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Research Article

Assessing the Tensile Properties of Asphalt Concrete

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Keywords

Asphalt Concrete,
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Abstract

The tensile strength of asphalt concrete is essential to control the rutting behavior of the pavement. In the present work, asphalt concrete mixtures were compacted at optimum binder content to a target density using roller compaction. Extra mixtures with 0.5 % binder content above and below the optimum were also prepared. Core specimens were extruded from the compacted slab samples for testing. The tensile strength of asphalt concrete was assessed using the indirect tensile strength test and the semi-circular bending test. It was detected that the tensile strength as obtained by SCB is five and half fold and five-fold higher than that obtained by ITS when the specimens are tested at (20 and 0) °C respectively. The SCB tensile strength increase by 72.1 % when the specimens are tested at 0°C as compared with the testing at 20°C. However, it was observed that the tensile strength obtained from the Semi-Circular Bend test (SCB) increases as the binder content increase when compared with that obtained from Indirect tensile strength test (ITS). The slope of the SCB – Binder content at both testing temperature relationship increases while the intercept declines as the binder content increase. This can refer to the sensitivity of the SCB test to the binder and temperature variation. The ITS declines when the testing temperature changes from (0 to 20 and 40) ° C by (48.3, and 80.1) %, (48.5, and 78.1) %, and (48.3, and 81.3) % for mixtures with (4.4, 4.9, and 5.4) % binder respectively.

1. Introduction

Huang et al.,2005 [1] studied the variation in tensile strength obtained from ITS and SCB test. It was revealed that the deformation under the loading strips of the ITS test is undesirable to evaluate the cracking potential of asphalt concrete mixtures. However, SCB test can reduce the loading strip-induced deformation and it is more suitable for the evaluation of the tensile properties of asphalt concrete mixtures. It was revealed that the test results from ITS and SCB test were fully convertible and comparable. Falchetto et al.,2018, [2] investigated the low-temperature behavior of asphalt concrete mixture as determined with the aid of indirect tensile strength (ITS) and the semi-circular bending (SCB) experimental methods. Un-notched and Notched SCB tests are conducted. A set of simple linear relations between the tensile strength value experimentally measured on ITS specimens and numerically determined SCB strength on notched specimens is derived. It was revealed that the proposed relationship can be used to predict the asphalt concrete strength of ITS specimens based on SCB notched fracture tests. However, no good correlation could be found between ITS measurements and the corresponding SCB strength on un-notched specimens. Arabani and Ferdowsi,2009, [3] evaluated the SCB test for determining tensile and fracture resistance of asphalt concrete mixtures.

It was revealed that the test results from ITS and SCB methods, were fully convertible and comparable. It was concluded that the tensile strength from ITS and SCB test were different due to their different stress states under loading. Szydłowski et al.,2018, [4] stated that the fracture properties of asphalt concrete can be related to laboratory test results such as bending of semi-circular beams (SCB). It was revealed that one of the frequently used and most suitable methods is the bending test of semi-circular specimens (SCB). The fracture toughness is the basic parameter that defines the strength properties of an asphalt concrete mixture in the SCB test. Pszczola and Szydlowski,2018, [5] stated that the highest value of failure stress and the lowest value of failure temperature were obtained for the asphalt concrete using the SCB test, it also proved a better resistance of the asphalt mixture to low-temperature cracking. Artamendi and Khalid,2006, [6] reported that the fracture properties of two asphalt concrete mixtures, have been determined by means of three-point bending tests on notched specimens and semi- circular bending technique. Comparisons were made based on two fracture parameters, the fracture energy, and the stress intensity factor. Experimental results indicated that there is good agreement between the stress intensity factors obtained from the two specimen geometries.

Moreover, both geometries have been found suitable to study mixed-mode fracture of asphalt concrete materials. Nsengiyumva et al.,2017, [7] examined the testing variables for a semicircular bending (SCB) fracture test and evaluated the fracture characteristics of asphalt concrete mixture at intermediate service temperatures. Statistical analysis of test results indicated that a range of a specimen thickness of 6 to 4 cm, and a testing temperature between (40 to 15) °C showed the reasonably low coefficient of variance value of fracture energy within less than 10 %. However, the loading rates (10 to 0.1 mm/min.) which was attempted in the study did not show any significant differences in the testing repeatability. Montestruque et al.,2010, [8] used the semi-circular bending (SCB) test for evaluation of the fracture resistance of fine aggregate mixtures. It was found that the total energy dissipated along the SCB test can better differentiate the mixtures. Yang et al.,2021, [9] investigated the effect of applied loading type and specimen configuration on the measured fracture toughness using different test specimens including Semi-Circular Bend (SCB), Single Edge Notch Beam (SENB). The tests were conducted at two low temperatures (-5 and -25) °C. It was concluded that the fracture toughness values of all tested asphalt concrete specimens were increased linearly by the decline of the test temperature. The fracture toughness measurements were conducted by Shahryari et al.,2021, [10] on edge notch disc compression, edge notch disc bend, and semi-circular bend configurations under two low testing temperatures and two loading rates. It was observed that the fracture resistance was increased by reducing the test temperature and increasing the loading rate. By considering the effect of the maximum normal strain value and the tensile stress as constant material property, the fracture toughness value for any of the investigated samples was estimated in terms of the fracture results of the other specimens. Faun et al.,2021, [11] performed an experimental study using Semi-circular bend (SCB) and edge notch disc bend (ENDB) asphalt concrete specimens.

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The thickness of SCB and ENDB asphalt concrete specimens, the test temperature, and the loading rate are considered as variable. It is found that the fracture toughness values obtained from both ENDB and SCB testing techniques are in good agreement. It was concluded the load carrying capacity and the fracture toughness value of asphalt concrete increases by increasing the specimen thickness and the loading rate, and by decreasing the test temperature. Experimental program has been designed by Somé et al.,2018, [12] to evaluate the influence of: asphalt content, testing temperature, and loading rate on the total fracture energy and the fracture toughness. The results show that the influent parameters are as follows: loading rate, temperature, and binder content. The temperature is the most influent parameter on the total fracture energy, while the loading rate is the least influent one. Polynomial functions have been used for modeling. The effects of testing temperature and loading mode on the fracture resistance of asphalt concrete under static loading was investigated by Pirmohammad and Ayatollahi,2014, [13]. Semi-circular bend specimen containing an asymmetric vertical edge crack was employed. Results showed that both loading mode and temperature influence the fracture resistance of asphalt concrete. For all the fracture tests performed under low temperature and different modes of loading, the fracture resistance of asphalt concretes first increased and then below a certain temperature of (-20) °C declined. Reliability of (SCB) specimen for measuring the fracture behavior of asphalt pavement materials under static and cyclic loadings has been investigated by Mubaraki and Sallam, 2018, [14]. Three different SCB specimen were used for the prediction of the fracture behavior of asphalt pavement materials. The relation between the stress intensity factor range, there liability of SCB specimen for the measurement of the fatigue behavior of pavement materials, and the crack opening displacement through the whole life of the specimen was examined. A simple test that combines the advantages of both disc-shaped compact tension and SCB configurations has been developed and successfully used under the name of Fénix tests. Pérez-Jiménez et al.,2013, [15] presented the results of applying the Fénix and SCB tests in the assessment of fracture behavior of asphalt concrete mixtures and the influence of both loading rate and temperature on the results obtained. It was concluded that both Fénix and SCB tests provides similar information when comparing two types of asphalt concrete mixtures or selecting mixtures resistant to cracking. Notched SCB fatigue test was conducted by Huang et al.,2013, [16] on asphalt concrete mixtures made with different asphalt binders. The fracture parameters were obtained by the implementation of regression analysis. The test results show that the change in asphalt binder properties resulted in the differences in fracture resistance of asphalt mixtures.

The aim of the present assessment is to verify the tensile properties of asphalt concrete mixtures with different binder content using the indirect tensile strength test and the semi-circular bending test at various testing temperatures. Correlation of the test results of both methods will also be investigated.

2. Materials Properties and Testing Methods

2.1. Asphalt Cement

Asphalt cement binder with a penetration grad 40-50 was implemented in this assessment. The asphalt binder was obtained from AL-Nasiriya oil Refinery. The physical properties of the asphalt cement binder are demonstrated in Table 1.

2.2. Fine and Coarse Aggregates

Crushed coarse aggregates passing sieve size of 19 mm and retained on sieve No. 4 was obtained from AL-Ukhaider quarry. Natural and crushed sand mixture was implemented as Fine aggregate (passing sieve No.4 and retained on sieve No.200). It was obtained from the same source. The aggregates were washed, then air dried and sieved into different sizes. The physical properties of aggregates are demonstrated in Table 2.

Table 1. Physical Properties of the Asphalt Cement Binder

Property	Test Conditions	ASTM, 2016,[17] Designation	Test Value
Penetration	25˚C, 100gm 5 sec	D5-06	42
Softening Point	(ring &ball)	D36-895	49
Ductility	25˚C, 5cm/minutes	D113-99	150+
Specific Gravity	25˚C	D70	1.04
Flash Point	Cleave land open cup	D92-05	269
	After thin film oven test		
Penetration	25˚C, 100gm, 5 sec	D5-06	33
Ductility of Residue	25˚C, 5cm/mi	D113-99	130
% Loss on Weight	163ºC, 50g, 5 hr.	D1754-06	0.175

Table 2. Properties of Coarse and Fine Aggregate as per ASTM,2016, [17]

Property	Fine Aggregate	Coarse Aggregate
Bulk Specific Gravity (ASTM C 127 and C 128).	2.658	2.642
Percent Water Absorption (ASTM C 127 and C 128)	1.83	1.07
Percent Wear (Los-Angeles Abrasion) (ASTM C 131)	-	18 %

2.3. Mineral Filler

The mineral filler used in the present investigation is the limestone dust which was obtained from Karbala governorate. Most of the filler passes sieve No.200 (0.075mm). The physical properties of the mineral filler are presented in Table 3.

Table 3. The Physical Properties of Mineral Filler

Property	Value
Bulk specific gravity	2.617
% Passing Sieve No.200	94

2.4. Selection of the Aggregates Combined Gradation

The selected combined aggregates gradation in the present work follows SCRB,2003, [18] specification for dense graded wearing course pavement layer with 12.5 mm nominal maximum size of aggregates. Table 4 shows the selected aggregate gradation.

Table 4. Aggregates Gradation implemented for Wearing Course as per SCRB, 2003, [18]

Sieve size (mm)	19	12.5	9.5	4.75	2.36	0.3	0.075
Selected limit	100	95	83	59	43	13	7
SCRB, 2003 Specification	100	90-100	76-90	44-74	25-58	5-21	4-10

2.5. Preparation of the Asphalt Concrete Mixture and the Test Specimens

The fine and coarse aggregates were combined with mineral filler to meet the specified gradation for asphalt concrete wearing course. However, the combined aggregates were heated to 160 ᵒC before mixing with asphalt cement. The asphalt cement binder was heated to 150 ᵒC as recommended by SCRB, 2003, [18]. Then, the binder was added to the heated aggregate to the desired amount and mixed thoroughly by hand using a spatula for two minutes until the aggregate particles were coated with a thin film of the asphalt cement binder. The optimum percentage of asphalt cement was 4.9%. Such optimum asphalt binder percentage was determined based on trial mixes and the prepared Marshall specimens using various asphalt percentages. Details of obtaining the optimum binder content may be referred in Sarsam and Sultan, 2015,[19]. Extra mixtures with 0.5 % binder above and below the optimum requirement were also prepared. The mixtures were rolled in a slab mold of (40 x 30 x 6) cm by practicing the roller compaction to the target bulk density according to EN12697-33, 2007,[20]. The applied static load was 5 kN while the number of load passes depended on the target density of the mixture. Details of the compaction process may be referred to Sarsam, 2016,[21]. The compaction temperature was maintained to 150 °C. The slab samples were left to cool overnight. Core specimens of 50±2 mm high and102 mm diameter were obtained from the compacted slab sample using the Diamond core bit. The total number of core specimens obtained was twelve, while the number of casted slabs was three. Part of the core specimens were cut to semi-circular shape using a diamond saw. Core specimens were subjected to the indirect tensile strength determination as per AASHTO. T322-07, 2013, [22], while, the semi-circular specimens were subjected to SCB test as per AASHTO. TP105- 13, 2013, [23]. Figure 1 exhibit the roller compactor implemented.

Figure 1. The Roller Compactor

Figure 2 shows the semi-circle bending test setup while Figure 3 shows the indirect tensile strength test setup. The semi-circular bending test was conducted at (0, and 20) ° C, while the indirect tensile strength test was conducted at (0, 20, and 40) ° C. Table 5 demonstrates the Marshall properties of asphalt concrete mixture.

Figure 2. Semi-circular Bend

Table 5. Marshall Properties of Asphalt Concrete

Property	Test result
Optimum binder content %	4.9
Marshall stability kN	11.25
Marshall flow mm	2.9
Bulk Density gm/cm³	2.282
Volume of Voids %	4.2
Voids in Mineral Aggregates %	15.1
Voids Filled with Binder %	71.8

Figure 3. Indirect Tensile test

3. Results and Discussions

3.1. Relationship between ITS and SCB Test Results

Figure 4 demonstrates the relationship between the ITS and SCB test results at 20°C environment, the tensile strength of asphalt concrete could be obtained from both testing techniques. It can be detected that the SCB test exhibit higher tensile strength values as compared with the indirect tensile strength test. The tensile strength as obtained by SCB is five and half fold higher than that obtained by ITS when the specimens are tested at 20°C.

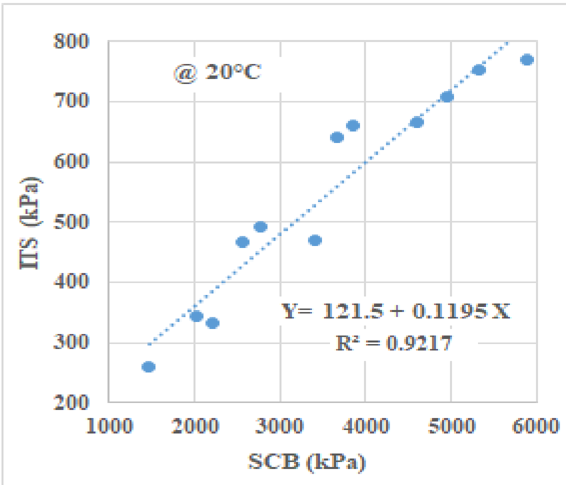

Figure 4. ITS-SCB Test Results Relationship

However, the tensile strength as obtained by SCB is five-fold higher than that obtained by ITS when the specimens are tested at 0°C. This can be attributed to the fact that the two-point loading in case if ITS can exhibit deformation under the testing strips and initiate micro cracks while the three points loading in case of SCB exhibits exhibit more bending than deformation. Huang et al., 2005, [1] reported similar findings. The linear mathematical model shown in Figure 4 exhibits high coefficient of determination and may be implemented to correlate the two testing techniques.

3.2. Influence of binder content on Tensile Strength

Figure 5 demonstrates the influence of binder content on the relationship between the indirect tensile strength ITS and the Semi-circular Bending SCB test. Both testing was conducted at 20 °C. It can be observed that as the binder content increases, the slope of the relationship declines. The tensile strength obtained from the Semi-Circular Bend test (SCB) increases as the binder content increase when compared with that obtained from indirect tensile strength test (ITS).

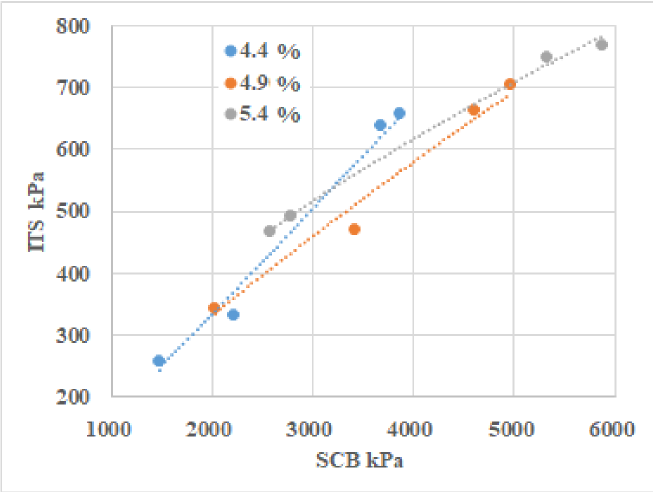

Figure 5. Influence of Binder content on ITS-SCB test relationship

Table 5 exhibits the ITS-SCB power relationship parameters, it can be detected that the intercept, which represent the tensile strength at the starting point of the relationship, increases by (3.8, and 23.7) % as the binder content increases from (4.4 to 4.9 and 5.4) % respectively. However, the slope, which represent the rate of change in the tensile strength, declines by (20.5, and 39) % as the binder content increases from (4.4 to 4.9 and 5.4) % respectively. On the other hand, the mathematical models exhibit high coefficients of determination and the tensile strength as obtained by the ITS test can be represented in terms of the tensile strength obtained using the SCB test. The load applied on the specimen in the semi-circular bending test is resisted by the tensile strength of the mixture which is based on the adhesion between the binder and aggregates and the cohesion of the binder which binds the aggregates in the mixture. Similar trend was addressed by Falchetto et al., 2018, [2]. Arabani and Ferdowsi,2009, [3] evaluated the SCB test for determining tensile and fracture resistance of asphalt concrete mixtures. It was stated that the results from SCB, and ITS methods, were fully convertible and comparable. It was concluded that the tensile strength from ITS and SCB test were different due to their different stress states under loading. Such behavior agrees with the work of Pszczola and Szydlowski, 2018, [5].

Table 5. ITS-SCB Test Parameters

Binder content %	İntercept (kPa)	Slope	Mathematical model	Coefficient of Determination
4.4	0.1467	1.0171	$Y = 0.1467\ X^{1.0171}$	0.9862
4.9	0.7134	0.8080	$Y = 0.7134\ X^{0.808}$	0.9753
5.4	3.6244	0.6195	$Y = 3.6244\ X^{0.6195}$	0.9952
Y = Indirece tensile strength (kPa) X = Semi-circle bending strength (kPa)				

3.3. Influence of Testing Temperature on SCB Tensile Strength

Figure 6 exhibits the influence of the testing temperature on SCB tensile strength, a linear mathematical model relationship with significant coefficient of determination of 0.9809 could be noted regardless of the binder content. The SCB tensile strength increase by 72.1 % when the specimens are tested at 0°C as compared with the testing at 20°C.Such finding agrees with Shahryari et al., 2021, [10].

Table 6. ITS-SCB Test Parameters

Binder content %	İntercept (kPa)	Slope	Mathematical model	Coefficient of Determination
4.4	13.464	0.7601	$Y = 13.464\ X^{0.7601}$	0.9499
4.9	2.9773	0.9401	$Y = 2.9773\ X^{0.9401}$	0.9972
5.4	2.9189	0.9444	$Y = 2.9189\ X^{0.9444}$	0.9878
Y = Semi-circular bend strength (kPa) @ 0° C X = Semi-circle bend strength (kPa) @ 20° C				

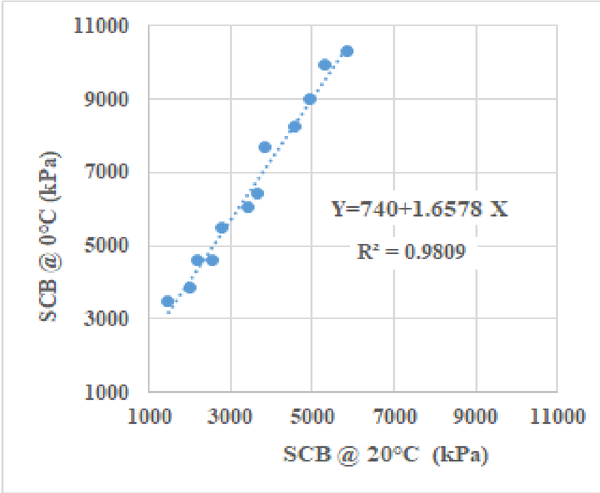

Figure 6. Influence of the Testing Temperature on SCB Tensile Strength

However, Figure 7 exhibits the influence of asphalt binder content on the SCB with both testing temperatures. The slope of the relationship increases while the intercept declines as the binder content increase. This can refer to the sensitivity of the SCB test to the temperature variation. The intercept declines by (77.8, and 78.3) % when the binder content increases from (4.4 to 4.9 and 5.4) % respectively. However, the slope increases by (23.6, and 24.2) % when the binder content increases from (4.4 to 4.9 and 5.4) % respectively.

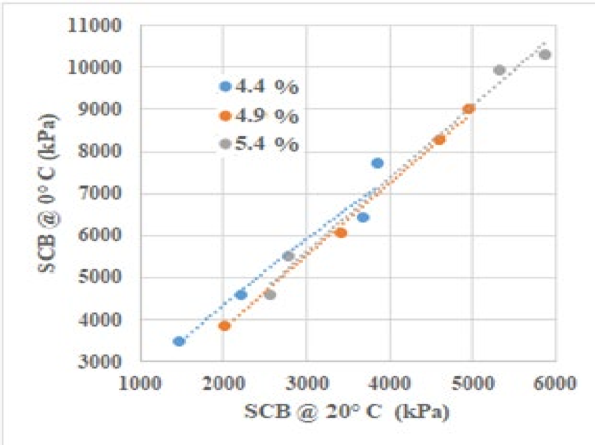

Figure 7. Influence of Binder Content and Temperature on SCB Tensile Strength

3.4. Influence of the Testing Temperature on the Indirect Tensile Strength

Figure 7 demonstrates the influence of the testing temperature on ITS, it can be observed that the ITS significantly decline as the testing temperature increases.

This could be attributed to reduction in the viscosity of the binder which lead to the reduction in the adhesion between the binder and aggregates. Mixtures with higher binder content exhibits higher decline in the ITS. At low and moderate testing temperature of (0, and 20) ° C, the influence of binder content on ITS is effective. Such behavior agrees with Pérez-Jiménez et al., 2013, [15].

However, at high testing temperature of 40 ° C, no significant variation in the ITS could be detected among various binder content. Table 7 exhibit the mathematical modes of the variation in ITS with the testing temperature. The linear models exhibit high coefficient of determination. The ITS declines when the testing temperature changes from (0 to 20 and 40) ° C by (48.3, and 80.1) %, (48.5, and 78.1) %, and (48.3, and 81.3) % for mixtures with (4.4, 4.9, and 5.4) % binder respectively.

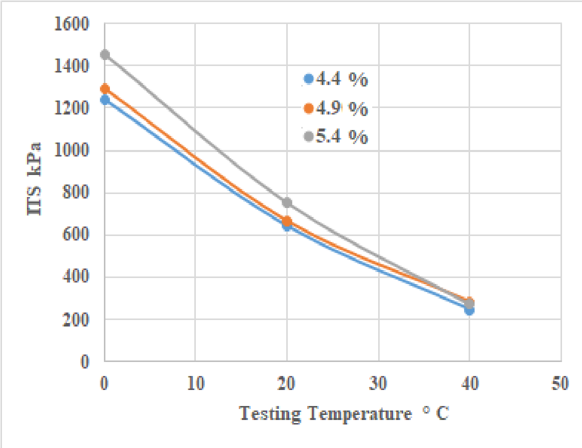

Figure 7. Influence of Temperature on ITS Tensile Strength

Table 7. ITS Test Parameters

Binder content %	İntercept (kPa)	Slope	Mathematical model	Coefficient of Determination
4.4	1206	24.85	Y = 1206 – 24.85 X	0.9862
4.9	1254	25.30	Y = 1254 – 25.30 X	0.9807
5.4	1419	29.62	Y = 1419 – 29.62 X	0.8701
Y = Indirece tensile strength (kPa)		X = Testing temperature (° C)		

4. Conclusions

Based on the limitations of the implemented materials and the testing program, the following conclusions can be addressed.

- The tensile strength as obtained by SCB is (5.5, and 5) fold higher than that obtained by ITS when the specimens are tested at (20, and 0) °C respectively.
- The tensile strength obtained from the Semi-Circular Bend test (SCB) increases as the binder content increase when compared with that obtained from Indirect tensile strength test (ITS).
- The SCB tensile strength increases by 72.1 % when the specimens are tested at 0°C as compared with the testing at 20°C.
- The ITS declines by (48.3, and 80.1) %, (48.5, and 78.1) %, and (48.3, and 81.3) %when the testing temperature changes from (0 to 20 and 40) ° C for mixtures with (4.4, 4.9, and 5.4) % binder respectively.
- The obtained mathematical models can be implemented for evaluating the tensile strength of asphalt concrete at various binder content and testing environment.
- Both of the ITS and SCB testing techniques can be implemented to measure the tensile strength of asphalt concrete.

Declaration of Conflict of Interests

The author declares that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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