Effect of Hot Glue Additive on the Rheological Properties of Asphalt Cement and Mixtures Performance

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Abstract—**In general, the physical and rheological properties of asphalt binder are directly affecting the resistance of asphalt mix to the permanent deformation (rutting), water damage, and thermal cracking. The degradation in these properties leads to severe distresses that appear in the pavement and, consequently, make the repair and maintenance very expensive. Since the modified-asphalt cement may help to minimize such aforementioned distresses, this research is established for this purpose. It aims to investigate the physical and rheological properties of modified-asphalt cement with silicone, dense silicone rubber, and ethylene propylene diene monomer rubber. Five contents for each type of hot glue are investigated; 0.4, 0.8, 1.2, 1.6, and 2% of the asphalt cement weight. Conventional asphalt cement tests such as penetration, softening point, dynamic viscosity, and ductility tests are conducted to evaluate the hot glue-modified asphalt cement properties. Moreover, the Marshall and indirect tensile strength tests are conducted to examine the effect of hot glue on the performance of the asphalt mixtures at concentrations of 0.8 and 1.6% of the asphalt cement weight. The results show that the hot glue-modified asphalt cement leads to an increase in the hardness and consistency, and a reduction in the temperature susceptibility of asphalt cement. These features lead to better Marshall stability and tensile strength ratio, as compared with the standard asphalt cement mixture.**

Index Terms—**Hot glue, Silicone, Dense silicone rubber, Ethylene propylene diene monomer rubber, Modified asphalt cement, Indirect tensile strength, Marshall Stiffness.**

I. Introduction

In Iraq, the asphalt pavement has significant distress due to both climatic conditions and the growing traffic volume of heavy trucks; accumulation of these factors with inadequate maintenance has caused distresses on pavement surface in recent years. Due to this, it is essential to modify asphalt cement with materials that can help achieve the best performance of the asphalt to improve its qualities.

Lewandowski (1994) summarized the main reasons that led to the modification of asphalt cement with various types of additives that play a role in obtaining softer mixtures to resist cracking at low temperatures or stiffer blends to reduce rutting at high temperatures or to improve the fatigue resistance of mixtures or to increase the stability and strength of mixtures. According to King and King (1986), the selection of an asphalt cement modifier for a given project may be influenced by various other factors such as cost, availability, expected performance, and workability.

Fernando and Guirguis (1983) found that rubber is a great organic polymer for blending with asphalt cement to modify the type of road binder due to its inherently chemical components. The resulting binder has improved durability, distortion resistance, flexibility at low temperatures, and viscosity at high temperatures. On the other hand, Tayebali, et al. (1992) concluded that using reclaimed rubber obtained from used tires, polyethylene in the form of low density (LDPE) for asphalt cement modification performed satisfactorily. Similarly, Khodary Moalla Hamed (2010) investigated how scrap tires (Crumb rubber) affected the rheological characteristics and fatigue resistance of asphalt mixtures, comparing them to commercial polymers such as styrene-butadiene-styrene (SBS). The outcomes show a significant enhancement in the fatigue behavior of all used modifier types compared to conventional mixtures.

Kumar, Choudhary and Kumar (2019) researched the use of ethylene-propylene-diene-monomer (EPDM) rubber waste from scrapped automotive rubber parts other than tires to modify asphalt binder. The results showed that EPDM-modified binders perform better than the control (unmodified) binders in terms of rutting, fatigue, and cracking. In addition, the results of the mix performance displayed that mixtures with modified EPDM binders have enhanced stiffness, stability, and resistance to moisture damage. Al-Ani (2009) experimentally investigated rubber silicones' asphalt mixture performance. Rubber-silicone was added to asphalt cement in four different percentages (1%, 2%, 3%, and 5%). The findings indicated that Rubber-Silicone has great effects on the performance of asphalt mixture by increasing the Marshal stability and the

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flexibility properties of the mix, which appears by reducing the permanent deformation by about (30–70) %.

Zhang, Yu, and Wu (2010) verified that using the polymer to enhance the asphalt binder can reduce temperature susceptibility, permanent deformation (rutting), and fatigue cracking. However, the viscosity and stiffness of the asphalt mixture are increased by adding the polymer, which lowers its workability.

II. Experimental Program

A. Materials Characterization

The materials used in this study are locally available and currently used in road construction in Iraq.

Asphalt cement

One type of asphalt cement with a penetration grade of (40–50) was used in this study, brought from the Hal band oil refinery in northern Iraq. The qualities of asphalt must meet the parameters laid out in the Iraqi specifications. To find out the penetration, ductility, specific gravity, softening point, Flash point, and Fire point, tests were carried out. The physical properties of the asphalt samples are given in Table I.

Hot melt glue sticks

Silicones are renowned for their retention of flexibility and low compression set characteristics within one of the elastomers' widest working temperature ranges. Three different types of hot glue sticks were used in this study.

A silicone rubber rod is a round bar that made of solid silicone rubber, see the Fig.1. The red glue sticks are used to provide high levels of compressibility across a broad temperature range, have a non-stick, watertight surface, and perform well against weathering. The advantages of silicone rubber rods are unmatched by the other types of rubber. Silicone rubbers have great heat and cold resistance, fine electrical characteristics, strong chemical stability, and flame retardancy. The properties of the silicone rubber rod are given in Table II (adopted from Alibaba.com).

The black glue sticks are used for all types of weather. EPDM cords shown in the Fig.2 are highly popular due to their suitability for use in a wide variety of applications and working environments. Due to their versatility for usage in a wide range of applications and working situations, EPDM cords are very common largely due to the material's ability to combine mechanical strength with resistance, and it is widely known for its excellent resistance to weathering. This enables the EPDM solid rubber cord to deliver constant performance in both indoor and exterior applications. In addition, the tensile strength, tear resistance, and flexibility of EPDM cables are well-balanced, guaranteeing that the cord is durable and easy to use. The properties of the EPDM cords are given in Table III (adopted from the rubber company).

Transparent hot glue sticks as shown in the Fig.3 work with heat guns. It is perfect for gluing wood, paper, pottery, fabric, and other items. It dries instantly, providing a strong binding between the components. The properties of the transparent sticks are given in Table IV (adopted from Polymax Group).

TABLE I
Physical Properties of Asphalt Cement

Properties	Unit	ASTM	Test results
Penetration at (25°C, 100 g, 5 s)	0.1 mm	D5	45
Specific gravity at 25° C	-	D70	1.02
Softening point (ring and ball)	°C	D36	56.4
Ductility (25°C, 5 cm/min)	Cm	D113	138
Flash point	°C	D92	270
Fire point	°C	D92	318

TABLE II
Red Hot Glue Sticks Properties

Properties	Test results	Unit
Material	Dense Silicone Rubber Material	
Standard hardness	60±5	Shore A
Viscosity	9500 @ 193°C	Centipoises
Minimum temperature	−40	°C
Maximum temperature	+220	°C
Softening point	81	°C
Working time	70	S

TABLE III
Black Hot Glue Sticks Properties

Properties	Test results	Unit
Material	Ethylene Propylene Diene Monomer Rubber	
Standard hardness	70±5	Shore A
Viscosity	12000 @ 193°C	Centipoises
Minimum temperature	−30	°C
Maximum temperature	+150	°C
Softening point	85	°C
Working time	40	S

TABLE IV
Transparent Hot Glue Sticks Properties

Properties	Test results	Unit
Material	Silicone (VMQ)	
Standard hardness	60±5	Shore A
Viscosity	6000 @ 193°C	Centipoises
Minimum temperature	−60	°C
Maximum temperature	+230	°C
Softening point	88	°C
Working time	15	S

Aggregates

This study used the 12.5 mm maximum size dense gradation in the hot asphalt concrete wearing course mix based on the State Corporation of Roads and Bridges specifications (SORB, 2007). The coarse and fine aggregate utilized in this investigation was brought from the Darbande Zeoi quarry near Sulaymaniyah and mechanically crushed at Tanjero hot mix asphalt plant. The specification limits and selected gradation of manufactured asphalt mixtures are shown in Table V. An ordinary Portland cement with a specific gravity of (3.15) was used as a mineral filler.

B. Laboratory Specimen Preparation and Test Methods

Penetration test

The penetration test is the method used most frequently worldwide to categorize asphalt cement. The test includes

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TABLE V
Selected Combined Gradation of Aggregate and Filler According to SORB Specifications

Sieve size	Specification range	Selected gradation
1/2"	100	100
3/8"	90–100	95
No. 4	55–85	70
No. 8	32–67	50
No. 50	7–23	15
No. 200	4–10	7

measuring the vertical penetration of a standard steel needle into a bitumen sample at 25°C temperature to determine the consistency of the bitumen. 100 g of needle weight is loaded over 5 s. The needle penetration depth in the bitumen sample is 0.1 mm; therefore, the penetration unit is 0.1 mm. The penetration is a numerical representation of the bitumen's reaction to temperature changes. ASTM D5 explains how to conduct the test.

Softening point test

The asphalt cement softening point provides a measure of its thermal stability. The asphalt cement softening point is evaluated using the ring and ball method. The softening point determines the temperature at which the asphalt cement starts to flow and becomes soft enough to no longer support the weight of a metal ball. The rings and assembly are submerged to a depth of 105 ± 3 mm in a water bath, each specimen is centered on a 9.5 mm steel ball bearing weighing 3.50 ± 0.05 g, and the temperature is raised at a rate of 5 ± 0.5°C/min. The average of two temperatures at which the two balls fall and touch the base plate is recorded as the softening point. The test procedure is described in ASTM D36.

Ductility test

The asphalt cement ductility test is one of the most important tests that must be performed when constructing the road. A material's ductility refers to its ability for plastic deformation (permanent deformation) before material rupture. When two ends of a briquet specimen of the material are pulled apart at a speed of 5 cm/min ± 0.5 and at a temperature of 25 ± 0.5°C, the ductility of asphalt cement is determined by the length in centimeters (cm) to which the asphalt cement sample will stretch before breaking. The test procedure is described in ASTM D113.

Dynamic viscosity test

The viscosity test of the asphalt cement sample is one of the crucial tests on asphalt cement to be conducted before road construction. Viscosity measures the degree of fluidity of the asphalt cement sample to ensure the quality of the asphalt cement used as a binder by giving a measure of fluidity at a particular temperature. The ASTM D2171 test method describes the steps for using capillary viscometers under vacuum at 60°C to measure the dynamic viscosity of asphalt cement.

Flash and fire point test

To determine the safe mixing and application temperature ranges for a specific asphalt cement grade, the flash and fire point test is applied to asphalt cement. Using the Pensky-Martens closed cup tester, the flash and fire point of the asphalt binder were determined. The ideal rate of heating the bitumen should be 5°C/min. When the sample ignites and flashes, note the temperature at that time, which is the bitumen's Flash point. Then, heat the sample further at the same pace and apply the test flame for every 2°C rise. Note the temperature at this moment, which is the bitumen fire point, when the material catches fire and burns for at least 5 s. The test procedure is described in ASTM D92.

Fig. 1. Red hot glue sticks.

Fig. 2. Black hot glue sticks.

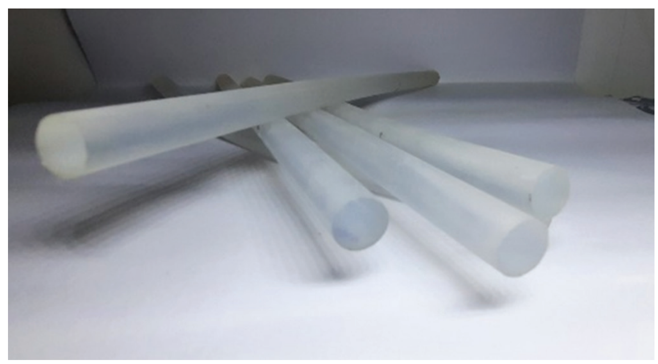

Fig. 3. Transparent hot glue sticks.

Resistance to plastic flow (Marshall method)

The method covers the measurement of the resistance to plastic flow of cylindrical specimens of bituminous paving mixture loaded on the lateral surface by means of the Marshall apparatus according to (ASTM D1559). The prepared mixture is placed in preheated mold (4 in) (101. 6 mm) in diameter by (3 in) (76. 2 mm) in height, and compacted with a hammer of 10 lb. (4. 536 kg) sliding weight, and a free fall of (18 in) (457.2 mm) on the top and bottom of each specimen. The specimens are then left to cool at room temperature for 24 h. Marshall stability and flow tests are performed on each specimen according to the method described by ASTM D-1559. The cylindrical specimen is placed in a water bath at 60°C for 30–40 min, then compressed on the lateral surface at a rate of 2 in/min (50.8 mm/min) until the maximum load resistance and corresponding flow value is recorded. Three specimens for each combination are prepared and the average results are reported. The bulk specific gravity is determined for each specimen in accordance with ASTM D-2726.

Indirect tensile strength

Indirect tensile testing was performed to evaluate the moisture susceptibility of asphalt mixtures according to AASHTO T283 test procedure. Six specimens of each mix were prepared and divided into two groups. The first group of specimens was placed at 25°C for 2 h to measure the tensile strength at dry conditions. The indirect tensile strength is the maximum tensile stress calculated from the peak load applied at break and the dimensions of the specimen according to the following equation:

$$\sigma_{IDT} = \frac{2000\,P_{max.}}{2tD} \quad (1)$$

Where σ_{IDT} is indirect tensile strength (kPa), P_{max} is peak load (N), t is specimen thickness (mm), and D is specimen diameter (mm).

The second group of specimens was put in a water bath of 60°C for 24 h before being conditioned in a 25°C of water bath for 2 h. The indirect tensile strength is the maximum tensile stress calculated from the peak load applied at break and the dimensions of the specimen according to the following equation:

$$T.S.R = \frac{\sigma_{IDT-Wet}}{\sigma_{IDT-dry}} \quad (2)$$

Where $\sigma_{IDT-Wet}$ is the indirect tensile strength at wet condition (kPa), and $\sigma_{IDT-dry}$

$\sigma_{IDT-dry}$ is the indirect tensile strength at dry condition (kPa).

C. Testing Methodology

To achieve the objectives of this study, three different types of hot glue sticks were added with five different content (0.4%, 0.8%, 1.2%, 1.6%, and 2.0%) to the asphalt cement, the research methodology has been divided and performed into two stages: first, evaluation of asphalt cement properties with different types and contents of hot glue, and second, evaluation of the mixture performance, such as Marshall stability flow and stiffness of asphalt cement with optimum hot glue content for each type. The research methodology of the present study is presented stepwise in the form of the flowchart, as shown in Fig. 4.

III. Results and Discussion

A. Evaluation of Asphalt Cement Properties

Three types of hot glues (transparent sticks made from silicone, red sticks made from silicone dense silicone rubber, and black sticks made from ethylene propylene diene monomer rubber) were added with five different percentages (0.4, 0.8, 1.2, 1.6, and 2.0%) to the asphalt cement. The influence of adding hot glue on the physical properties of asphalt cement samples was instigated. Fig. 5 is representing the relationship between the penetration values and hot glue content. It is observed that a decrease in penetration values with increasing hot glue content, this dramatic decrease was due to the base asphalt cement becoming stiffer with an increase in the hot glue content. Furthermore, it is noted in Fig. 6 that adding hot glue enhances the softening point of asphalt cement.

The ductility of asphalt cement at a temperature of 25°C drops sharply with increased hot glue content, as shown in Fig. 7. This can be attributed to the hot glue reducing the homogeneity of the structure and thereby weakening the ductility of asphalt cement, whereas the dynamic viscosity of the asphalt cement becomes greater with an increase in the hot glue content at test temperature (60°C), as shown in Fig. 8. The increase in viscosity is a result of the hardening

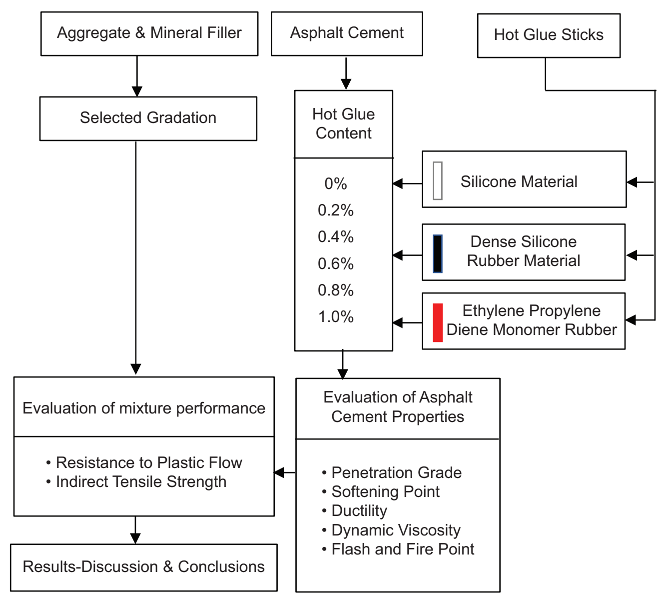

Fig. 4. The flow chart of the study

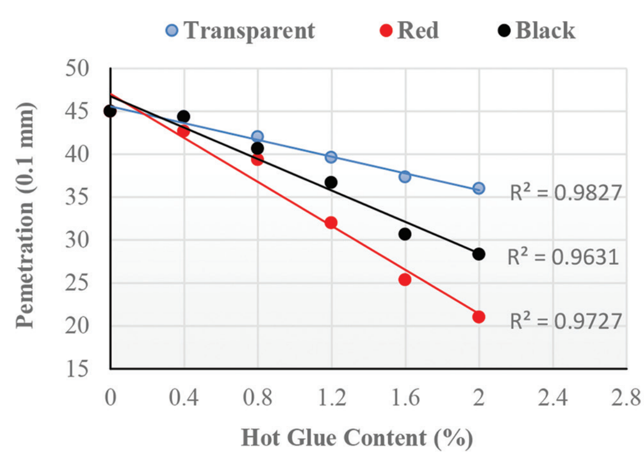

Fig. 5. Effect of hot glue content on penetration of asphalt cement.

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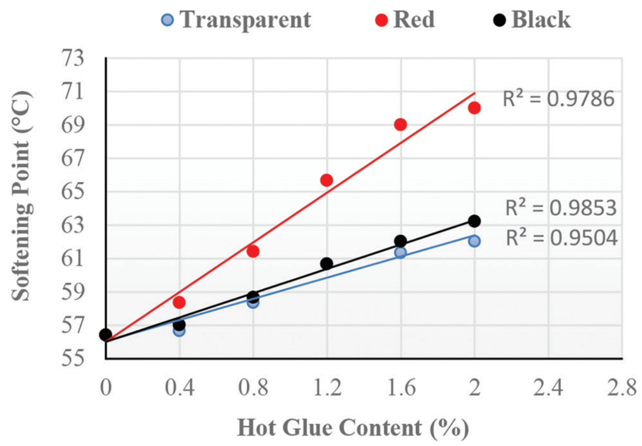

Fig. 6. Effect of hot glue content on softening point of asphalt cement.

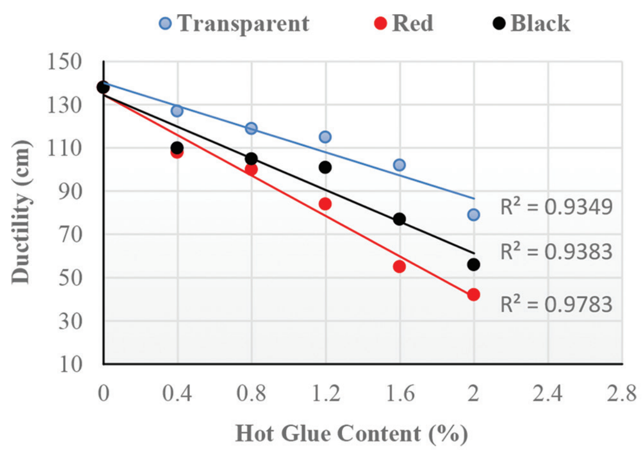

Fig. 7. Effect of hot glue content on ductility of asphalt cement.

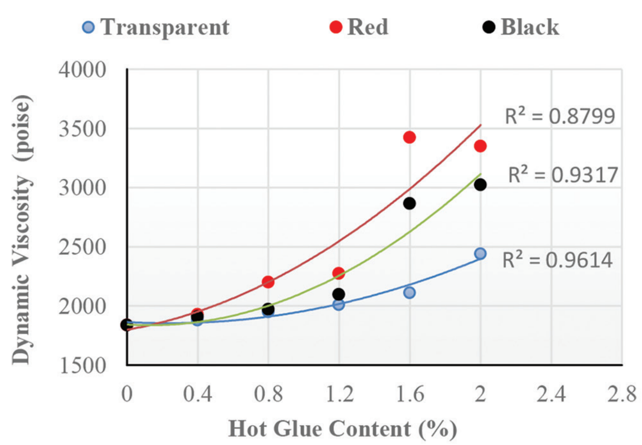

Fig. 8. Effect of hot glue content on dynamic viscosity of asphalt cement.

due to adding the hot glue. The increased viscosity of asphalt cement might be due to the better dispersion of the hot glue in the asphalt cement, which increases the bonding strength by restricting the flow of asphalt and making it harder.

The flash and fire points of asphalt cement samples with various hot glue content are shown in Figs. 9 and 10, respectively. The results showed that when the hot glue content in the asphalt cement increased, the flash, and fire

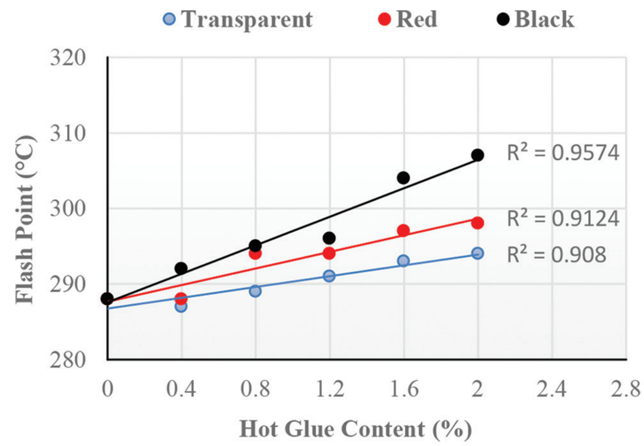

Fig. 9. Effect of hot glue content on flash point of asphalt cement.

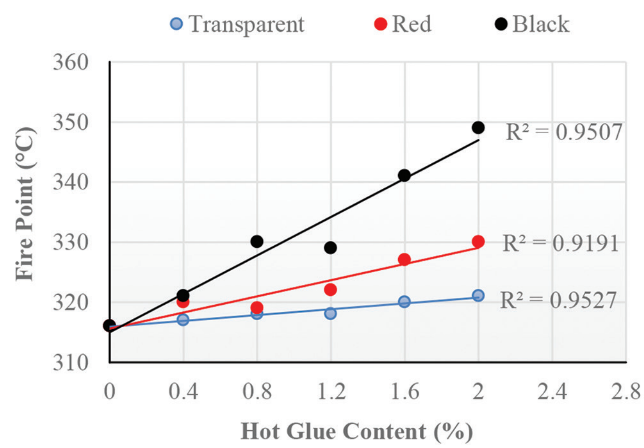

Fig. 10. Effect of hot glue content on fire point of asphalt cement.

TABLE VI
Marsh all Test Results

Marshall properties	Units	Asphalt content %				
		4.0	4.5	5.0	5.5	6.0
Marshall stability	KN	8.57	9.857	11.921	12.28	11.479
Marshall flow	mm	2.935	2.988	3.019	3.532	5.882
Bulk density	g/cm^3	2.202	2.290	2.311	2.318	2.280
Air voids	%	5.865	5.681	4.367	3.412	2.012
Marshall stiffness	KN/mm	2.868	3.259	3.822	3.477	1.952

points increased as compared with the conventional samples of the asphalt cement. This is because some of the asphalt cement was replaced by hot glue, indicating that more heat will be needed to release the volatile components in the modified asphalt cement.

B. Evaluation of Mixture Performance

According to the adopted gradation, several specimens were prepared using various percentages of asphalt cement content ranging from (4–6) % at an increment of 0.5% blended with the aggregates and Portland cement filler. The Marshall test has determined the properties of asphalt mixtures such as the Marshall stability, flow value, percentage of air voids, and Marshall Stiffness. The results are represented in Table VI which showed the optimum asphalt contents equal to 5.2%.

The effect of hot glue on the performance of hot mix asphalt (HMA) was evaluated using the optimum asphalt content mixed with three different types of hot glue sticks (Silicone, Dense silicone rubber, and Ethylene propylene diene monomer rubber) added by two contents (0.8% and 1.6%) of the total weight of the asphalt cement. The results of the Marshall test are shown in Figs. 11-14. According to the results, the performance of the mixtures for all types of hot glue showed improvement in Marshall stability, Marshall flow, and Marshall stiffness, whereas the air voids increased

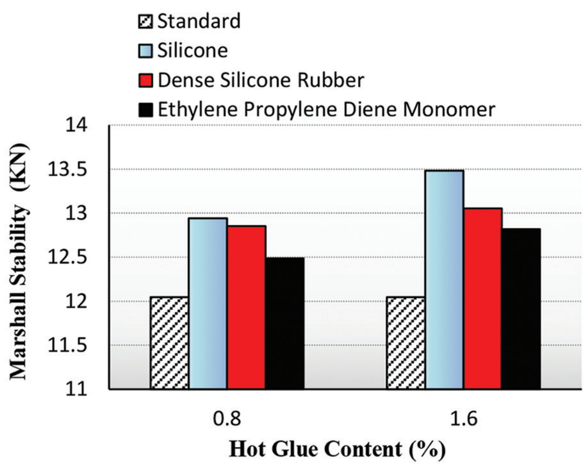

Fig. 11. Effect of hot glue types on Marshall stability of the mixture.

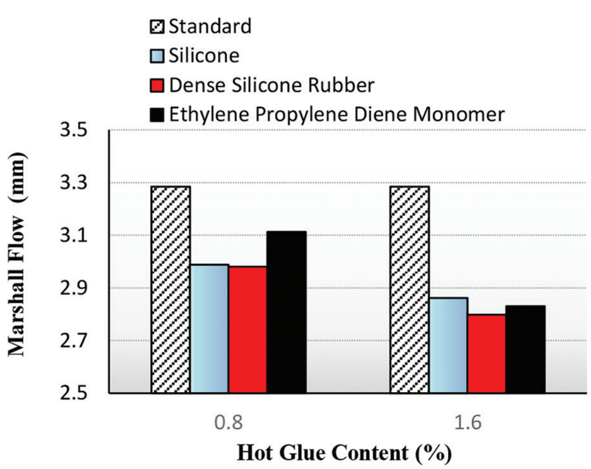

Fig. 12. Effect of hot glue types on Marshall flow of the mixture.

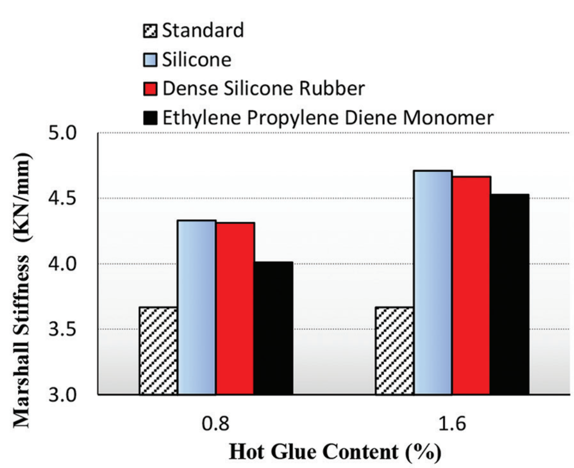

Fig. 13. Effect of hot glue types on Marshall stiffness of the mixture.

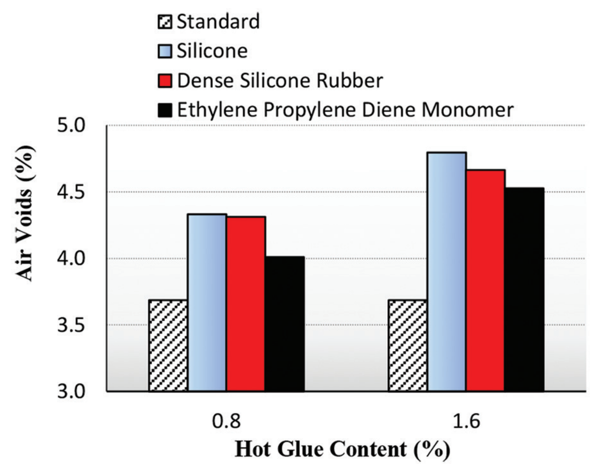

Fig. 14. Effect of hot glue types on air voids of the mixture.

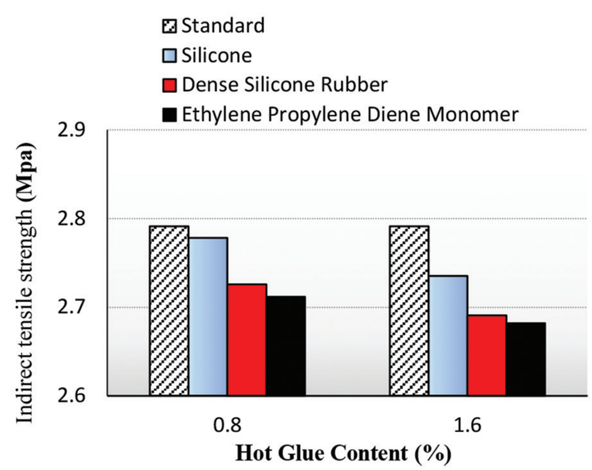

Fig. 15. Effect of hot glue types on indirect tensile strength (unconditioned).

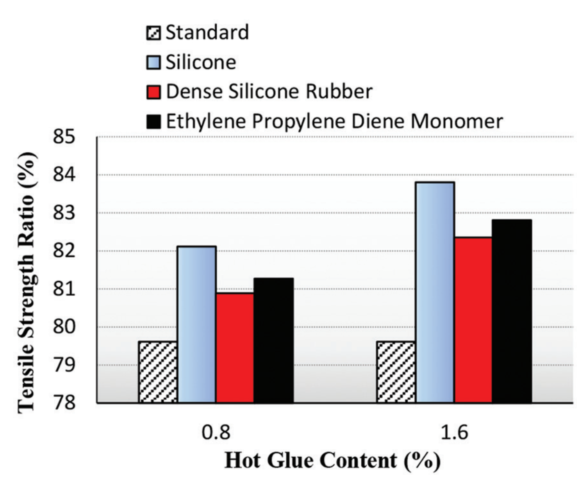

Fig. 16. Effect of hot glue types on tensile strength ratio.

TABLE VII
Indirect Tensile Strength Results for Different types and contents of hot glue

Hot glue content %	Properties	Standard	Hot glue type		
			Silicone	Dense silicone rubber	Ethylene propylene diene monomer rubber
0.8%	Indirect tensile strength – Unconditioned (MPa)	2.791	2.778	2.726	2.712
	Indirect tensile strength – Conditioned (MPa)	2.222	2.281	2.205	2.204
	Tensile strength ratio (%)	79.61	82.11	80.89	81.27
1.6%	Indirect tensile strength – Unconditioned (MPa)	2.791	2.735	2.691	2.682
	Indirect tensile strength – Conditioned (MPa)	2.222	2.292	2.216	2.221
	Tensile strength ratio (%)	79.61	83.80	82.35	82.81

as compared with the standard mixture. This can be due to an increase in viscosity which resulted from the hardening effect of hot glue. This increase in viscosity reduces softening and bleeding problems for asphalt materials at high temperatures, and also, it helps strengthen adhesion with aggregates and increases the stability of the mixture.

The indirect tensile test results are represented in Figs. 15 and 16. The findings indicated that the addition of the hot glue decreased the tensile behavior of the mixture. This can be attributed to the presence of hot glue resulted in decreasing the ability of modified asphalt cement to stretch. Since the hot glue is typically water-resistant, the mixture's tensile strength ratio improved reasonably compared to the standard mixture. The results of the indirect tensile strength for conditioned and unconditioned cases are shown in Table VII.

IV. Conclusions

In this study, the evaluation of the asphalt cement was presented according to the conventional physical and rheological properties of asphalt cement by adding hot glue sticks (silicone, dense silicone rubber, and ethylene propylene diene monomer rubber). Test data obtained from the testing program yields the following outcomes:

1. Results of physical properties showed that the addition of silicone, dense silicone rubber, and ethylene propylene diene monomer rubber into asphalt cement led to a decrease in penetration measurements, whereas the flash and softening points increased, implying the improvement of temperature susceptibility and the consistency asphalt cement.
2. The modified asphalt cement with dense silicone rubber, ethylene propylene diene monomer rubber up to a percentage of 0.8%, and silicone modified asphalt cement up to a percentage of 1.6%, demonstrated significant high adhesion performance and acceptable ductility values.
3. The addition of hot glue into asphalt cement resulted in a significant increase in dynamic viscosity, indicating an improvement in the stiffness and hardness of the modified asphalt cement.
4. The Marshall stability and Marshall stiffness improved by 12% and 28%, respectively, in asphalt cement modified by 1.6% silicon content, which had the best performance of the asphalt mixture as compared with the other types of hot glue.
5. Even though the indirect tensile strength decreased by adding 0.8% and 1.6% of hot glue into modified mixtures, the tensile strength ratio was slightly enhanced compared with the standard mixture.

V. Recommendations

1. Further work is required to investigate the effect of chemical compositions of the different types of hot glues on the performance of hot mix asphalt.
2. Additional research is needed to study the effect of hot glue properties on the resistance of the mixture to low-temperature cracking, rutting, and fatigue.

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