Indirect tensile strength assessment of hot mix asphalt subjected to solvent soaking at high-temperature

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The objective of this paper is to assess the effect of solvent (benzene) on the indirect tensile strength (ITS) of the Hot Mix Asphalt (HMA) during the peak summer of Iraq (60 C°) when dropped on an asphaltic road as a measure of durability. Two conditioning cases are applied, the (unconditioned case) where the samples are tested in dry condition at 25 °C and (the conditioned case by soaking in benzene for 30 minutes after 30 minutes conditioning in water bath at 60 °C) the conditioned case prepared to simulate an existing road at peak summer in Iraq. Thirty-six marshal specimens are prepared for three different air void content 4, 6 and 8%. Two asphalt types are used neat (AC 40-50) and modified (AC 40-50 + 4%SBS) with three different filler content 6%, 8% and 10%. The tensile strength ratio (TSR) results show clearly defect in conditioned samples where the TSR decreased about 8%, 10% and 17% for samples used neat asphalt with 4%, 6% and 8% air void content respectively. On the other hand, the conditioned samples using modified asphalt showed better resistance where only 5%, 7% and 10% decrease in TSR. Nevertheless, the seriousness effect of benzene on the durability of HMA using modified asphalt with 10% filler content at 4% air void content provides 94% TSR while the minimum TSR is 82% for modified asphalt with 6% filler content at 8% air void content. On the other side, the minimum TSR results are observed on samples using neat asphalt regardless the filler and air void content the TSR are less than 80% which is not acceptable according to the State Corporation of Roads and Bridges (SCRB) limits. As a result, it is recommended to use modified asphalt to sustain the durability for Iraqi roads.

Keywords: Modified asphalt SBS; tensile strength TSR; rutting; rheological properties; Iraqi roads.

1. INTRODUCTION

Nanotechnology considered one of the most promising technologies in enhancing the mechanical properties of hot mix asphalt and sustain the durability during the service life of the road by improving the moisture susceptibility and rutting resistance at high temperature. Loss of the bond between aggregates and the surrounding asphalt mastic in presence of moisture or any solvents frequently known as stripping. As a result, lowering the mixture stability and load-carrying capacity. Subsequently, the stripping is considered one of the main causes of rutting, shoving and fatigue cracking [1, 2]. Since the asphalt has viscoelastic property which make it viscous liquid at high temperatures and elastic solid at low temperatures, it is essential to study the effect of heat on HMA roads. Heat can soften the asphalt by breaking the internal bonding as a result loss of cohesion. Oxidation of asphalt with time known as Aging can stiffing the asphalt mastic and enhance its cohesion property to some extent. As a result of aging the hardening component of asphalt known as Asphaltene is dominated by losing the light components which is known as maltene [3, 4]. Modifiers such as styrene butadiene styrene SBS can enhance the moisture susceptibility of hot mix asphalt by improving the cohesion and adhesion properties of asphalt mastic [5]. Some vehicular fuel like benzene dropped by chance on particular areas of asphalt roads, this hydrocarbon contaminates can penetrate the road surface and effects the pavement durability specially the indirect tensile strength of hot mix asphalt. Diesel could reduce viscosity and ITS by 30-50% [6]. Fuel spills caused up to 50% ITS loss while gasoline could weaken binder and increased stripping [7]. Tensile strength of HMA are highly sensitive to aromatic solvent with increased stripping and permanent deformation [8]. Investigation on the Kerosene exposure state that ITS reduced by 30–40% [9]. The influence of fuel contamination on the strength and durability of asphalt mixtures is studied and the results indicated that fuels like diesel and gasoline reduced the stiffness modulus and ITS significantly, depending on exposure duration. The longer the exposure, the more pronounced the weakening effect [10]. Detailed evaluation using dynamic modulus (|E*|) and ITS tests are conducted to assess HMA modified with PCS. The results indicated that contamination led to binder softening and a notable decline in tensile strength and stiffness [11]. The mechanical performance of asphalt concrete is conducted under exposure to motor oil and gasoline. They found that aromatic hydrocarbons led to more severe degradation than aliphatic hydrocarbons due to stronger interaction with the binder, reducing tensile strength by up to 60% [12]. The inclusion of petroleum-contaminated soil (PCS) in HMA. They found that ITS decreased significantly when the PCS content exceeded 15%. Mixes with up to 15% PCS maintained acceptable performance levels for low-volume roads [13]. In this research we will study the effect of hot weather in Iraq at summer on asphalt roads subjected to benzene dropped by vehicles.

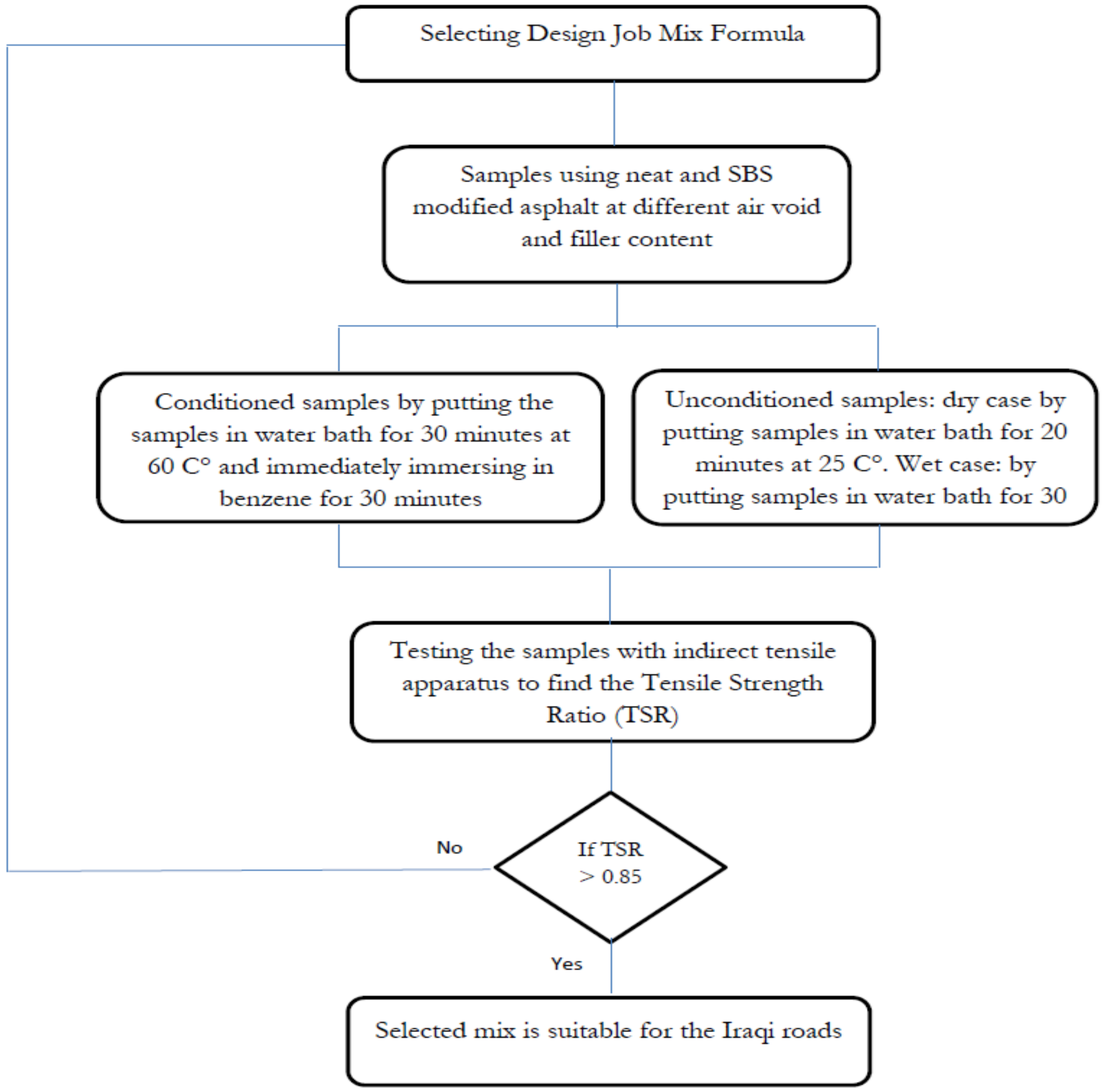

Figure 1 Methodology of work.

2. MATERIALS

3.1. Binder

The neat bitumen (AC 40-50) used in this study is obtained from the al Doura refinery. The main physical properties according to ASTM and State Corporation for Roads and Bridges (SCRB-R9) [14] to [17] are summarized in Table 1 and Figure 1.

3.2. Styrene butadiene styrene

Styrene-Butadiene-Styrene (SBS) is a thermoplastic elastomer for use modifying asphalt to produce high performance polymer-modified bitumen. When Styrene-Butadiene-Styrene added in asphalt, an elastomeric network created which dramatically improving the asphalt's flexibility, elasticity, and resistance to deformation. These benefits because high temperature rutting improves, low temperature cracking reduces, and high traffic loading fatigues are reasons to use SBS-modified asphalt. This type of asphalt is used for paving and preserving highways, airport runways, bridges and all other pavements required highest road performance [18].

3.3. Modified binder

Styrene Butadiene Styrene (SBS) is used as the modifying polymer. The addition of 4% by weight of Styrene Butadiene Styrene polymers to a neat asphalt binder (AC 40-50) would change the performance grades from (64-16) to (76-16). Physical properties are presented in Table 2.

3.4. Aggregates

Crushed aggregates from Al-Nibaie quarry is utilized in this work which is commonly used for HMA in Baghdad city. Physical and Chemical properties of aggregates are shown in Tables 3 and 4 [19] to [25].

3.5. Filler

The filler used in this research is limestone dust brought from the lime factory in Karbala' governorate. The physical properties are shown in Tables 1-5.

Table 1 Properties of asphalt cement, according to ASTM requirements and Iraqi specifications.

Test	ASTM Designation	Units	PENETRATION GRADE 40/50	
			TEST RESULTS	SCRB SPECIFICATION
penetration	D-5	1/10 mm	44	40-50
Rotational viscometer	D-4402	Pas.sec	0.56 @135°C	……
			0.19 @165°C	
ductility	D-113	cm	>100	>100
Flash point	D-92	°C	275	Min.232
Specific gravity	D-70	…	1.049	……
Softening point	D-36	°C	51	……
Residue from thin film oven test, D-1754				
% Retained penetration of original	D-5	1/10 mm	67.4	> 55%
Mass loss	D-1754	%	0.38	<0.75
Ductility of residue	D-113	cm	45	>25

Table 2 Properties of modified asphalt cement, according to ASTM requirement and Iraqi specifications.

Test	ASTM Designation	Units	Original 40-50	Modified with 4% SBS	SCRB Spec.
penetration	D-5	1/10 mm	44	27	40-50
Rotational viscometer	D-4402	Pas.sec	0.56 @135°C	1.67 @135°C	……
			0.19 @165°C	0.41 @165°C	
ductility	D-113	cm	>100		>100
Flash point	D-92	°C	275	265	Min.232
Specific gravity	D-70	…	1.049	1.01	……
Softening point	D-36	°C	51	62	……
Residue from the oven test D-1754					
% Retained penetration of original	D-5	1/10 mm	67.4		> 55%
Mass loss	D-1754	%	0.38		<0.75
Ductility of residue	D-113	cm	45		>25

Table 3 Physical properties of Al-Nibaie aggregate.

No	Laboratory test	Designation	Test Results	SCRB Limits
1	coarse aggregate % fractured particles (Angularity %)	ASTM D-5821	97	90 Min
2	Fine aggregate angularity, %	T-304	61	45 Min.
3	Percent flat and elongated Particles, %	ASTM D-4791	1.6	10 Max.
4	Clay content by Sand equivalent,%	T-176	51	45 Min.
5	Toughness, by (Los Angeles abrasion)	T-96	15.28	30 Max.
6	Soundness loss by sodium sulfate solution,%	T-104	2.46	12 Max.
7	Deleterious materials, %	T-112	0.5	3 Max.

Table 4 Chemical composition of Al-Nibaie (national center for construction laboratories and researches).

Chemical compound	Content%
Silica, SiO_2	84.73
Lime,CaO	3.37
Magnwasia,MgO	0.53
Sulphuric Anhydride,SO	2.9
Alumina,AlO	0.62
Ferric Oxide,FeO	0.58
Loss on Ignition	6.25
Total	98.98
Mineral Composition	
Quartz	81.2
Calcite	10.02

Table 5 Physical Properties of limestone filler.

Property	Test result
Specific gravity	2.73
% Passing sieve No.200 (0.075mm)	98
Specific surface area	307.3

3.6. Benzene

Traditional normal Iraqi benzene from station with chemical and physical properties as shown in Table 6.

Table 6 Ministry of Oil–Iraq. Technical specifications for gasoline production in Iraqi refineries Doura

Property	Typical Value / Range
Appearance	Clear, transparent liquid
Odor	Strong, characteristic odor
Physical State	Liquid (at room temperature)
Specific Gravity (at 15°C)	0.70 – 0.76 g/cm³
Density (kg/m³)	700 – 760 kg/m³
Boiling Range	30°C – 200°C
Flash Point	Below -40°C
Solubility in Water	Insoluble (slightly soluble)
Color	Colorless to pale yellow
Octane Number (RON)	87 – 91
Sulfur Content	< 50 ppm
Aromatic Content	25 – 35% by volume
Olefins Content	5 – 15% by volume
Benzene Content	< 1% by volume
Oxygenates	0 – 2% by volume
Flammability Limits (in air)	1.2% – 7.8% (v/v)
Chemical Stability	Stable under normal conditions
Combustion Products	CO_2, H_2O, CO, NO_x

4. DESIGN JOB MIX

Marshall Mix design method is selected to find the optimum binder content (O.B.C) for the reference mix. The job mix formula is selected within the state corporation of roads and bridges (SCRB) limits as shown in Figure 2. Three percentages of filler are used 6%, 8% and 10% for both neat and modified mixes [26-30].

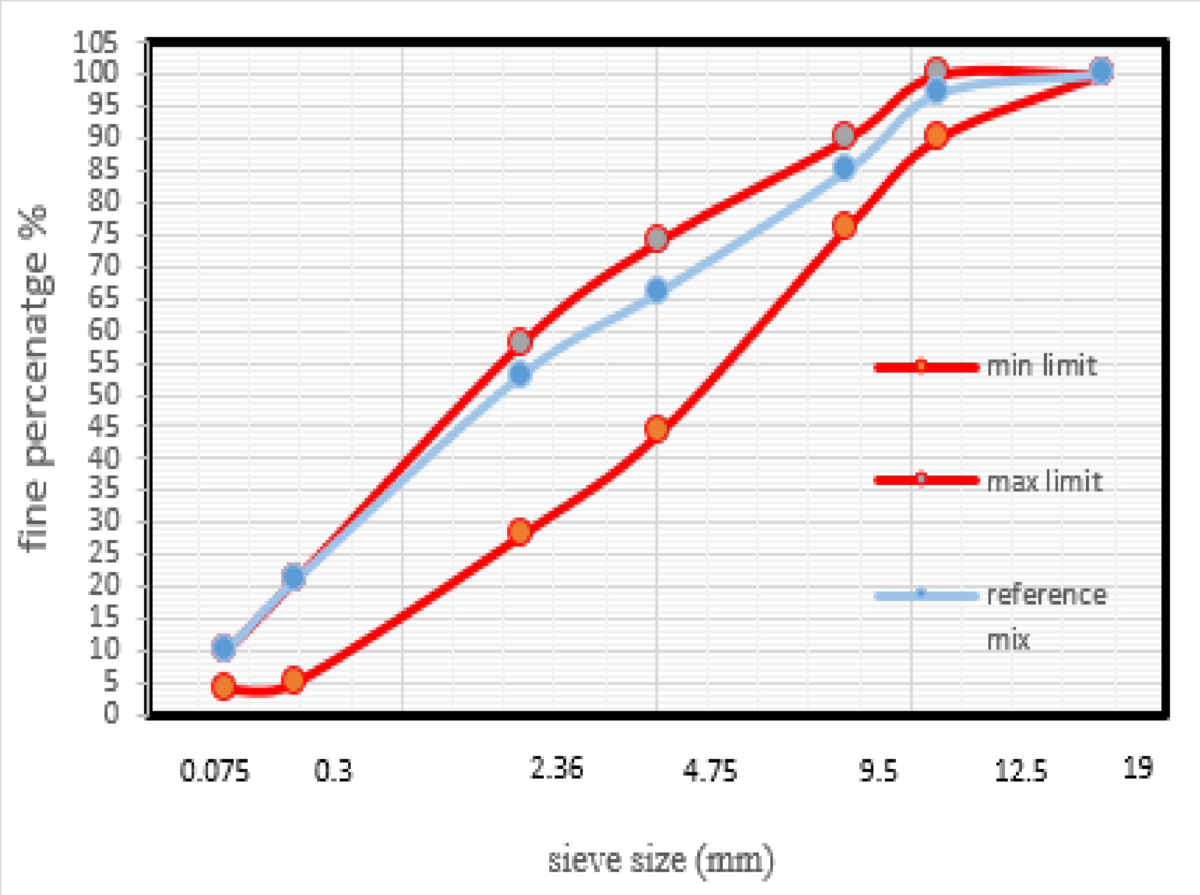

Figure 2 Design job mix formula with SCRB limits.

5. SAMPLES PREPERATION AND METHOD OF CONDITIONING

Thirty-six marshal specimens are prepared for the reference mix design at three different air void content, 4%, 6% and 8% which represent three different service life of roads. Twelve samples are prepared for each AV content, six samples using neat asphalt (AC40-50) and six samples with modified asphalt using (4%SBS+ AC 40-50) to be tested by indirect tensile strength (ITS) apparatus. Six samples of each group are prepared to be tested on dry condition while the other six samples are prepared to be tested after wet condition. For the unconditioned case, the samples are kept in water bath for 30 minutes at 25 C° and then tested by ITS apparatus to represent the dry condition and the wet samples are kept in water bath of 60 C° for 24 hours and then tested by ITS apparatus to represent the dry condition [31, 32]. On the other hand, the conditioned case for this research represented by putting the samples in water bath at 60 C° for 30 minutes to simulate the hot weather in Iraq at summer, after that the samples are took off from the water bath and put in can full of solvent (benzene) for 30 minutes. Then, the samples are directly tested by ITS apparatus. Once the specimens are put in the benzene, a quick boiling can be seen by small bubbles at the surface [33, 34]. After 30 minutes of conditioning an erosion of the binder can be seen at the surface due to solvent effect of benzene. The results are recorded for each condition to study the effect of benzene on HMA samples. Figures 3 and 4 shows the indirect tensile apparatus and the samples after testing.

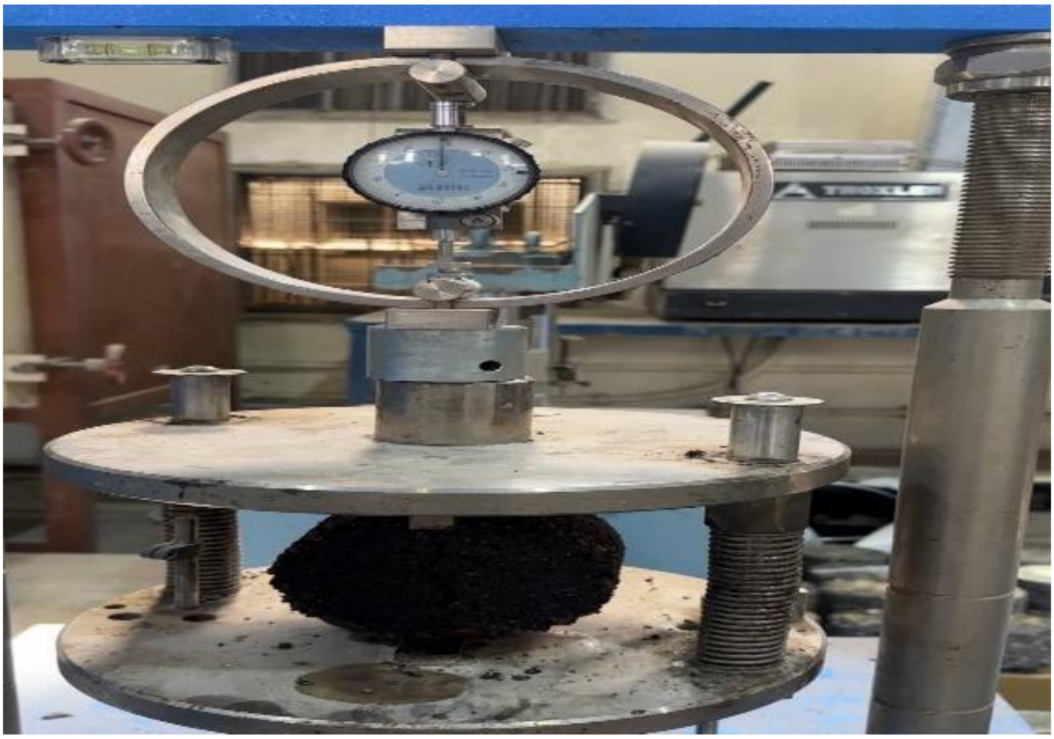

Figure 3 indirect tensile strength apparatus.

Figure 4 Samples after conditioning and testing.

6. RESULTS AND DISCUSSION

As the air void content plays major role in the expansion and contraction of asphalt mastic in atmosphere changes, three different air void content selected to measure the effect of air void content on the ITS of HMA subjected to solvent effect. Generally, from the collected results in figures 5, 6 and 7, it can be concluded that samples with 4% air void content showed better performance than samples with 6% and 8% void content. For unconditioned samples (not soaked in benzene), neat and modified asphalt samples showed that TSR results are increased by 2-3% when the air void decreased from 8% to 6% and from 6% to 4%. On the other hand, the conditioned samples (soaked in benzene) showed lower results due to the solvent effect on the HMA. For samples conditioned with neat asphalt have lower TSR about 10-11% than unconditioned samples. The samples using modified asphalt have TSR about 10% more than the samples using neat asphalt. On the other hand, the conditioned samples (soaked in benzene) using modified asphalt have TSR about 5% less than the unconditioned samples when the AV content is 4% on the other side, the conditioned samples have about 7 % and 10 % TSR less than the unconditioned samples when the AV content is 6% and 8 % respectively. Effect of filler content can be observed where increasing the filler content from 6 to 8% and from 8 to 10% exhibits an increment about 2-3% in TSR results regardless the conditioning status. For the conditioning samples with higher filler content 10% with modified asphalt at 4% air void content shows better performance with 94% TSR. The detrimental effect of benzene on the stability of asphalt is caused by its high aromatic solvency and its ability to separate the hydrocarbon bonding structure of the binder. The benzene easily dissolves the lighter maltene fractions, and destroys the structural balance that is necessary to stabilize asphaltene in the colloidal system of the binder. The dissolution of the binder reduces viscosity and softening point, effectively removing the stiffness and internal adhesion of the binder that worked with aggregate particles to provide internal cohesive strength. At a molecular level, this process weakens the forces that held the aggregates together. Consequently, pavements with meaningful exposure to benzene are often immediately raveled, stripped, and otherwise surface-damaged.

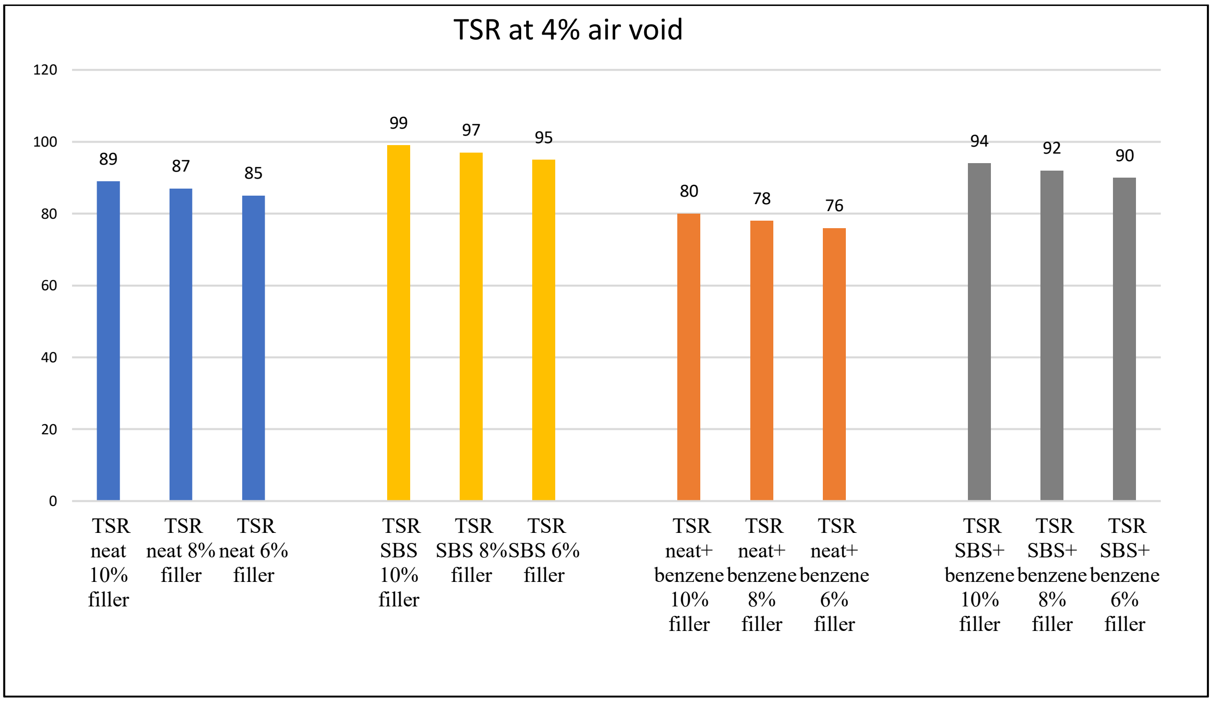

Figure 5 Samples after conditioning and testing at 4% air void.

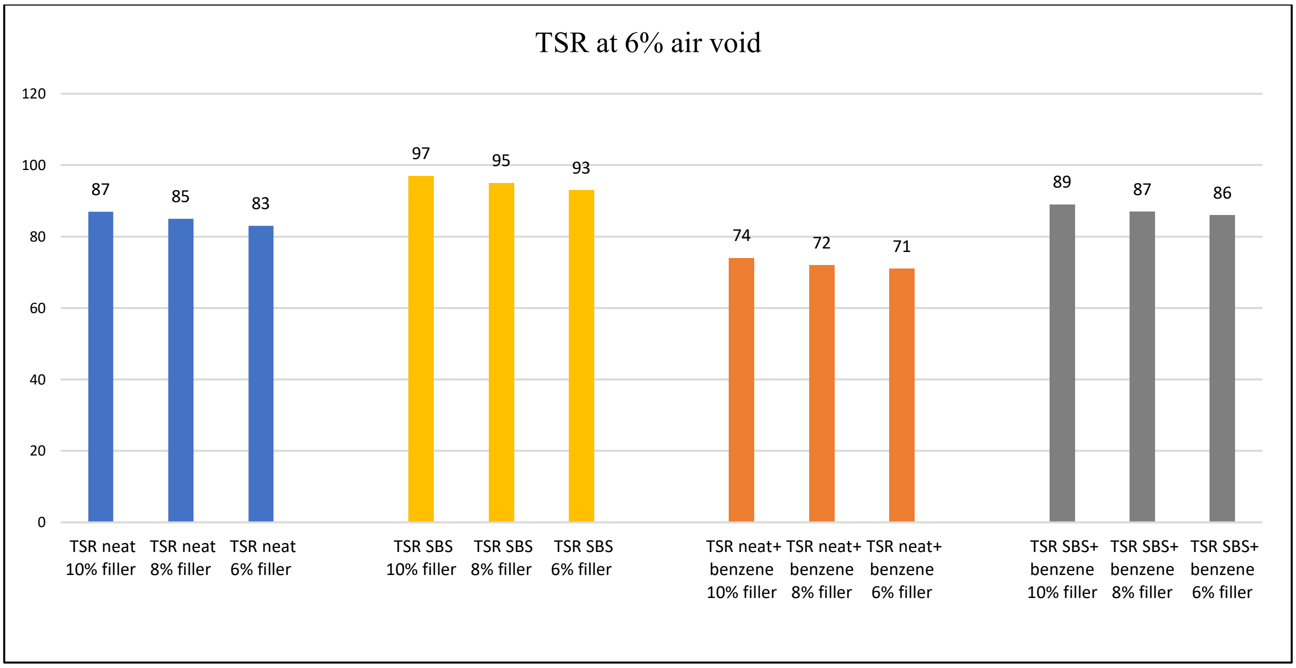

Figure 6 Samples after conditioning and testing at 6% air void.

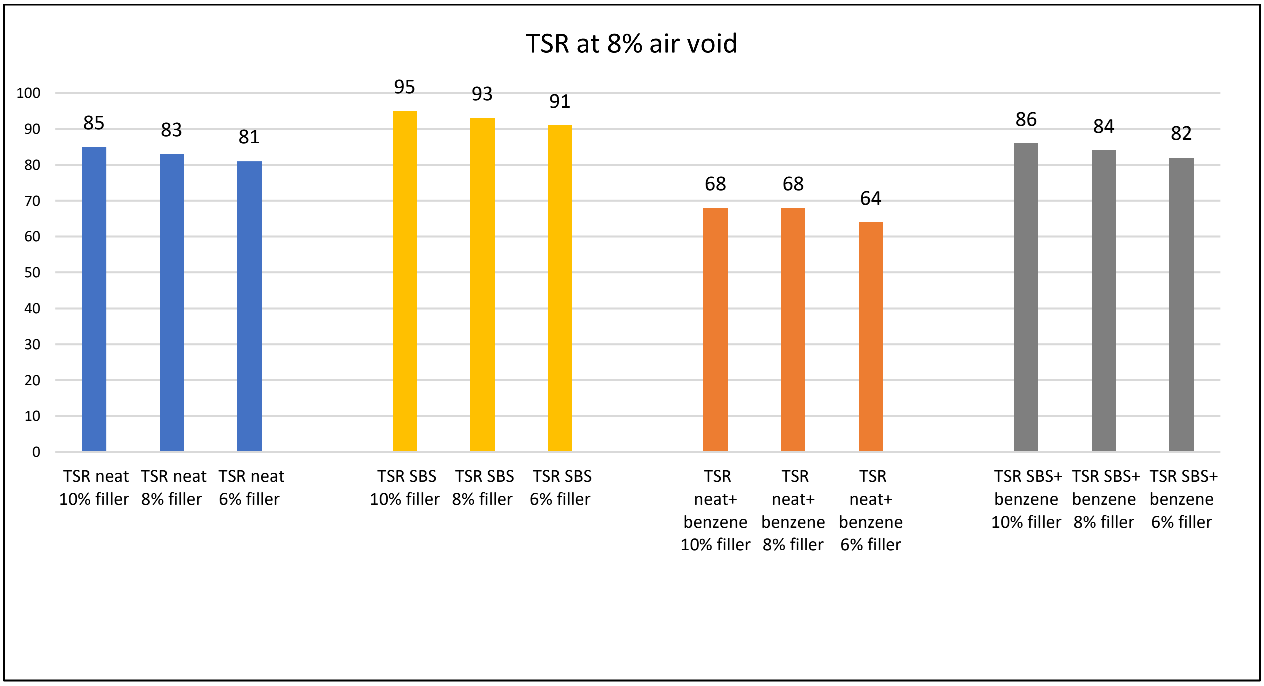

Figure 7 Samples after conditioning and testing at 8% air void.

7. CONCLUSIONS

The indirect tensile strength results show a comprehensible indication regarding the effect of air void content and type of asphalt on the moisture susceptibility of hot mix asphalt in hot weather. As long as the void content decreased, the mixture exhibits a better ITS results. For the unconditioned samples whether using neat or modified asphalt the tensile strength ratio increased about 3-4% when the air void content decreased from 8% to 6% and from 6% to 4%. For the conditioned samples using neat asphalt, the tensile strength ratio decreased about (9-10%), (12-15%) and (18-20%) for 4%, 6% and 8% air void content. On the other hand, for the conditioned samples using modified asphalt provides lower TSR than the unconditioned samples about 5%, 8% and 10% for 4%, 6% and 8% air void content respectively. Nevertheless, the TSR of the conditioned samples using modified asphalt are better than the same samples using neat asphalt. The effect of filler content can be clearly observed. regardless the filler percentage, as long as the filler content increased, the TSR increased and this belongs to the stiffening effect of asphalt mastic which the filler content makes the mastic more cohesive and more adhesive to the aggregate structure of HMA. Solvent (benzene) effect clearly indicates the hot mix asphalt susceptibility from the solvents by weakening the cohesion of asphalt mastic and the adhesion between the aggregates and the binding mastic. Using modified asphalt can improve the cohesion and adhesion of asphalt mastic and enhance the performance of the mix against tensile stresses. At last, it is recommended to use modified asphalt in paving Iraqi roads to sustain the high performance in their service life.

References

[1] Samer A.Naji, Alaa H.Abed. 24 (2021) 130-136 https://doi.org/10.29194/NJES.24020130
[2] Samer A.Naji, Alaa H.Abed 24 (2021) 137-143. https://doi.org/10.29194/NJES.24020137
[3] Ahmed F Al-Tameemi, Yu Wang, Amjad Albayati, Jonathan Haynes. 31 (2019) 4. https://doi.org/10.1061/(ASCE)MT.1943-5533.0002634
[4] M. Enneffati, B. Louati, K. Guidara, M. Rasheed, R. Barillé, Journal of Materials Science: Materials in Electronics, 29 (2018) 171. https://doi.org/10.1007/s10854-017-7901-7
[5] Ahmed F Al-Tameemi, Zahraa T.Al-Fayyadh, Hasan Al-Mosawe,Yu Wang,Aous A.Moyet. 11 (2025) 4. https://doi.org/10.28991/CEJ-2025-011-04-04
[6] Ding, Huang, Shu & Tang. 2673 (2019) 6. https://doi.org/10.1177/0361198119843100
[7] Yongkang Wu , Meizhu Chen , Qi Jiang , Jianwei Zhang ,Yansong Fan and Jun He. 17 (2024). 12. https://doi.org/10.3390/ma17123016
[8] Hossam F. Hassan, Amer Al Rawas , Abdel Wahid Hago, Ahmad Jamrah , Ahmed Al-Futaisi, Talal Al-Sabqi. 22 (2008) 6. https://doi.org/10.1016/j.conbuildmat.2007.01.017
[9] Rami Khamad. 3 (2015) 11. https://doi.org/10.15587/1729-4061.2015.43713
[10] M. Rasheed, et al., Journal of Advanced Biotechnology and Experimental Therapeutics, **6** (2023) 495. https://doi.org/10.5455/jabet.2023.d144
[11] M. Rasheed, O. Y. Mohammed, S. Shihab, A. Al-Adili, Journal of Physics: Conference Series, 1795 (2021) 012042. https://doi.org/10.1088/1742-6596/1795/1/012042
[12] Ming Lv, Hongjun Li ,Shiping Zhang, Wenchang Liu, Hongchao Zhang, Hongwei Lin, Mutian Sun. 12 (2024) 2. https://doi.org/10.3390/pr12020403
[13] Hassan, H. F., & Al-Rawas, A. A. 2205 (2011) 1. https://doi.org/10.3141/2205-02
[14] E. Kadri, et al., Journal of Alloys and Compounds, 705 (2017) 708. https://doi.org/10.1016/j.jallcom.2017.02.117
[15] A. Jaber, M. Ismael, T. Rashid, M. A. Sarhan, M. Rasheed, I. M. Sala, Eureka: Physics and Engineering, 4 (2023) 29. https://doi.org/10.21303/2461-4262.2023.002770

[16] D. Kherifi, A. Keziz, M. Rasheed, A. Oueslati, Ceramics International, 50 (2024) 1. https://doi.org/10.1016/j.ceramint.2024.05.317
[17] A. Zubaidi, L. M. Asaad, I. Alshalal, M. Rasheed, Journal of the Mechanical Behavior of Materials, 32 (2023) 1. https://doi.org/10.1515/jmbm-2022-0302
[18] Mohammed H.abduljabbar., Amjad Albayati. 2 (2019) 100012. https://doi.org/10.1016/j.rineng.2019.100012
[19] K. K. Khudair, F. Boudou, A. Mohammed, A. Sehmi, A. Belakredar, M. S. Ibrahim, Experimental and Theoretical NANOTECHNOLOGY, **10** (2026) 869. https://doi.org/10.56053/10.S.869
[20] M. S. Ibrahim, T. T. Issa, B. Yaqoob, E. N. Fayyadh, A. Rashid, R. S. Mahmood, Experimental and Theoretical NANOTECHNOLOGY, **10** (2026) 887. https://doi.org/10.56053/10.S.887
[21] H. M. I. Al-Zuhairi, I. Alshalal, H. H. Abbood, M. Al Nuaimi, Experimental and Theoretical NANOTECHNOLOGY, **10** (2026) 855. https://doi.org/10.56053/10.S.855
[22] H. M. I. Al-Zuhairi, I. Alshalal, H. H. Abbood, M. Al Nuaimi, Experimental and Theoretical NANOTECHNOLOGY, **10** (2026) 1093. https://doi.org/10.56053/10.S.1093
[23] F. Boudou, A. E. Sabar, M. I. Majeed, A. M. Ibraham, R. Jamal, A. Rashid, A. Belakredar, M. Bendahmane-Salmi, M. RASHEED, R. RASHEED, T. Saidani, H. D. Al-Bahadli, Experimental and Theoretical NANOTECHNOLOGY, **10** (2026) 821. https://doi.org/10.56053/10.S.821
[24] A. R. J. Katae, H. H. Hussein, A. S. Jaber, M. A. Sarhan, M. RASHEED, Experimental and Theoretical NANOTECHNOLOGY, **10** (2026) 725. https://doi.org/10.56053/10.2.725
[25] G. E. Alkinani, A. R. J. Katae, M. RASHEED, Experimental and Theoretical NANOTECHNOLOGY, 10 (2026) 1027. https://doi.org/10.56053/10.S.1027
[26] O. Alabdali, A. Guessab, *Filomat*, 34 (2020) 601. https://doi.org/10.2298/FIL2002601A
[27] A. J. Hussein, M. N. Al-Darraji, M. Rasheed, M. A. Sarhan, IOP Conference Series: Earth and Environmental Science, 1262 (2023) 022005. https://doi.org/10.1088/1755-1315/1262/2/022005
[28] M. Enneffati, M. Rasheed, B. Louati, K. Guidara, R. Barillé, Optical and Quantum Electronics, 51 (2019) 1. https://doi.org/10.1007/s11082-019-2015-5
[29] A. A. Abdulrahman, M. Rasheed, S. Shihab, Journal of Physics: Conference Series, 1879 (2021) 022118. https://doi.org/10.1088/1742-6596/1879/2/022118
[30] F. Dkhilalli, S. Megdiche, K. Guidara, M. Rasheed, R. Barillé, M. Megdiche, Ionics, 24 (2018) 169. https://doi.org/10.1007/s11581-017-2193-8
[31] H. K. Aity, E. Dhahri, M. Rasheed, Ceramics International, 50 (2024) 54666. https://doi.org/10.1016/j.ceramint.2024.10.324
[32] T. Saidani, M. Rasheed, I. Alshalal, A. A. Rashed, M. A. Sarhan, R. Barillé, Research on Engineering Structures and Materials, 9 (2023) 1. https://doi.org/10.17515/resm2023.21ma0922rs
[33] M. Rasheed, S. Shihab, O. Alabdali, A. Rashid, T. Rashid, Journal of Physics: Conference Series, 1999 (2021) 012077. https://doi.org/10.1088/1742-6596/1999/1/012077
[34] M. Rasheed, R. Barillé, Journal of Alloys and Compounds, 728 (2017) 1186. https://doi.org/10.1016/j.jallcom.2017.09.084