University of Baghdad
College of Engineering
JE
JOURNAL OF ENGINEERING

Journal of Engineering
journal homepage: www.joe.uobaghdad.edu.iq
Number 2 Volume 28 February 2022

Civil and Architectural Engineering

Permanent Deformation Characterization of Stone Matrix Asphalt Reinforced by Different Types of Fibers

Mohammed Q. Ismael *
Associate Professor
Department of Civil Engineering,
University of Baghdad
Baghdad, Iraq
drmohammedismael@coeng.uobaghdad.edu.iq

Mohammed Y. Fattah
Professor
Department of Civil Engineering,
University of Technology,
Baghdad, Iraq
40011@uotechnolog.edu.iq

Abbas F. Jasim
Assistant Professor
Department of Highway and Transportation Engineering,
Mustansiriyah University,
Baghdad, Iraq
abbas.jasim@uomustansiriyah.edu.iq

ABSTRACT

This paper focused on the stone matrix asphalt (SMA) technology that was developed essentially to guard against rutting distress. For this procedure, fibers play a racy role in stabilizing and preventing the drain down problem caused by the necessity of high binder content coupled with their strengthening effect. A set of specimens with cylindrical and slab shapes were fabricated by inclusions jute, polyester, and carbon fibers. For each type, three contents of 0.25%, 0.5%, and 0.75% by weight of mixture were added by lengths of 5, 7.5, and 10 mm. The prepared mixtures were tested to gain the essential pertained parameters discriminated by the values of drain down, Marshall quotient, rut depth, and dynamic stability. It has appeared that the fibers rate of 0.5% and 7.5 mm length is much appropriate to yield the best performance of modified mixtures. At these values, carbon fibers recorded the highest increase level of rutting resistance and dynamic stability by 53% and 100%, respectively while, jute fibers exhibited the lowest improvement by only 34% and 63%, respectively; nevertheless, they produced mixtures having the lowest drain down value. Regarding the index of plastic stiffness, polyester fibers embedded mixtures occupied the first rank of increasing by 38%.

Keywords: stone matrix asphalt, rutting, fibers, wheel tracking test, drain down, Marshall test.

توصيف التشوه الدائم لمصفوفة الاسفلت الحجرية المعززة بأنواع مختلفة من الألياف

محمد قادر اسماعيل*
أستاذ مشارك
جامعة بغداد- كلية الهندسة-قسم الهندسة المدنية

محمد يوسف فتاح
أستاذ
الجامعة التكنولوجية-قسم الهندسة المدنية

عباس فاضل جاسم
أستاذ مساعد
الجامعة المستنصرية-كلية الهندسة-قسم الطرق والنقل

الخلاصة

ركزت هذه المقالة على تقنية مصفوفة الأسفلت الحجرية (SMA) والتي تم تطويرها أساسًا للحماية من فشل التخدد. في هذه التقنية، تلعب الألياف دورًا فعالا في تثبيت ومنع مشكلة الصرف الناتجة عن ضرورة وجود محتوى عالٍ من المادة الرابطة إلى

---

*Corresponding author

Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2022.02.07

Article received: 26 / 12 / 2021
Article accepted: 27/ 1/ 2022
Article published:1/2/2022

جانب تأثير تقويتها. تم تصنيع مجموعة من العينات ذات الأشكال الأسطوانية واللوحية بواسطة الياف الجوت والبوليستر والكاربون. لكل نوع من الالياف تمت إضافة ثلاثة محتويات 0.25٪، 0.5٪، 0.75٪ من وزن الخلطة بأطوال 5، 7.5، 10 مم. تم اختبار الخلطات المحضرة لاكتساب المعلمات الأساسية ذات الصلة والتي تميزت بقيم الصرف، وصلابة مارشال، وعمق التخدد، والاستقرار الديناميكي. لقد ظهر أن معدل الألياف البالغ 0.5٪ وطول 7.5 مم مناسب جدًا لتحقيق أفضل أداء للخلطات المعدلة. عند هذه القيم، سجلت ألياف الكربون أعلى مستوى زيادة في مقاومة التخدد والاستقرار الديناميكي بنسبة 53٪ و100٪ على التوالي، بينما أظهرت ألياف الجوت أقل تحسن بنسبة 34٪ و63٪ فقط على التوالي؛ ومع ذلك، فقد أنتجوا خلطات لها أقل قيمة تصريف. فيما يتعلق بمؤشر الصلابة اللدنة، احتلت الخلطات المدمجة من ألياف البوليستر المرتبة الأولى حيث زادت بنسبة 38٪.

الكلمات الرئيسية: مصفوفة الاسفلت الحجرية، التخدد، الالياف، فحص مسار العجلة، التصريف، فحص مارشال.

1. INTRODUCTION

Among all designated distresses observed in asphalt pavement, the permanent deformation as manifested by its most harmful type of rutting catches the eyes as a serious challenge to the experts in this field of construction. Essentially, this distress progresses aggressively by the presence of high axle loads and a hot ambient environment. Subsequently, deep rutting depths encourage water accumulation, which causes hazard issues to the vehicles. Over the past years, numerous remedies have been tried to minimize the rutting extent. Some of these remedies concentrated on the nature of the asphalt mixture system. In this way, the employing of stone matrix asphalt yielded immense success **(Abu Abdo and Khater, 2018; Chilukwa and Lungu, 2019; Hamedi et al., 2021; Chin and Charoentham, 2021)**.

In fact, stone matrix asphalt (also known as stone mastic asphalt) is another form of hot mix asphalt which distinguished by a skeleton of a high percentage of coarse aggregate (approximately 70-80% by weight of aggregates) surrounded by a rich mortar of asphalt binder and filler composition **(Drüschner and Schäfer, 2000)**. This high portion of coarse aggregate produces a unique condition where these particles become in contact without the interference of other mixture components, leading to an increase in the contact loading area, which maximizes the stress resisting capacity of asphaltic pavement. Initially, this type of mixture was developed by German researchers in 1960 and has rapidly gained a prominent application across Europe and the United States over the past years. Because of high binder content, the durability and workability of this paving material are relatively high and considered a beneficial feature.

Essentially, this paving technology's main advantage is its high potential for rutting resistance due to the coarse nature of its mixture skeleton **(Bernard, 2017; Kumar and Ravitheja, 2019)**. Nevertheless, the necessity for relatively higher binder content arises a likely drain down problem, which might occur during transporting and placement of paving mixture. To solve this critical issue, stabilizing additives like fibers are utilized in the mixture preparation process **(Kumar and Shankar, 2019; Huang et al., 2020)**. To hold the drain value to 0.3% or less, the AASHTO M 325 **(AASHTO, 2008)** recommended using cellulose or mineral fibers as stabilizing additives with a dosage rate of 0.3% and 0.4%, by total weight of mixtures, respectively.

1.1 Effect of Fibers on SMA Mixtures Properties

Although many studies proved the adequacy of using natural cellulose fibers in improving SMA mixtures properties **(Slebi-Acevedo et al., 2019; Kumar, Chandra and Bose, 2007; Huang et al., 2020)**, other fibers have experimented. In this line, an interesting work conducted by Putman and Amirkhanian, 2004 **(Putman and Amirkhanian, 2004)** has indicated the possibility of using carpet fiber as a stabilizer for SMA mixtures without any significant difference in performance parameters compared to the cellulose fiber. To minimize the problem of drain down, Chowdhury et al., 2006 **(Chowdhury, Button and Bhasin, 2006)** tested SMA mixtures that contained waste tire fibers. These mixtures outperformed the mixtures with no fibers or those with cellulose fibers. The Inclusion of glass fibers in SMA mixtures was assessed by Mahrez and Karim, 2007 **(Mahrez and Karim, 2007)**; they established a bold statement of adopting this fiber type to extend the resilient modulus value, which promotes the potential of rutting resistance. According to Kaloush et al., 2010 **(Kaloush et al., 2010)**, aramid fibers, typically considered synthetic polymer fibers, enhance the permanent deformation due to the contraction state at high temperatures. Awanti et al., 2012 **(Awanti et al., 2012)** carried out an experimental investigation on SMA mixtures prepared by incorporating coconut and cellulose fibers. The outcome of their work indicated that mixtures fabricated with coconut fibers consumed more binder content and exhibited higher tensile strength—however, the drain down test results leaned in favor of the inclusive cellulose mixtures. Using jute fibers recorded an earlier experience by Kumar et al., 2004 **(Kumar et al., 2004)**, as they compared the SMA mixtures containing these fibers with a synthetic one, the results have depicted that jute fibers enhance the resistance to permanent deformation better than synthetic fibers. Raghuram and Chowdary, 2013 **(Raghuram and Chowdary, 2013)** have performed the wheel tracking test on specimens fabricated using different fiber types such as coconut fibers, oil palm fibers, and jute fibers and compared the rut depth after 20000 load applications with the control mixture. In conclusion, their study has indicated that jute fibers introduce mixtures with a higher rutting resistance value equals 42%. Depending on the wheel tracking test results, Yang et al., 2006 **(Yang et al., 2006)** have proponent the use of polyester fibers than celluloses. This effort has been emphasized by the research work of Chen and Xu, 2010 **(Chen and Xu, 2010)** that encourages using polyester fibers to increase the mechanical properties of SMA mixtures. They justify this performance enhancement by higher ductility and asphalt absorption of this fiber. Lavasani et al., 2015 **(Lavasani, Latifi Namin and Fartash, 2015)** tried to incorporate the polyester and rock wool fibers in the preparation of SMA, and their efforts articulated the improvement in mixtures' mechanical properties with no significant difference in permanent deformation between the two fibers types.

Notwithstanding, it seems that polyester fibers, due to their lower specific gravity, need lower weight to present at an optimum content. Sheng et al., 2017 **(Sheng et al., 2017)** carried out an experimental study to incorporate polyester fibers in SMA mixtures in this context. The results revealed that a higher Marshall stability value was obtained by using such types of fibers compared to lignin fibers. Furthermore, their work has suggested that the optimum content of polyester fibers should be higher than 0.3%. Due to exceptional stiffness and tensile strength properties, the carbon fibers are outstanding in all other types of reinforcement fibers **(Liu and Wu, 2011; Slebi-Acevedo et al., 2019)**. The work research carried out by Kareem et al., 2010 **(Kareem, Ahmed and Asmael, 2010)** referred to that carbon fibers exhibited high tensile strength properties for SMA mixtures at 5 °C compared to the mixtures fabricated by utilizing polypropylene fibers. However, this behavior is reversible at 25 °C. In addition, they reported higher flow and lower Marshall stability values for carbon fibers modified mixtures. In contrast, the work conducted by Karunakar et al., 2018 **(Karunakar et al., 2018)** indicated that carbon fibers elevated the Marshall stability by approximately 12% more than glass fibers did; besides, the drain down results favored using carbon fibers.

2. OBJECTIVE OF THE STUDY

The present work sought to evaluate the use of different natural and synthetic fibers incorporated by different values of content and length to produce SMA-mixtures that can effectively withstand the rutting distress. This aim is intended to be achieved by conducting several laboratory tests.

3. MATERIALS and TESTING METHODS

An elaborate effort should be devoted to the SMA design even though many design features for this mixture type are harmonized with the conventional hot mix asphalt. The essential aspect is to provide the concept of "stone-on-stone contact" for the coarse aggregate skeleton. This design target is achieved by keeping the aggregate passing sieve No.4 to around 30%. However, another primary concern in this production process is providing a relatively high amount of bitumen-filler mortar, which needs a higher amount of filler. This high content of very fine particles causes more bitumen to be absorbed in turn. The following items demonstrate in detail the individual components of SMA mixtures preparation in addition to the testing methodology.

3.1 Asphalt Cement

The decision was made to utilize the high viscosity asphalt cement of 40/50 grade due to its suitability in the areas of elevated temperature that are significantly associated with the appearance of rutting. It was brought from Al-Daurah refinery in Baghdad city. **Table 1** lists the physical properties in parallel with the Iraqi specification requirements, SCRB R/9 2003 **(The State Coporation for Roads and Bridges, 2003)**.

Table 1. Properties of asphalt cement.

Test	Unit	Method	Result	SCRB
Penetration	0.1 mm	ASTM D5	43	40-50
Softening Point	°C	ASTM D36	53	……
Specific Gravity	……	ASTM D70	1.04	……
Ductility	cm	ASTMD113	124	>100
Flash Point	°C	ASTM D92	317	> 232
Residue from TFOT				
Retained Penetration,%	%	ASTM D5	82	> 55
Ductility	cm	ASTM D113	72	> 25

3.2 Aggregates

To ensure maximum load-carrying capacity and follow the path of design strategy specified by AASHTO M 325, all the coarse and fine aggregate particles have been selected from entirely crushed gravel brought from certified and experienced local sources. As for the fine part that passed sieve No.4, which approximately comprised 10 percent of the whole aggregate bulk.

The limestone dust with no agglomerations or organic impurities has been utilized regarding the mineral filler. The gradation of the combined aggregate follows the proportions prescribed by AASHTO M 325 with a nominal aggregate maximum size of 12.5 mm, which is regularly implemented for the wearing course construction is shown in **Fig. 1**; while **Tables 2** and **3** display the main properties of these aggregates.

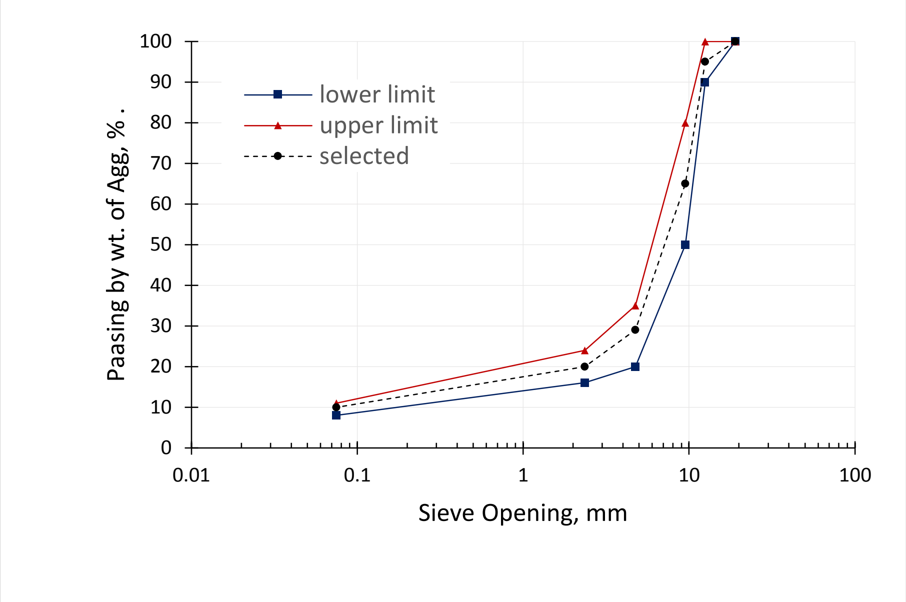

Figure 1. Gradation of combined aggregate.

Table 2. Properties of coarse aggregate.

Test	Method	Specification	Result
Los Angeles Abrasion, %	AASHTO T96	≤ 30	12
Flat and Elongated, %	ASTM D4791	≤ 20	4
Absorption, %	AASHTO T85	≤ 2	0.8
Soundness, %	AASHTO T104	≤ 15	3

Table 3. Properties of coarse aggregate.

Test	Method	Spec.	Result
Liquid Limit, %	AASHTO T89	≤ 25	4
Soundness, %	AASHTO T104	≤ 15	1.5

3.3 Fibers

Three different types (natural and synthetic sources) were used in varying quantities and lengths: jute, polyester, and carbon fibers. Their amounts are 0.25, 0.5, and 0.75 as a percentage of a total mixture weight. For each dosage, three lengths were appropriated, which are 5, 7.5, and 10 mm. The jute is a plant's naturally produced fibers and consists mainly of cellulose (77%) and lignin (12%). Because of its high strength, low price, and environment-friendly relation, jute fiber is the second globally produced natural fiber directly ranked after cotton and is employed chiefly in the sacking industry **(Gani and Ali, 2018; Islam and Ali, 2018)**. The polyester fiber, produced by polymerization of the crude oil components **(Abtahi, Sheikhzadeh and Hejazi, 2010; Ismael and Al-Taher, 2015)**, is considered one of the most widely used synthetic organic fibers as it occupies about 20% of all produced plastic material. It exhibited a high melting point associated with extremely tensile strength properties **(McDaniel, 2015; Mohajerani et al., 2019)**. The carbon fibers consist primarily of fragile carbon component strands, which exhibit ultra tensile strength, making them possibly the most robust existing material. Furthermore, they manage to resist approximately all types of chemical and physical corrosion coupled with low conditions variations caused by temperature changes **(Gite and Margaj, 2013; Wu et al., 2015; Mawat and Ismael, 2020)**. **Table 4** shows some properties of these fibers, while **Fig. 2** depicts their samples.

Table 4. Properties of utilized fibers.

Property	Unit	Jute	Polyester	Carbon
Density	g/cm^3	1.42	1.36	1.82
Diameter	µm	31	20	8
Melting Point	°C	…..	255	970
Tensile Strength	MPa	356	550	≥ 4000
Price	$/kg	2	4	37

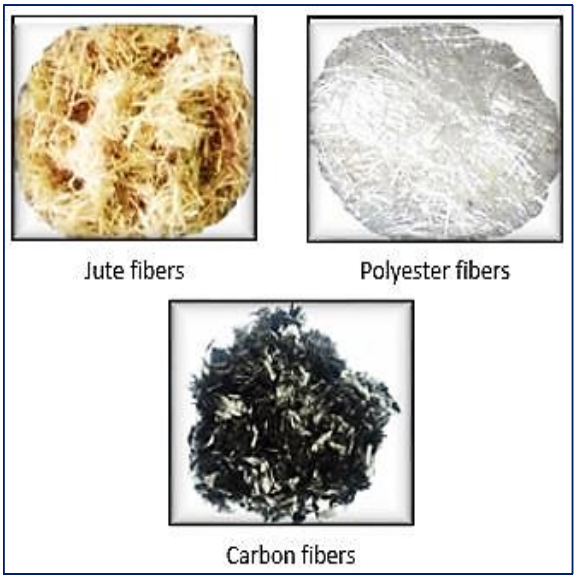

Figure 2. Samples of utilized fibers.

3.4 Preparation of SMA Mixtures

In order to comply with the design standard practice, the following volumetric parameters have been calculated depending on equations listed below, voids in mineral aggregate, VMA >17%, and total air voids content of 3-4%.

$$VMA = 100 - \frac{G_{mb}}{G_{sb}}\ P_s \tag{1}$$

$$V_a = 100\ \times \left(1 - \frac{G_{mb}}{G_{mm}}\right) \tag{2}$$

Where: G_{mb} = the bulk sp. gr. of the compacted mixture, G_{sb} = the bulk sp. gr. of the total aggregate; P_s = the percent aggregate in the mixture, and G_{mm} = the theoretical maximum density of the mixture.

Following the mixtures' ingredients preparation phase, the fibers have been added to the aggregate rather than blending with hot bitumen to avoid any possibility of heterogeneous or melting issues. Visual inspection to avoid any clumping situation while mixing was helpful for this purpose. The fibers addition process shorty preceded the hot bitumen blending. The mixing and compaction temperatures were achieved based on the viscosity threshold of 170±20 cSt and 280±30 cSt, respectively. Then, the optimum asphalt content becomes the primary concern. For this purpose, the air void content value of 4% is marked as the main criterion. Accordingly, the 6.5% by mixture weight was designated as the optimum asphalt content. Following this step, a set of specimens have been fabricated, as shown in **Fig. 3**.

Figure 3. Asphalt mixtures preparation and specimens.

3.5 Drain Down Test

This test is comprehensively illustrated in ASTM D6390 **(ASTM D 6390, 2017)**. Briefly, it is constituted of weighing the drained-off material across the net of a wire basket after one hour of heating at 10 °C above the anticipated plant production temperature (i.e., 170 °C). The ratio of drained-off mass to the original loss mixture (i.e., 1200 g), as shown in Eq. (3), is expressed as drain down level. This criterion is limited by the AASHTO T 305 to be not more than 0.3%.

$$Drain\ down, \% = \frac{C-B}{A} * 100 \tag{3}$$

Where: A= basic weight of the tested mixture, B= weight of the pan, and C= weight of the pan plus the drained out bitumen material.

3.6 Marshall Quotient

Conventionally, the Marshall test measures both stability and the corresponding flow magnitude, and their ratio produces the Marshall quotient. The cylindrical specimens (101.6 mm in diameter and 63.5 mm in height) consumed approximately 1210 g of the prepared mixture. The compaction effort was maintained at 75 blows for each face. To bring the specimens to the specified testing temperature, they were immersed in a hot water bath conditioned at 60 °C for 40 minutes. Afterward, the specimens were speedily mounted in the Marshall apparatus to avoid temperature drop. A pressurized load was subjected across the diametrical specimen orientation until failure occurred; at this point, the load coupled with the corresponding failure flow was recorded.

3.7 Wheel Tracking Test

To practically monitor the propagation of the rut depth, the wheel tracking test was performed according to the requirements enclosed in AASHTO T 324. This test was conducted at 55 °C with applied stress of 0.55 MPa. This stress was induced by loading 100 kg total weight over a nearly circular contact area of 5 cm diameter, imprinted by a 20 cm steel wheel covered by hard rubber. The number of passes was maintained at 30 per minute. Approximately 13 kg of prepared SMA mixture was needed to fabricate a slab-shaped specimen with dimensions of 400*300*50 mm. The termination criterion was marked at 25 mm depth or 10000 cycles (whichever comes first) **(Saleem and Ismael, 2020; Ismael, Fattah and Jasim, 2021)**. This test yields also another significant rutting related index labeled by the dynamic stability value that represents the number of repetitions needed to produce 1.0 mm incremental deformation that induced during the last 2500 of load application as demonstrated by the following equation:

$$D.S=\frac{10000-7500}{R_{10000}-R_{7500}} \tag{4}$$

Where: D.S = Dynamic stability (cycle /mm), R_{10000} = Rut depth @ 10000 cycle (mm), and R_{7500} = Rut depth @ 7500 cycle (mm). **Fig. 4** shows the asphalt mixtures performed tests.

Figure 4. Performed tests for asphalt mixtures.

4. RESULTS and DISCUSSION

Fig. 5 to **7** visualize the outputs of the drain down test. At first glance, it seems that the control mixtures exhibited relatively exceeded drain down value. For the three fibers types, as a general trend, increasing the dosages of fibers dropped the value of drain down, and it was found that jute fibers are the most influential type followed by polyester fibers, while carbon fibers ranked last to this test requirement. Numerating this, the drain down value dropped to only 0.05% as the jute fibers incorporated by 0.75% content and 5 mm length. Similarly, the polyester and carbon fibers trace the same steps, and for the same percentage and length, the reduction value became 0.18% and 0.20%, respectively. The justification of this behavior belongs to the natural source of jute fibers that has an almost rough texture that absorbs more bitumen. The results also indicated that increasing the length negatively influenced the drain down value for the same percent of fibers and regardless of the kind. As a clear demonstration, when the jute fibers length increased from 5 mm to 10 mm, the drain down value witnessed an undesirable increase that reached 140% for the upper content limit of 0.75%. However, this adverse effect was slightly minimized when the fibers' contents decreased for the polyester and carbon fibers. Explaining this behavior is based on the fact that as the length of fibers becomes long, the corresponding dispersed amount becomes lower, which means less opportunity to act as an absorbing membrane.

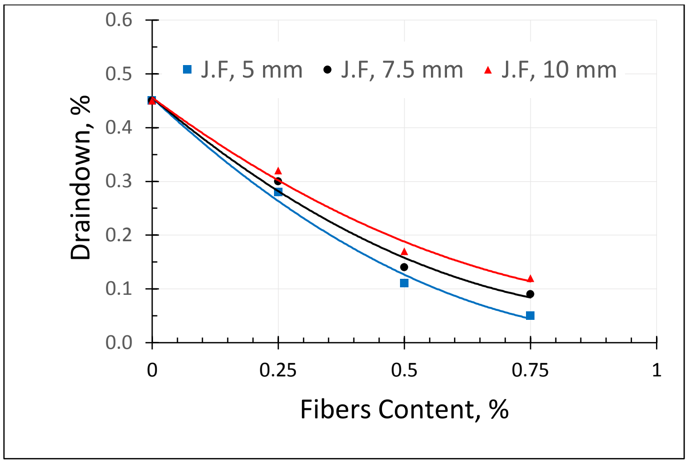

Figure 5. Effect of jute fibers on drain down.

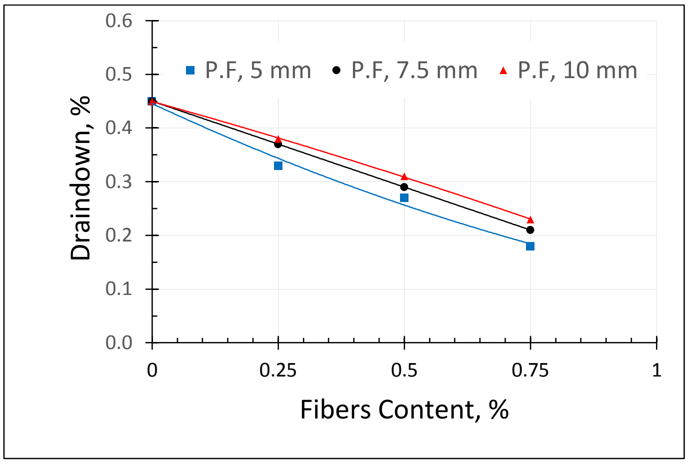

Figure 6. Effect of polyester fibers on drain down.

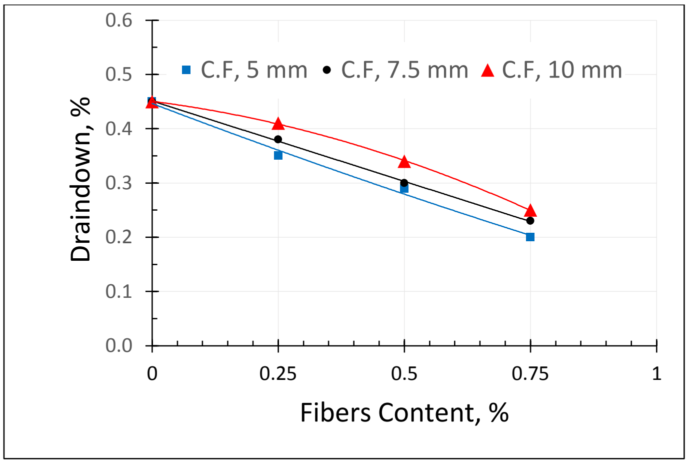

Figure 7. Effect of carbon fibers on drain down.

Figs. 8 to **10** graphically demonstrate the practical relations between the Marshall quotient (index of plastic stiffness) and the variation imposed in quantities and lengths for the three experimented fibers. These figures, despite the behavior of carbon fibers, noticeably depict that implication fibers in specimens' structure raised their stiffness level to a certain extent; thereafter, a slight reduction have occurred. In detail, the polyester fibers acquired the higher score in this test, where the 0.5% amount of 7.5 mm length raised the stiffness value by 38%. This growth value was also almost achieved when the same length utilized the carbon fibers but at higher content of 0.75%. The jute fibers occupied the last rank of modification; herein, the Marshall stiffness improved by 19% at a content of 0.5% and a length of 7.5 mm.

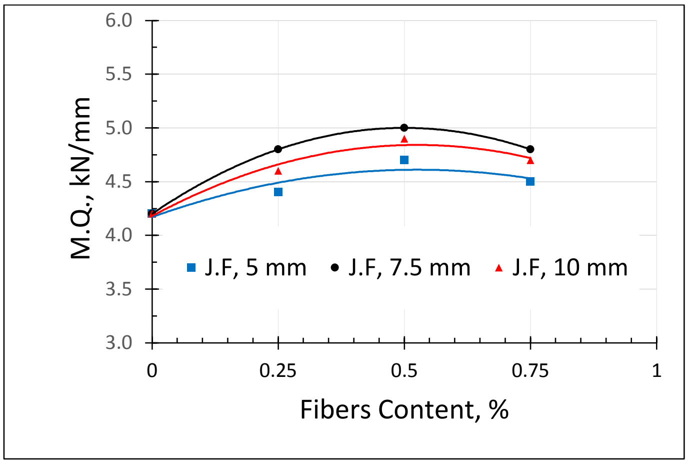

Figure 8. Effect of jute fibers on Marshall quotient.

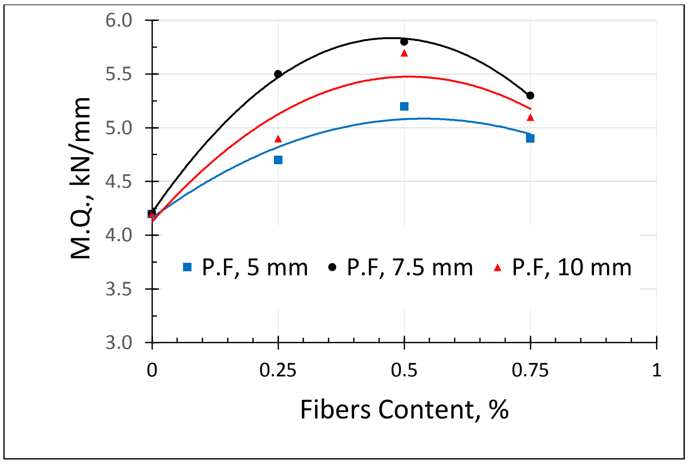

Figure 9. Effect of polyester fibers on Marshall quotient.

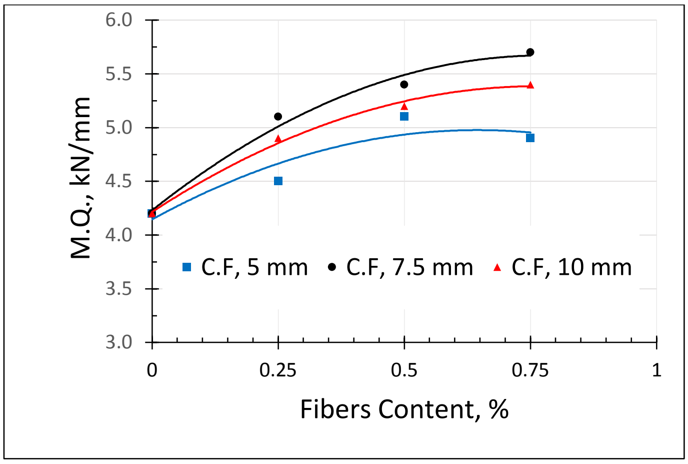

Figure 10. Effect of carbon fibers on Marshall quotient.

Table 5 lists all the gained results of the wheel tracking test. Also, **Fig. 11** shows the rutting depth as a function of the applied load cycles for the best mixtures performance, while **Fig. 12** demonstrates the accumulated rutting depth at cycle number 10000. Regarding dynamic stability, **Fig. 13** display the best-achieved results. Generally, these outputs elucidated that carbon fibers embedded with 0.5% content and 7.5 mm length has made the rut depth remarkably plummet from 9.5 mm for control mixtures to just about 4.5 mm, allocated the peak point of resistance by an approximate value of 53%. In addition, the dynamic stability of these fiber-modified mixtures became two times as being elevated from 464 cycle/mm to 926 cycle/mm. Likewise, the best performance was achieved at the exact dosage mentioned above and length for the polyester and jute fibers but with relatively lower increasing values of 42% and 34%, respectively. The improvement for the jute and polyester fibers reached 68% and 63% of the dynamic stability index, respectively. The explanation of carbon fibers' outstanding performance may have been attributed to their high tensile strength and heat resistance which gives them a chance to remain in regular orientation while mixing and compaction process. Nevertheless, when the subject hits the cost interest and closely observes the results, the polyester fibers may be nominated as an excellent alternative to carbon fibers with their relatively low price.

Table 5. Final rut depth for utilized fibers.

Fibers	Jute			Polyester			Carbon		
%	5 mm	7.5 mm	10 mm	5 mm	7.5 mm	10 mm	5 mm	7.5 mm	10 mm
0.25	7.6	7.1	7.4	6.7	6.2	6.4	5.8	5.1	5.3
0.50	6.7	6.3	6.5	5.8	5.2	5.5	5.0	4.5	4.7
0.75	7.1	7.5	7.8	6.3	5.7	6.0	5.2	4.8	5.0

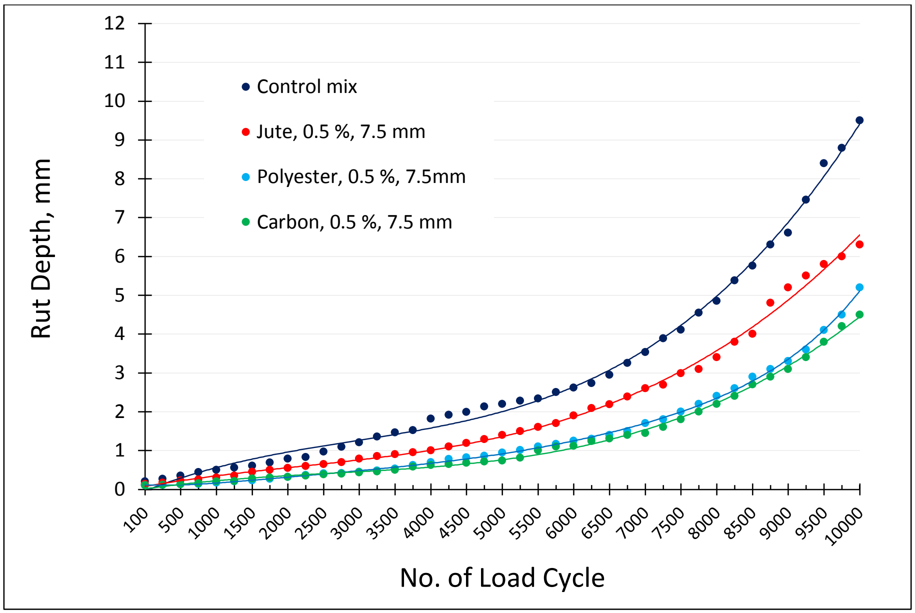

Figure 11. Rut depth vs. load cycle.

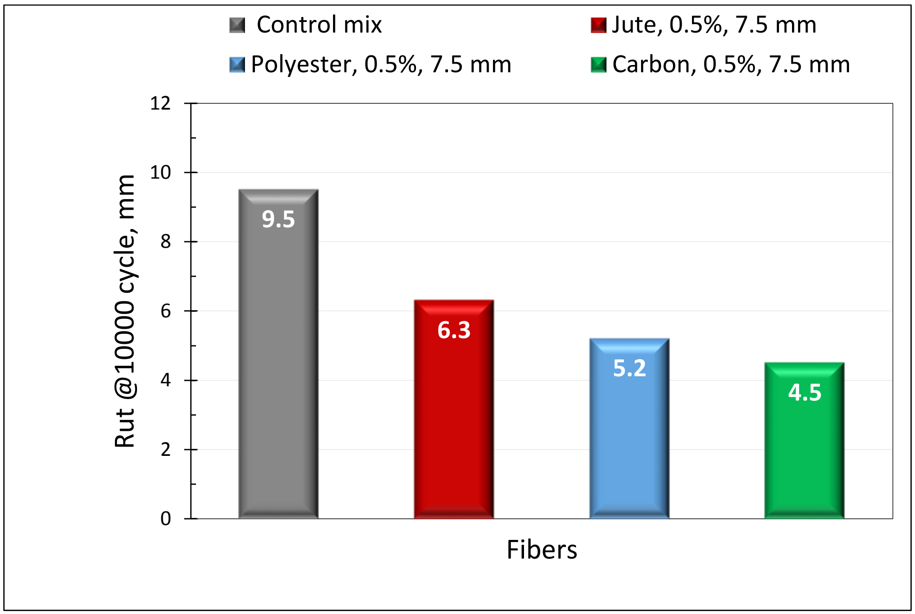

Figure 12. Best rutting resistance results.

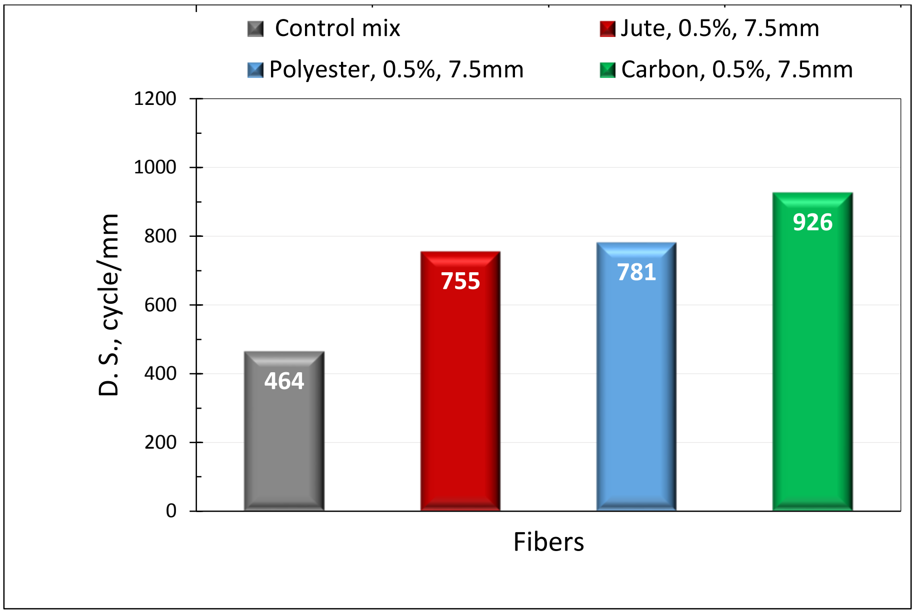

Figure 13. Best dynamic stability results.

5. REGRESSION MODEL

The statistical effort involved operating SPSS software to establish a regression model for rutting prediction. The final accumulated rutting (RD) was set as a response variable, while the explanatory variables consisted of fibers type (FT), fiber content (FC), fibers length (FL), drain down (DR), Marshall quotient (MQ), and dynamic stability (DS). **Tables 6** and **7** show the descriptive statistics and ANOVA results, respectively, for these variables. The model building was set at a 95% confidence level (i.e., 0.05 significance level). The produced model shown in Eq. (5) has a high R^2 value (0.962), indicating a solid relationship among correlated variables.

Table 6. Descriptive statistics.

	Mean	**Std. Deviation**	**N**
RD	6.1679	1.15279	28
FT	1.9286	.89974	28
FC	.4821	.22493	28
FL	7.2321	2.48507	28
DR	.2625	.10226	28
MQ	4.9964	.40596	28
DS	774.0714	98.00715	28

Table 7. ANOVA results.

Model		SS	df	MS	F	Sig.
1	Regression	34.535	6	5.756	89.775	.000^{b}
	Residual	1.346	21	.064		
	Total	35.881	27			

$$RD = 16 - 0.36\,FT + 0.45\,FC + 0.02\,FL + 1.3\,DR - 0.98\,MQ - 0.05\,DS \quad (5)$$

6. CONCLUSIONS

The value of this research lies in addressing the role played by three factors of fibers: type, quantity, and length in influencing the performance of SMA-mixtures related to the resistance of permanent deformation. In the light of several test outputs, the following conclusions were drawn.

- All types of fibers succeeded in improving the mixtures' rutting resistance. The carbon fibers (0.5% content and 7.5 mm length) recorded the most remarkable improvement (53% increase). Moreover, the results indicated a 100% increase in the value of dynamic stability for the same fibers. In like manner and for the exact utilized dosages and lengths, the polyester and jute fibers notably raised the rutting resistance by 42% and 34%, respectively. Furthermore, they boosted the dynamic stability by 68% and 63%, respectively.
- Because SMA-mixtures need more asphalt content for fabrication, a detrimental effect discriminated by the drain down problem appeared. All the used fibers effectively reduced this defect; in this context, the jute fiber marked the highest percentage of decreasing, when only 0.05% of drain down occurred for a quantity of 0.75% and 5 mm length. On the other hand, the polyester and carbon fibers recorded lesser reduction values for the same content and length as the drain down became 0.18 % and 0.20 %, respectively.
- Marshall's quotient witnessed a significant increase by 38% for polyester fibers modified mixtures at a rate of 0.5% and 7.5 mm length. Likewise, the carbon fibers included at a rate of 0.75% and 7.5 mm length produced mixtures with almost the same previous improvement, while the 7.5 mm length of jute fibers modified mixtures recorded the least improvement level by only 19% at a content of 0.5%.
- Although the carbon fibers modified mixtures ranked firstly of rutting resistance improvement, this research, by taking into account the costing issue, recommends using polyester fibers at a rate of 0.5% and a length of 7.5 mm to get an excellent performance SMA-mixtures.

REFERENCES

- AASHTO, 2008. *Standard specification for stone matrix asphalt (SMA)*.
- Abtahi, S.M., Sheikhzadeh, M. and Hejazi, S.M., 2010. Fiber-reinforced asphalt-concrete–a review. *Construction and Building Materials*, 24(6), pp.871–877.
- Abu Abdo, A.M. and Khater, M.E., 2018. Enhancing rutting resistance of asphalt binder by adding plastic waste. *Cogent Engineering*, [online] 5(1), pp.1–7. Available at: <http://doi.org/10.1080/23311916.2018.1452472>.
- ASTM D 6390, 2017. *Standard Method of Test For Determination of Draindown Characteristics In Un-compacted Asphalt Mixtures*. ASTM International, West Conshohocken, PA.
- Awanti, S.S., Habbal, A., Hiremath, P.N., Tadibidi, S. and Hallale, S.N., 2012. Characterization of stone matrix asphalt with cellulose and coconut fiber. In: *Advances in Civil Engineering and Building Materials - Selected Peer Reviewed Papers from 2012 2nd International Conference on Civil Engineering and Building Materials, CEBM 2012*. pp.639–642.
- Bernard, B., 2017. A Review on Various Issues Related to Stone Matrix Asphalt. *Int. J. Pavement Res. Technol.*, 4(12), pp.588–591.
- Chen, H. and Xu, Q., 2010. Experimental study of fibers in stabilizing and reinforcing asphalt binder. *Fuel*, 89(7), pp.1616–1622.
- Chilukwa, N. and Lungu, R., 2019. Determination of Layers Responsible for Rutting Failure in a Pavement Structure. *Infrastructures*, 4(2), p.29.
- Chin, C. and Charoentham, N., 2021. Laboratory investigation of stone mastic asphalt mixtures containing coconut fiber. *Engineering and Applied Science Research*, 48(2), pp.131–136.
- Chowdhury, A., Button, J.W. and Bhasin, A., 2006. *Fibers from recycled tire as reinforcement in hot mix asphalt*.
- Drüschner, L. and Schäfer, V., 2000. *Stone Mastic Asphalt*.
- Gani, M.N. and Ali, M.S., 2018. Md. Mahbubul Islam. Nutritional Requirements of Newly Released Tossa Jute MG-1. *American Journal of Food, Nutrition and Health*, 3(2), pp.31–34.
- Gite, B.E. and Margaj, M.S.R., 2013. Carbon fibre as a recent material use in construction. *Civil Engineering Portal. Retrieved from http://www. engineeringcivil. com/carbon-fibre-as-arecent-material-use-in-construction. html*.
- Hamedi, G.H., Sakanlou, F., Omari, B. and Azarhoosh, A., 2021. Laboratory Investigation of the Effect of Ceramic Fiber on Stone Matrix Asphalt Rutting Performance. *Journal of Materials in Civil Engineering*, 33(1), p.4020431.
- Huang, Y., Liu, Z., Liu, L., Zhang, Y. and Xu, Q., 2020. Hybrid Modification of Stone Mastic Asphalt with Cellulose and Basalt Fiber. *Advances in Materials Science and Engineering*, 2020.
- Islam, M.M. and Ali, M.S., 2018. Industrial Research Advances of Jute in Bangladesh. *International Journal of Agricultural and Biosystems Engineering*, 3(1), pp.1–9.
- Ismael, M.Q. and and Al-Taher, H.M., 2015. Reinforcement of Asphalt Concrete by Polyester Fibers to Improve Flexural Bending Fatigue Resistance. *Journal of Engineering/UoBaghdad*, 21(1), pp.115–130.
- Ismael, M.Q., Fattah, M.Y. and Jasim, A.F., 2021. Improving the rutting resistance of asphalt pavement modified with the carbon nanotubes additive. *Ain Shams Engineering*

Journal, [online] 12(4), pp.3619–3627. Available at: <https://doi.org/10.1016/j.asej.2021.02.038>.

- Kaloush, K.E., Biligiri, K.P., Zeiada, W.A., Rodezno, M.C. and Reed, J.X., 2010. Evaluation of fiber-reinforced asphalt mixtures using advanced material characterization tests. *Journal of Testing and Evaluation*, 38(4), pp.400–411.
- Kareem, Q.S., Ahmed, A.I. and Asmael, N.M., 2010. Effect of Additives Types and Contents on the Properties of Stone Matrix Asphalt Mixtures. *Engineering and Technology Journal*, 28(21), pp.6414–6426.
- Karunakar, K., Sravana, P., Goud, K.G. and Sowjanya, T., 2018. Properties of Stone Matrix Asphalt Using Carbon Fiber and Glass Fiber. *International Journal of Engineering Sciences Invention (IJESI)*, 7(6), pp.45–52.
- Kumar, G.S. and Shankar, A.U.R., 2019. Evaluation of Workability and Mechanical Properties of Stone Matrix Asphalt Mixtures Made With and Without Stabilizing Additives. *Transportation Infrastructure Geotechnology*, pp.1–14.
- Kumar, N.L.N.K. and Ravitheja, A., 2019. Characteristics of stone matrix asphalt by using natural fibers as additives. *Materials Today: Proceedings*, 19, pp.397–402.
- Kumar, P., Chandra, S. and Bose, S., 2007. Laboratory investigations on SMA mixes with different additives. *International Journal of Pavement Engineering*, 8(1), pp.11–18.
- Kumar, P., Sikdar, P.K., Bose, S. and Chandra, S., 2004. Use of jute fibre in stone matrix asphalt. *Road materials and pavement design*, 5(2), pp.239–249.
- Lavasani, M., Latifi Namin, M. and Fartash, H., 2015. Experimental investigation on mineral and organic fibers effect on resilient modulus and dynamic creep of stone matrix asphalt and continuous graded mixtures in three temperature levels. *Construction and Building Materials,* [online] 95, pp.232–242. Available at: <http://dx.doi.org/10.1016/j.conbuildmat.2015.07.146>.
- Liu, X. and Wu, S., 2011. Study on the graphite and carbon fiber modified asphalt concrete. *Construction and Building Materials*, 25(4), pp.1807–1811.
- Mahrez, A. and Karim, M.R., 2007. Rutting characteristics of bituminous mixes reinforced with glass fiber. In: *Proceedings of the Eastern Asia Society for Transportation Studies Vol. 6 (The 7th International Conference of Eastern Asia Society for Transportation Studies, 2007)*. Eastern Asia Society for Transportation Studies.p.282.
- Mawat, H.Q. and Ismael, M.Q., 2020. Assessment of moisture susceptibility for asphalt mixtures modified by carbon fibers. *Civil Engineering Journal (Iran)*, 6(2), pp.304–317.
- McDaniel, R., 2015. *NCHRP SYNTHESIS 475 Fiber Additives in Asphalt Mixtures*.
- Mohajerani, A., Hui, S.Q., Mirzababaei, M., Arulrajah, A., Horpibulsuk, S., Kadir, A.A., Rahman, M.T. and Maghool, F., 2019. Amazing types, properties, and applications of fibres in construction materials. *Materials*, 12(16), pp.1–45.
- Putman, B.J. and Amirkhanian, S.N., 2004. Utilization of waste fibers in stone matrix asphalt mixtures. *Resources, conservation and recycling*, 42(3), pp.265–274.
- Raghuram, K.B. and Chowdary, V., 2013. Performance evaluation of stone matrix asphalt (SMA) using low cost fibres. In: *JourNal of The INdIaN roads CoNgress Volume 74-2*. p.159.
- Saleem, A.A. and Ismael, M.Q., 2020. Assessment Resistance Potential to Moisture Damage and Rutting for HMA Mixtures Reinforced by Steel Fibers. *Civil Engineering Journal*, 6(9), pp.1726–1738.
- Sheng, Y., Li, H., Guo, P., Zhao, G., Chen, H. and Xiong, R., 2017. Effect of fibers on mixture design of stone matrix asphalt. *Applied Sciences*, 7(3), p.297.

- Slebi-Acevedo, C.J., Lastra-González, P., Pascual-Muñoz, P. and Castro-Fresno, D., 2019. Mechanical performance of fibers in hot mix asphalt: A review. *Construction and Building Materials*, [online] 200, pp.756–769. Available at: <https://doi.org/10.1016/j.conbuildmat.2018.12.171>.
- The State Coporation for Roads and Bridges, 2003. *Standard Specifications for Roads and Bridges, Section R/9:Hot-Mix Asphalt Concrete Pavement*. Baghdad, Iraq.
- Wu, M.-M., Li, R., Zhang, Y.-Z., Fan, L., Lv, Y.-C. and Wei, J.-M., 2015. Stabilizing and reinforcing effects of different fibers on asphalt mortar performance. *Petroleum Science*, 12(1), pp.189–196.
- Yang, J., Shi, X., Wan, J., Qian, G., Pan, W. and Yang, Y., 2006. Evaluation of rutting resistance of double-layered asphalt mixes. *Road materials and pavement design*, 7(4), pp.533–542.