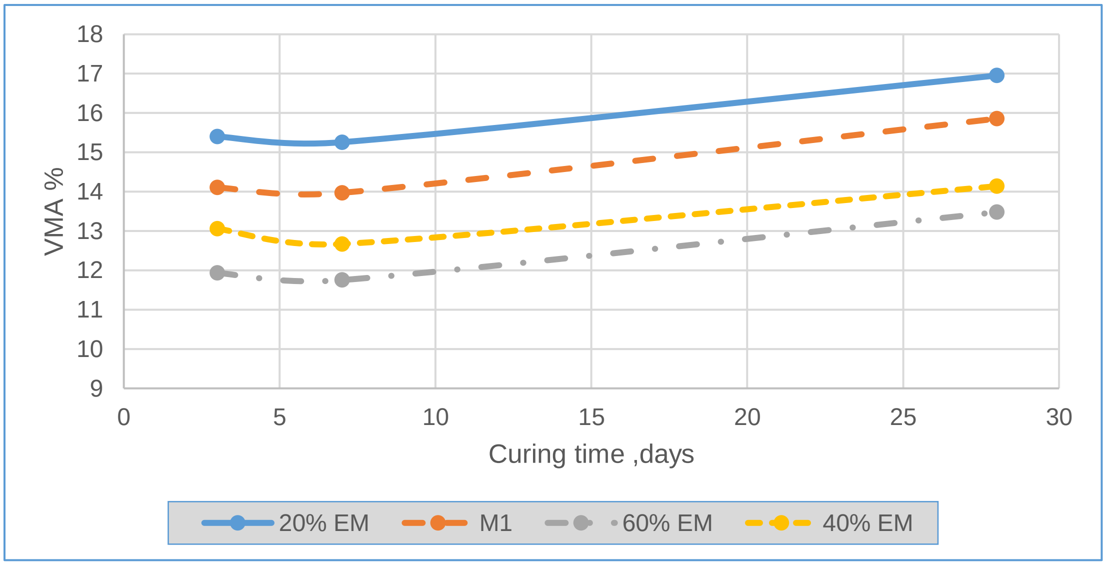

Figure 4 VMA vs. curing time of SFP

Figure 5 shows the results of the voids filled with asphalt (VFA) of all SFP mixtures. The VFA decreases with increasing curing age, and the density decreases for the same reason. VFA is calculated as a percentage of the VMA that contains a binder.

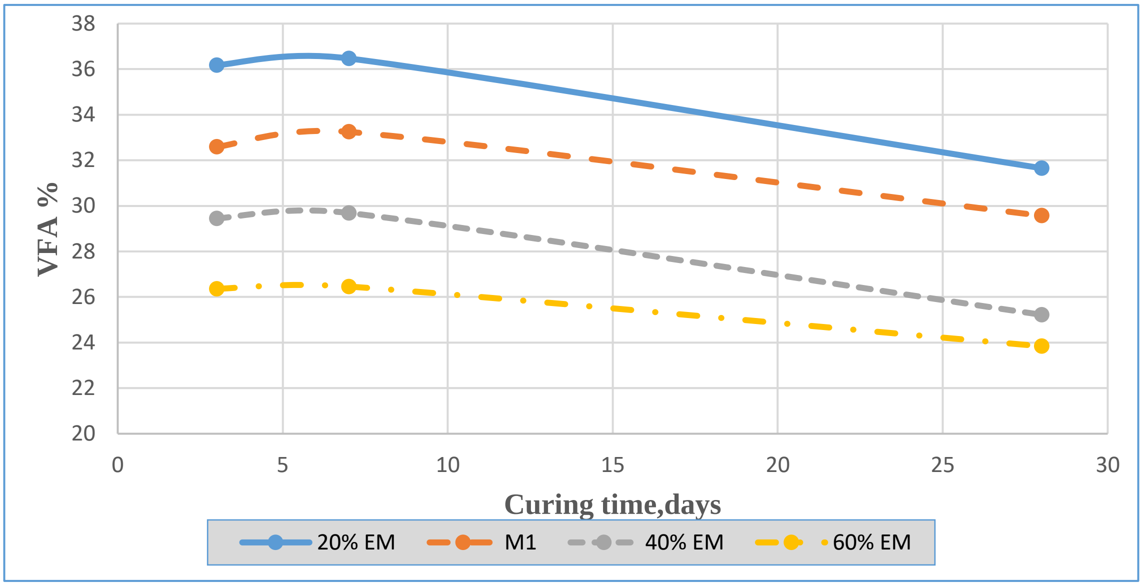

Figure 5 VFA vs. curing time of SFP

3.2 Result of Mechanical Properties

3.2.1 Indirect Tensile Strength (ITS)

Figure 6 shows the result of ITS for four types of mixtures and ages 3, 7, and 28 days. Also, figure 7 shows the result of indirect tensile strength at 28 days. Through the results, it was found that the ITS of all mixtures, develops with an increase in curing time and this is because the cement hydration process needs time to complete the reaction and thus increase the strength. This is agreed with [32, 33]. For comparison between the four mixtures, the highest values for ITS are for the M1, while the lowest values for ITS are for mixtures containing 60% EM. Because increasing emulsion decreases the ITS, the ITS for a mixture containing 20% is greater than the ITS for a mixture containing 60%. This occurred because the emulsion contains a percentage of water, which reduces the indirect tensile strength, as well as because of the hydration process, and agree with [1].

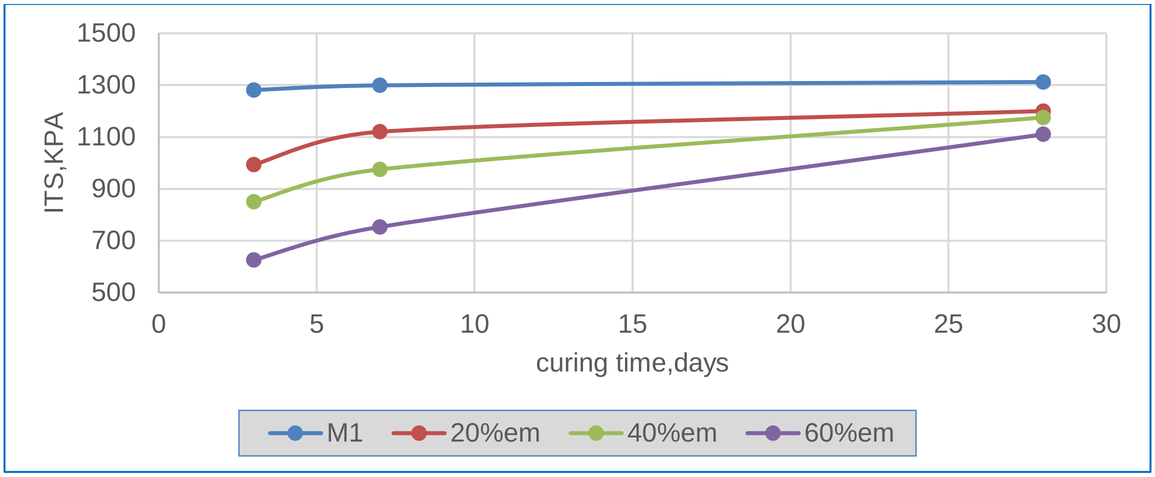

Figure 6 ITS test of SFP for different ages

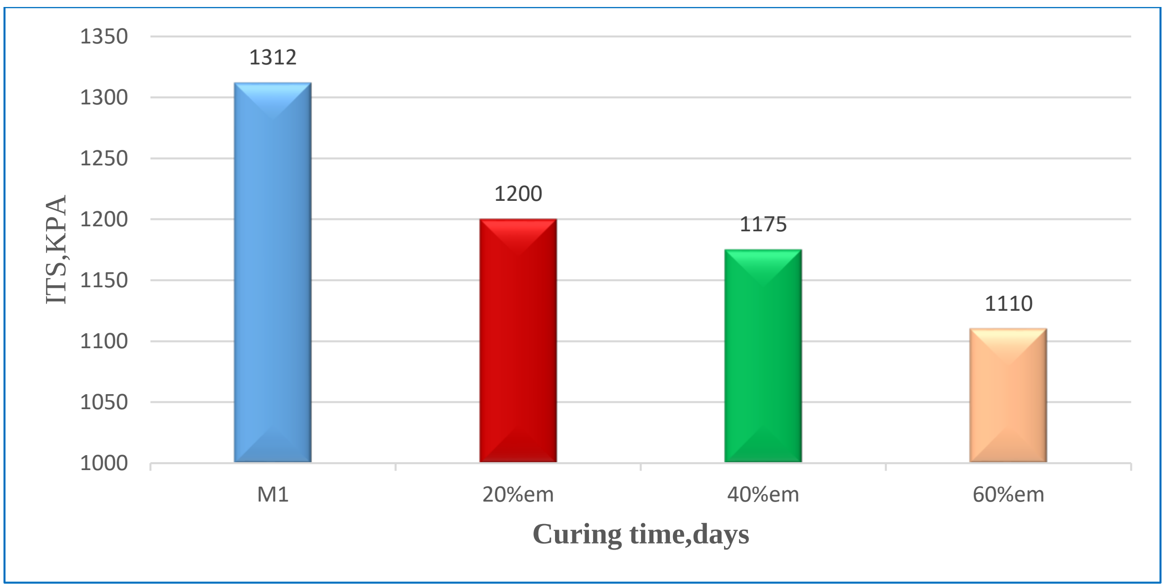

Figure 7 ITS test of SFP at 28 days

3.3 Result of Durability Properties

3.3.1 Tensile Strength Ratio (TSR)

Figure 8 shows the ITS and TSR results for both conditional and unconditional samples at the age of 28 days. The ITS for unconditional samples is higher than the ITS for conditional samples, according to the findings. The highest indirect tensile strength for unconditioned mixtures is M1.

However, the highest indirect tensile strength value for conditional mixtures that containing 40% EM. The results show that the ITS for conditional samples is smaller than the ITS for unconditional samples, as expected. That is, the samples' adaptation to moisture led the mixtures to deteriorate, and as a result, the indirect tensile strength of the mixtures was significantly reduced. As the amount of asphalt emulsion in the mixture increases, so does the TSR value of SFP. On the other hand, SFP without emulsion (mixture M1) has a very lower TSR value and can only satisfy the minimal standards for an asphalt mixture that has a very lower TSR value and can only meet the minimum requirements. TSR values are greater in all SFPs with emulsion. As a result, SFP with emulsion has a higher resistance to TSR values. TSR is a test that determines how resistant a mix is to moisture damage. As a result, SFP with emulsion exceeds SFP without emulsion when it refers to moisture resistance. There are two possible explanations for this phenomenon: (1) Due to the viscoelastic nature of asphalt, the mixture including emulsion can absorb more stripping energy than the mixture without emulsion [34]; (2) The water absorption of the mixture with emulsion is lower than the mixture without emulsion because to the hydrophobicity of asphalt [35]. The maximum TSR value for all mixes is 88.7%, which corresponds to the findings obtained by [1].

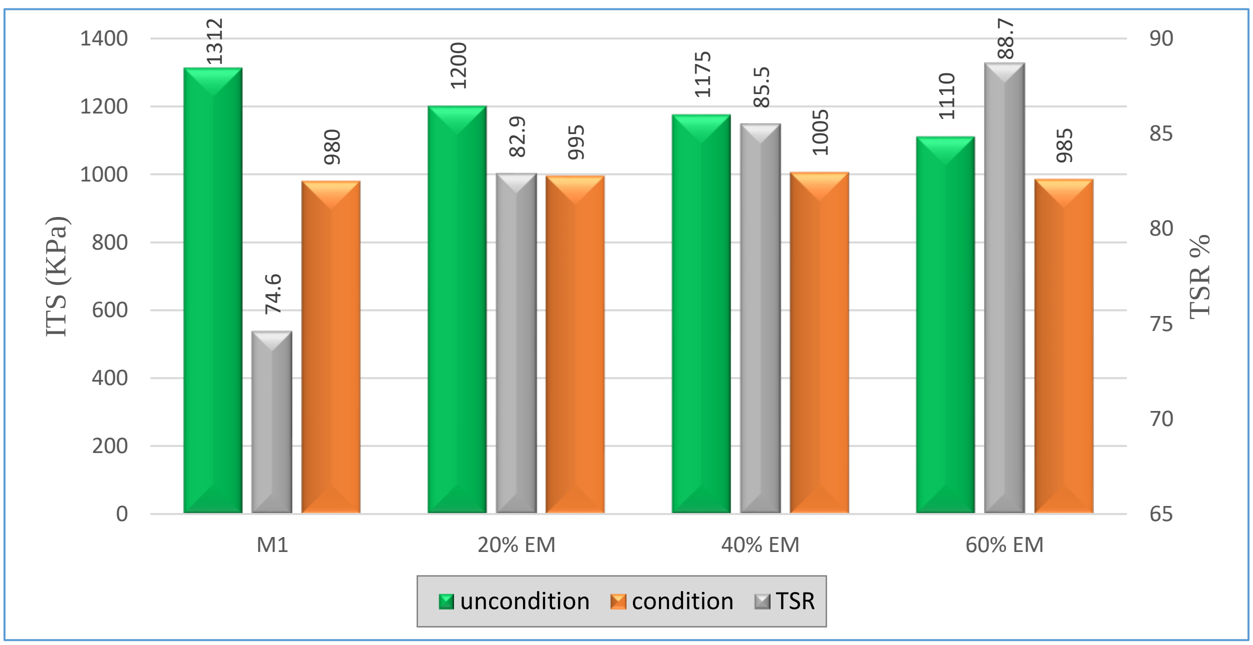

Figure 8 Tensile Strength Ratio (TSR) for various mixtures

4. Conclusion

Cracking resistances of SFP mixes were measured using the ITS and TSR tests. The following are the conclusions:

1. The results show that with increasing age the density decreases and the air void for semi-flexible mixtures increase. In addition to that, the VMA is inversely proportional to the VFA.
2. The ITS increased with the curing time increased and using 20% EM give the highest ITS.
3. Using 60% on the EM in the mixture give the highest TSR. This indicates that the TSR increased with the increment of the percentage of emulsion.

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تقييم التكسير لمقارنة خليط الرصف شبه المرن مستحلب البيتومين الجص المعدل

الخلاصة: *نظرًا لقدرته الممتازة على التحمل، فقد حظي الرصيف شبه المرن (SFP) بالكثير من الاهتمام في السنوات الأخيرة. يتم فحص قوتها ومقاومتها للتشقق وتكوينها بدقة أثناء الفحوصات. ومع ذلك، هناك نقص في المعرفة حول قدرتها على التكسير وآليتها. يتم استخدام اختبار مقاومة الشد غير المباشر (ITS) ونسبة مقاومة الشد (TSR) لتقييم قدرة التكسير لمخاليط SFP في هذا البيبر. عندما يتم ملء هيكل الإسفلت المسامي بمادة الحشو القائمة على الأسمنت، يكون الرصيف شبه المرن (SFP) يعمل بشكل فعال في بناء الطرق وأرصفة المطارات ذات التحميل الثقيل. أظهرت النتائج أن ITS مرتفع بالنسبة للخلائط بدون مستحلب، وعند زيادة المستحلب ينخفض . أعلى قيم لـ ITS هي للخليط بدون مستحلب (1M) بينما أدنى قيم لـ ITS هي للمخاليط التي تحتوي على 60٪ EM، علاوة على ذلك فإن إضافة مستحلب يودي إلى تحسين الخليط TSR واستخدام مستحلب 60٪ يعطي أعلى لـTSR.*