Impact of Preparing HMA with Modified Asphalt Cement on Moisture and Temperature Susceptibility

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ABSTRACT

Many researchers tried to prevent or reduce moisture damage and its sensitivity to temperature to improving the performance of hot mix asphalt because it is decreasing the functional and structural life of fixable pavement due to the moisture damage had exposed to it.
The main objective of this study is to inspect the effect of (fly ash “3%, 6%, 12%”, hydrated lime”5%, 10%, 20%” and silica fumes”1%, 2%, 4%) referring to previous research by the net weight asphalt cement as a modified material on the moisture and temperature sensitivity of hot mix asphalt. This was done using asphalt from AL-Nasiria refinery with penetration grade 40-50, nominal maximum size (12.5) mm (surface course) of aggregate and one type of mineral fillers (limestone dust) with 7%.
To achieve the requirements of this study, the indirect tensile strength test according to (AASHTO T 283) criteria and compressive strength test were adopted to evaluate the index of retained strength according to (ASTM D 1075) to identify the moisture damage as well as indirect tensile strength test to evaluate sensitivity to temperature of the hot mix asphalt using modification and net asphalt.
These tests showed that there is a significant evolution in the resistance to moisture damage and decrease in the sensitivity to temperature of hot mix asphalt with modifying asphalt compared to the reference mixture.
Key words: modifying materials, modified asphalt, moisture damage, and temperature sensitivity.

تأثير إعداد الخلطة الأسفلتية الحارة بأستخدام الأسفلت المحسن على حساسية الخلطة الأسفلتية الحارة للرطوبة والحرارة

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الخلاصة

العديد من الباحثين درس تحسين اداء الخلطة الاسفلتية الحارة من خلال تقليل الضرر بالرطوبة والحساسية للحرارةوذلك لانهما يقللان العمر الوظيفي والانشائي للتبليط الاسفلتي.
الغرض الرئيسي من الدراسة هو إيجاد تأثير وأشارةً إلى البحوث السابقة (الرماد المتطاير بنسبة 3%، 6%، 12%- الجير المطفأ بنسبة 5%، 10%، 20% ومادة السليكا بنسبة 1%، 2%، 4%) من وزن الأسفلت الصافي كمواد محسنة لحساسية الخلطة الأسفلتية الحارة للرطوبة والحرارة.
تم إستخدام أسفلت مصفى الناصرية بأختراق 40-50 مع ركام ذو مقاس رمزي أقصى 12.5 ملم للطبقة السطحية ونوع واحد من المادة المالئة (غبار الحجر الجيري) بنسبة 7%.

ولغرض الوصول إلى متطلبات البحث تم أعتماد فحص الشد الغير مباشر إستناداً إلى AASHTO T 283 وفحص الضغط لتقييم مؤشر القوة المتبقية إستناداً إلى ASTM D 1075 لمعرفة ضرر أو حساسية الرطوبة وأعتمد فحص الشد الغير مباشر لمعرفة حساسية الخلطة الأسفلتية المحسنة بالأسفلت المحسن وكذلك الخلطة المرجعية للحرارة.
من خلال الفحوصات المنفذة وجد ان هناك تطور ملحوظ في مقاومة الضرر بالرطوبة ونقصان في حساسية الحرارة للخلطات الأسفلتية الحارة ذات الاسفلت المحسن مقارنة مع الخلطة المرجعية.
الكلمات الرئيسية: مواد محسنة، الأسفلت المحسن، ضرر الرطوبة، الحساسية للحرارة.

1. INTRODUCTION

Many researchers studied how to improve asphalt concrete mixture resisting moisture damage and reducing temperature sensitivity by modifying it using additives as a partial replacement of mineral filler or using the same materials to modify the asphalt cement with many methods. **Table 1** summarized some of the previous work.

Little and **Jones, 2003** defined the moisture damage as: due to the effects of moisture, asphalt mixtures loss its strength and durability and it occurs in two forms, softening (reduction in strength due to the reduction of cohesion of the asphalt mixture) and stripping (loss of adhesion and the physical separation of the asphalt cement and aggregate).

Brown, et al., 2001 represented that: Three main mechanisms lead to moisture damage, these are: -

1. Asphalt film loss cohesion;

2. Adhesion between the aggregate particles and the asphalt film that it has been losing; and

3. Due to freezing aggregate particles degradation.

Xiao, et al., 2009 stated that using the Reclaimed Asphalt Pavement (RAP) as a modifying mixture indirect tensile strength and tensile strength ratio were increased compared to the control mix.

Sarsam, and **Al-Janabi 2014** showed that there was less susceptibility to moisture damage when using recycling asphalt mixtures by an average value of 53% compared to the control mix.

Hayder, 2015 concluded that the SBS improved tensile and compressive strength as well as Marshall Properties. **Stuart, et al., 2001**, conducted that improvement in resistance to moisture damage was done using modified polymer (SBS & SBR) mixtures.

2. CHARACTERISTICS OF USED MATERIALS

To meet the requirements of this study; AL-Nasiria refinery asphalt cement (40-50) penetration grade was used. **Table 2** shows the physical properties of it.

Limestone dust was used as mineral filler and this was obtained from Lime Factory in Karbala governorate, south east of Baghdad city.

2.1 Modifying Materials

To prepare modified asphalt; locally available materials have been used such as Fly Ash (FA) of low cost and specific gravity, Hydrated Lime (HL) (from Karbala plant in powder form) and Silica Fume (SF) (a pozzolanic material of a white and fluffy powder). **Table 5** illustrated the physical properties and **Table 6** shows their chemical composition.

2.2 Aggregate

Coarse and fine aggregate crushed quartz from Al-Nibaie quarry were used in this study. According to the requirements of surface course gradation of **(SCRB, 2003/ R9)** specification, coarse and fine aggregate were sieved and recombined. **Fig.1** shows the gradation curve for the selected aggregate for surface course. To evaluate the physical properties of aggregate; routine tests were performed. The results are summarized in **Table 7**.

3. MODIFIED ASPHALT PREPARATION

Modified asphalt was prepared according to the **Sarsam, 2015** procedure as follows: -

1. Heating the asphalt cement up to160^{o} C.
2. The modifying materials are added gradually with mechanical continuous stirring. The percentage of adding starts by 3%, 5% and 1% for fly ash, hydrated lime and silica fume respectively with duplicated increment.
3. Mixing the asphalt cement with modifying materials at 5000 rpm about 45 min at the same temperature.

4. MIX PREPERATION

After preparing modified asphalt and according to the Marshall Design procedure (ASTM D1559), optimum asphalt content for the mixture of each type and percent of modifying materials. **Table 8** explains the optimum asphalt content of the prepared specimen. The difference in optimum asphalt content between control mix with net asphalt and modified mixes was within the S.O.R.B tolerance (±0.3%) so the optimum asphalt content of the control mix to all mixes (5.2) was used.

5. TESTING OF MIXTURE

The prepared specimens of modified and net asphalt were subjected to a number of tests to evaluate the effect of modifying asphalt on moisture sensitivity and temperature susceptibility of hot mix asphalt as shown below:

5.1 Moisture Sensitivity

To find out the moisture sensitivity of asphalt concrete mixture; two groups of a mixture of each type of asphalt modification for all percent of modifying were adopted; the first group: un conditioned group consists of three dry specimens were tested at 25^{o}C. The second group: conditioned group consists of three specimens were immersed in water bath at 60 ^{o}C for 24hr and tested at 25^{o}C according to (AASHTO T 283) criteria at 7% air voids. Indirect tensile strength (ITS) and tensile strength ratio (TSR) were calculated by equations (1) and (2):

$$ITS = \frac{2000P}{tD\pi} \tag{1}$$

$$TSR = \frac{ITS_{CN}}{ITS_{UNC}} \tag{2}$$

On the other hand and to evaluate the moisture damage; the Index of Retained Strength Test according to (**ASTM D1075)** and Index of Retained Strength (IRS) were calculated by equation (3):

$$\boldsymbol{IRS = \frac{S_{CN}}{S_{UCN}} * 100} \tag{3}$$

5.2 Temperature Susceptibility

Equation (4) was used to evaluate the temperature susceptibility, **Husham, 1999**:

$$\boldsymbol{TS} = \frac{\boldsymbol{ITS_{t1} - ITS_{t2}}}{\boldsymbol{t_2 - t_1}} \tag{4}$$

6. RESULTS

To assess the effect of using modified asphalt on moisture sensitivity of hot mix asphalt; **Table 9** illustrated the results of the indirect tensile strength (ITS) through values of tensile strength ratio (TSR) for the control and modified mixture adopted and percent of change in it is value. On the other hand, **Fig. 2** shows the tensile strength ratio result. **Fig. 3** explains the value of the index of retained strength (IRS). **Table 9 and Fig. 4** illustrates the result of temperature susceptibly after completing indirect tensile strength test. **Fig. 5** explains the percent of change in the value of moisture and temperature susceptibility for the mixture with modified asphalt compared to the control mix. Finally, **Table 10** explained the result of checking Marshall Stability and flow as well as volumetric properties of the mixture with and without modifying asphalt.

7. CONCLUSIONS

From the findings of this study; the following conclusions can show how the use of modified asphalt affected the moisture and temperature sensitivity:

1. All prepared mixtures meet the required specifications for each adopted test except the control mix in the compression test to check the index of retained strength.

2. Adding 3%, 6% and 12% of fly ash as a modifying material by weight of asphalt cement; percent increase in tensile strength ratio was by 7.77, 9.95 and 10.79, percent increase in Index of retained strength was: 9.27, 11.41 and 16.17 and the percent decrease in temperature sensitivity was: 7.27, 15.21 and 17.48 respectively compared to the control mix.

3. Using 5%, 10% and 20% of hydrated lime as a modifying material by weight of asphalt cement; the percent increase in tensile strength ratio was: 13.05, 18.28 and 18.71, percent increase in Index of retained strength was: 17.26, 22.10 and 26.37 and the percent decrease in temperature sensitivity was: 21.28, 23.80 and 30.12 respectively compared to the control mix.

4. Supplement of 1%, 2% and 4% of silica fume as a modifying material by weight of asphalt cement gave percent increase in tensile strength ratio by: 22.76, 23.01 and 25.99, percent increase in Index of retained strength: 31.86, 37.76 and 42.31 and the percent decrease in temperature sensitivity: 46.65, 48.47 and 72.33 respectively compared to the control mix.

5. Volumetric properties, Marshall Stability and flow met the requirements of the specification for all the used percent of modified materials by weight of asphalt.

6. According to the experimental work; any increase in the percent of materials to modify asphalt other than that used in this study will adversely affect the properties of hot mix asphalt.

7. The results indicate that specimens modified with silica fume have the highest resistance to moisture damage and least temperature sensitivity as the other modified materials. This may be due to its high surface area.

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NOMENCLATURE

ITS = Indirect Tensile Strength; KPa
P = ultimate load to failure; N
t = thickness of Specimen; mm
D = diameter of Specimen; mm
TSR = tensile Strength Ratio; %
ITS_{CN} = conditioned Indirect Tensile Strength; KPa
ITS_{UNC} = UN- Conditioned Indirect Tensile Strength; KPa
IRS = index of Retained Strength; %
S_{CN} = conditioned Compression Strength; KPa
S_{UNC} = Uc Conditioned Compression Strength; KPa
TS = temperature Susceptibility (kPa / ºC); %
ITS_{t1}= indirect Tensile Strength at 25ºC; KPa
ITS_{t2} = indirect Tensile Strength at 40ºC after 30 min immersed in water; KPa.

Table 1. Summary of previous studies using modified asphalt in HMA

NO.	Author and Year	Modifier Materials	Additives by Asphalt Cement weight;%	Test	Summary of Finding
1	Eman *et al*; 2010	EVA copolymer	2, 4, 6, 8, 10, 12	**1.** Storage Stability Test. **2.** Softening point; **3.** Ductility; **4.** Penetration Test.	**1.**Increasing of polymer content; increasing in Viscous and elastic properties of modified asphalt. **2.**Decreasing in penetration value; **3.**Increasing in softening point value; **4.**Decreasing in ductility value
2	Sarsam; 2014	Fly ash	3, 6, 9, 12	**1.**Penetration Test. **2.**Softening point Test. **3.**Penetration index Test. **4.**Stiffness Modulus Test. **5.**Viscosity Test.	**1.** Decreasing in viscosity value when using Fly Ash; **2.** Increasing in viscosity value when using Silica fumes; **3.** Increasing in softening point; **4.** Decreasing in stiffness modulus value; **5.** Decreasing in temperature susceptibility value.
		Silica fumes	1, 2, 3, 4		
3	Sarsam; 2015	Silica fumes	1, 2	**1.** Softening point; **2.**Ductility; **3.** Penetration by needle; **4.**Penetration by cone;	**1.**Decreasing in penetration value; **2.**Increasing in softening point value; **3.**Temperature sensitivity controlled **4.**(10-60) % range of reduced in ductility

		Hydrated Lime	10, 20	**5.**Resilience (ball strain recovery); **6.**Oklahoma elastic strain recovery, and **7.** Cold bond adhesion and cohesion at 0 ºC	value after ageing process. **5.**(6-8) % range of increase in softening point value after ageing process. **6.** (10-60) % range of reduced in ductility value after ageing process.
4	Prajna S, & Anjum; 2015	Sulfur	3, 6, 9, 12	**1.**Marshall Stability; **2.**Volumetric properties.	**1.** At 9% sulphur and 5% asphalt cement content; Marshall Stability have the maximum value of 30.22 kN while it is 26.88 KN at the same percent for the net asphalt cement. **2.** Increasing in bulk density value. **3.** Decreasing in air voids.
5	Ilham & Mehan; 2015	Zycotherm Modyfiedmaterial	(0.1, 0.3, 0.5) directly added to asphalt cement (1, 3, 5) Diluted with water	**1.**Indirect Tensile Strength. **2.**Penetration Test. **3.**Softening Point Test.	**1.** Tensile Strength Ratios increased from (71.73 -86.46)%. **2.** Retained Stability Index increased from (65.62- to 95.38)%. **3.** Increase resistance to rutting and fatigue.
6	Al-Jumaili; 2016	Polyproplene Cellulose	1, 3, 5	**1.**Rotational viscosity test. **2.**Dynamic Shear Rheometer test. **3.** direct tension tester. **4.** Softening point test; **5.** Ductility test; **6.**Penetration by needle test.	**1.**improved softening. **2.**increase in complex modulus value. **3.** decrease the phase angle. **4.** increase resistance to rutting and fatigue. **5.** improve the physical and rheological properties of modified asphalt comparing with the natural asphalt cement.

Table 2. Properties of asphalt cement (40-50) penetration grade*.

Property	ASTM designation	Test Results	SCRB Specification
Penetration at 25°C,100 gm,5 sec. (0.1mm)	D-5	43	40 - 50
Rotational viscosity at 135°C (cP.s)	D-4402	483	------
Softening Point. (°C)	D-36	47	------
Ductility at 25 °C, 5cm/min,(cm)	D-113	>100	>100
Flash Point, (°C)	D-92	273	Min.232
Specific Gravity	D-70	1.038	------
Residue from thin film oven test - Retained penetration,% of original - Ductility at 25 °C, 5cm/min,(cm)	D-1754 D-5 D-113	 72.1 89	 >55 >25

*: Tests conducted in the laboratory of the University of Karbala

Table 3. Physical properties of filler used**.**

Specific Gravity	Specific Surface (m^2/kg)	Percent Finer than 75 microns
2.44	244	96

*: Tests conducted in the laboratory of the University of Karbala

Table 4. Chemical composition of filler used**.**

SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	Loss on Ignition
2.23	-----	-----	68.3	0.32	1.2	27.3

*: Tests conducted in the laboratory of the University of Karbala

Table 5. Physical properties of modified materials.

Tested Properties	Modified Materials		
	Fly Ash	Hydrated Lime	Silica Fume
Specific Gravity	2.05	2.77	2.16
Specific Surface (m2/kg)	650	395	16000
Percent Finer than 75 microns	94	98	100

*: Tests conducted in the laboratory of the University of Karbala

Table 6. Chemical composition of modified materials**.**

Chemical Composition (%)	Modified Materials		
	Fly Ash	Hydrated Lime	Silica Fume
SiO_2	61.95	1.38	99.1
Fe_2O_3	2.67	0.12	35 ppm
Al_2O_3	28.82	0.72	0.03
CaO	0.88	56.1	0.03
MgO	0.34	0.13	52 ppm
SO_3	<0.07	0.21	<0.07
Loss on Ignition	0.86	40.6	0.70

*: Tests conducted in the laboratory of the University of Karbala

Table 7. Physical properties of Al-Nibaie quarry aggregate**.**

Property	ASTM Designation	Test Results	SCRB Specification
Coarse Aggregate			
Bulk Specific Gravity	C – 127	2.615	------
Apparent Specific Gravity	C – 127	2.688	------
Water Absorption, %	C – 127	0.432	------
Percent Wear by Los Angeles Abrasion, %	C – 131	17.70	30 Max.
Soundness Loss by Sodium Sulfate Solution, %	C – 88	3.1	10 Max.
Fractured pieces, %	------	97	90 Min.
Fine Aggregate			
Bulk Specific Gravity	C – 127	2.665	------
Apparent Specific Gravity	C – 127	2.701	------
Water Absorption, %	C – 127	0.718	------
Sand equivalent,%	D-2419	52	45 Min.

Table 8. Optimum asphalt content**.**

Modified Materials								
Fly Ash			**Hydrated Lime**			**Silica Fume**		
3%	**6%**	**12%**	**5%**	**10%**	**20%**	**1%**	**2%**	**4%**
Optimum Asphalt Content*								
5.18	5.20	5.21	5.18	5.18	5.21	5.21	5.21	5.22

*: Optimum Asphalt Content for mix with nature asphalt = 5.2

Table 9. Indirect tensile strength result according to (AASHTO T 283).

TYPES OF ASPHALT MODIFICATION	MODIFIED MATERIALS PERCENT; %	TSR*	PERCENT CHANGE IN TSR	TS; KPa/ C°**	PERCENT CHANGE IN TS
Control	0	70.15		85.52	
Fly Ash F.A	3	75.60	7.77	79.31	-7.27
	6	77.67	9.95	72.52	-15.21
	12	78.53	10.79	70.57	-17.48
Hydrated Lime	5	80.40	13.05	67.32	-21.28

H.L	10	84.84	18.28	65.17	-23.80
	20	86.03	18.71	59.76	-30.12
Silica Fume S.F	1	89.73	22.76	45.62	-46.65
	2	90.80	23.01	36.32	-48.47
	4	93.75	25.99	23.66	-72.33

*TSR: = Tensile Strength Ratio; **TS: Temperature Susoeptility

Table 10. Marshall Stability& flow and volumetric properties.

TYPES OF ASPHALT MODIFICATION	MODYFIED MATERIALS PERCENT; %	MARSHALL STABILITY,(KN)	MARSHALL FLOW,(mm)	VOLUMETRIC PROPERTIES		
				VMA	AV	FVA
Control	0	11.34	3.37	18.23	4.23	76.80
Fly Ash F.A	3	15.02	2.65	15.76	4.01	74.56
	6	17.57	2.86	22.65	3.87	82.91
	12	18.22	2.51	16.34	3.65	77.66
Hydrated Lime H.L	5	21.98	2.42	19.51	3.57	81.70
	10	28.05	3.25	17.75	3.26	81.63
	20	29.73	2.28	21.45	3.32	84.52
Silica Fume S.F	1	31.16	2.25	18.63	3.35	82.02
	2	33.23	2.83	15.08	3.16	79.05
	4	36.04	3.22	18.31	3.05	83.34

*: Tests conducted in the laboratory of the University of Karbalaa

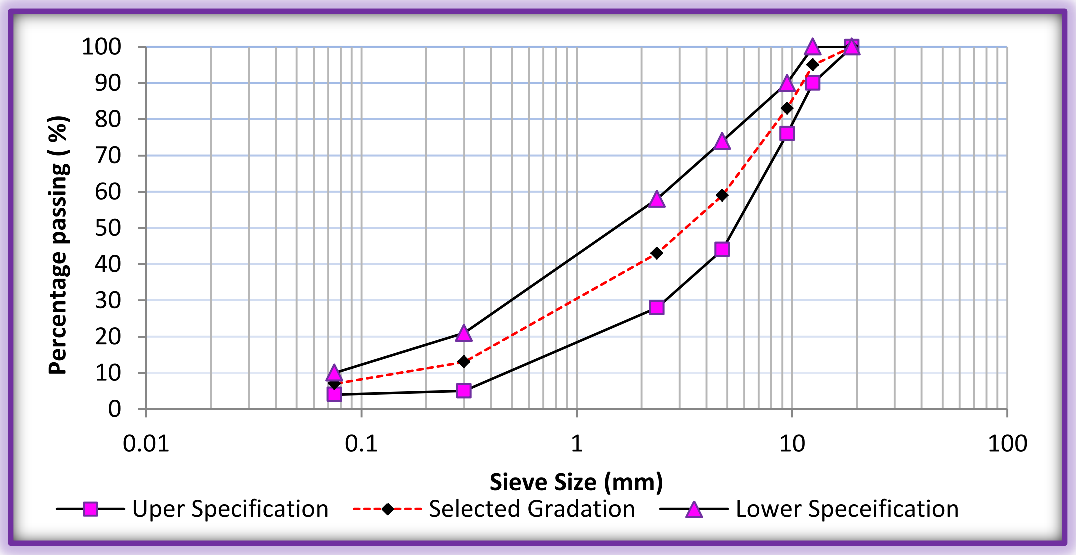

Figure 1. Gradation limit of surface course.

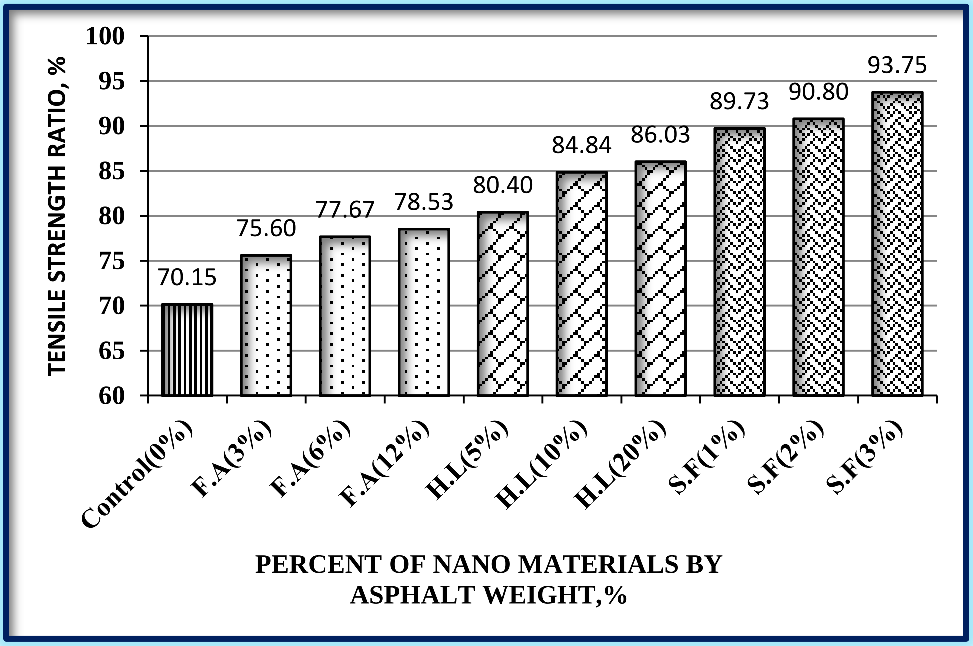

Figure 2. Results of tensile strength ratio (TSR).

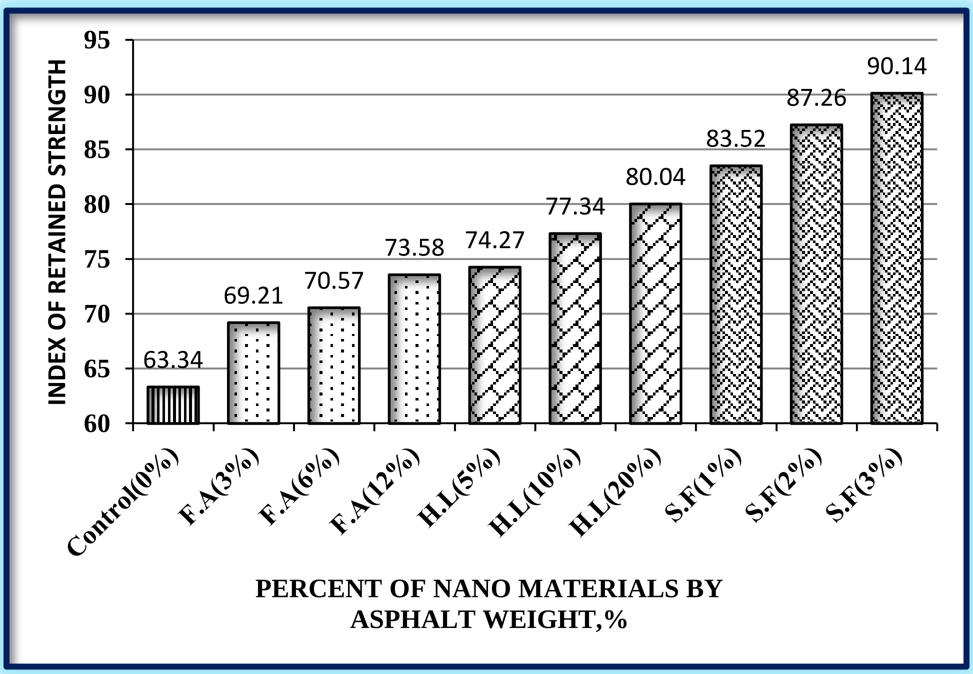

Figure 3. Results of index of retained strength**.**

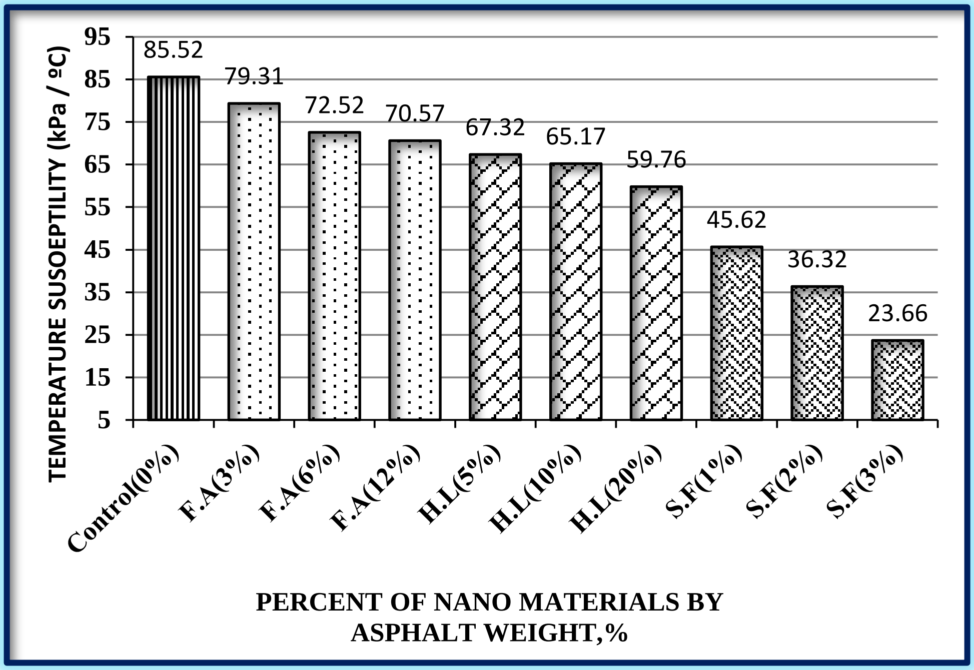

Figure 4. Results of temperature sensitivity**.**

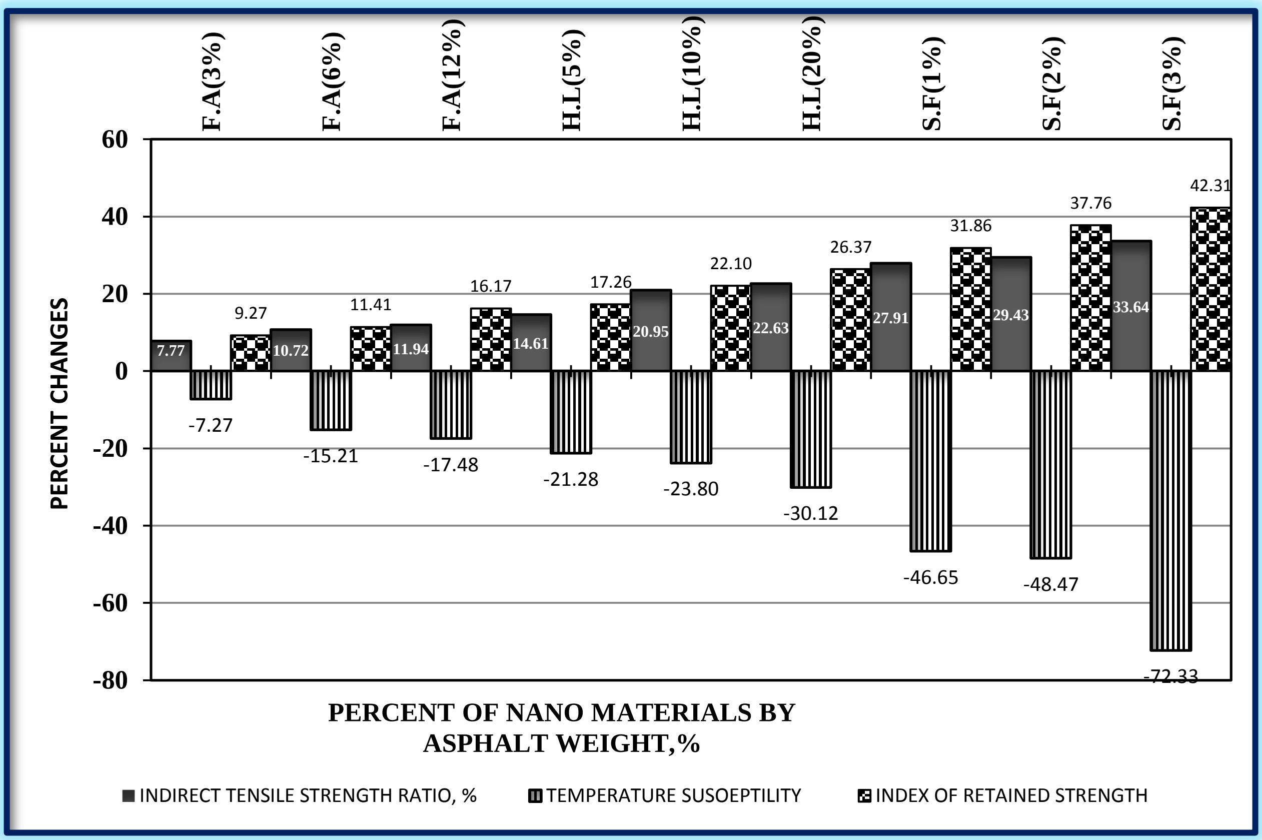

Figure 5. Percent change in temperature and moisture susceptibly.