DOI: 10.15649/2346030X.3243
Aibi revista de investigación, administración e ingeniería. Volume 11, Number 3, Pág 71-80, September - December 2023, ISSN 2346-030X

Effect of carbon fibers (length, dosage) on the Marshall and volumetric properties of HMA mixtures.

Nadheer Albayati[1], Mohammed Qader Ismael[2]
[1,2]*University of Baghdad, Baghdad - Irak*
ORCID: [1]*0009-0001-0607-2959*, *0000-0003-3254-0557*

Received: June 15, 2023.
Accepted: August 08, 2023.
Published: September 01, 2023.

***Abstract*—** This study investigates the effect of carbon fibers when added to HMA mixtures incorporating recycled concrete aggregate on Marshall properties. It included identifying the optimum asphalt contents according to the Marshall design method for mixtures containing 20, 40, 60, 80, and 100% coarse recycled concrete replaced with coarse virgin aggregate. Two lengths of 10 and 20 mm of carbon fibers had been added with three percentages of 0.15, 0.25, and 0.35% from the total weight of the mixture. The results showed all mixtures containing recycled concrete aggregate met SCRB 2003 Iraqi standard requirements for wearing coarse type IIIA. Replacement of virgin aggregate by recycled concrete aggregate led to an increase in optimum asphalt contents, in which the maximum increase reached 10.78% over the control mixture when 100% of coarse recycled concrete aggregate was utilized. The Marshall characteristics were altered with carbon fiber, which increased stability. The highest level of stability reached about 38.89% over the control mixture when using 60% recycled concrete aggregate and reinforced by 0.35% carbon fibers with a length of 20mm.

Keywords: marshall properties, recycled concrete aggregate, carbon fibers, HMA.

*Corresponding author.
Email: nazeer.khaled2101m@coeng.uobaghdad.edu.iq (Nadheer Albayati).

How to cite this article: N. Albayati and M. Q. Ismael, "Effect of carbon fibers (length, dosage) on the Marshall and volumetric properties of hma mixtures", *Aibi research, management and engineering journal*, vol. 11, no. 3, pp. 71-80 2023, doi: 10.15649/2346030X.3243

I. INTRODUCTION

Road network development is a key indicator of progress for a nation [1]. Road safety is closely related to the condition of the road where dangerous incidents are more likely to occur on deteriorated roads [2]. Around the world, hot mix asphalt (HMA) has demonstrated its ability to successfully provide a suitable paving surface for transportation services [3]. Asphalt pavement layers provide an important function in preserving the underlying structure by distributing vertical wheel loads to the lower or foundation layers [4]. A large portion of Iraq's roadways were constructed out of asphaltic concrete due to the availability of raw materials, ease of manufacturing, and low cost [5]. The asphalt mixture consists of the main components which are asphalt cement, coarse and fine aggregate, and filler [6]. In other words, the substance is a complicated mixture of multiple separate compounds, each of which affects the mixture's qualities differently [7]. The asphalt mixture consists of three essential phases: asphalt cement, aggregate, and air voids. Aggregate is a stiff substance that behaves as an elastic material, whereas binder exhibits visco-elastic behavior and will flow under the loads depending on ambient temperature. The primary intent of asphalt cement is to hold aggregate particles collectively in contact and reduce separation due to rolling tires. It is a vital component in asphalt mixtures because there is no other material to bind aggregate parts properly. Air voids are a fundamental characteristic of asphalt mixtures as well, which combine with aggregate and asphalt cement to generate a complex composition [8], [9].

Marshall characteristics can be categorized into two classes: plastic flow resistance (Marshall stability and flow) and volumetric properties, which can be separated into two groups, the primary one of which corresponds directly to the relative volume of the components in the asphalt mixture, such as the grain size of aggregates and binder volume, furthermore air voids. While the secondary part deal with to volumetric characteristics of the asphalt mixture, which are volume in mineral aggregate, and voids filled with asphalt [10].

As a consequence of the world's rapid population growth and industrialization over the last century, in addition, several current pavements have already reached the end of their useful lives, and others will soon need maintenance due to high traffic volumes and environmental alterations [11]. New construction and maintenance works lead to an increase in the demand for raw materials that form asphalt mixtures, which leads to an increase in their cost in addition to the environmental damage resulting from the destruction of natural lands [12], [13]. The excessive accumulation of construction waste, however, is another important and dangerous issue affecting the environment. This waste requires huge land areas for disposal and landfilling [14]. For these reasons, scientists and engineers have put a lot of effort into determining how to get rid of this hazardous waste that contains many materials therefore, a different strategy—namely, sustainability—must be adopted to lessen the negative effects on the environment [15]. It is imperative to evaluate the sustainability of construction projects to ensure that they do not damage the environment or contribute to the reduction of construction costs [16]. Because demolition waste incorporates several materials, including Portland cement concrete, which is formed of high-quality elements, the most significant of which is aggregate, there have been numerous prior studies on the use of waste cement concrete as aggregate in asphalt mixtures [17]. However, the recycled concrete aggregates generated by crushing Portland cement concrete differ in some properties from virgin aggregates, such as lower specific gravity, lower abrasion resistance, and a lower flaky index, high water absorption which make the need for additional amounts of asphalt cement due to the cement mortar adhered to them [18]. Asphalt concrete manufactured from recycled concrete aggregate exhibits high stability and flow with decreasing Marshall stiffness, possibly not sufficiently durable to withstand long-term deformation [19]. Consequently, it is crucial to investigate the asphalt compositions that contain RCA [20].

Engineers and scientists have been studying hard to enhance the characteristics of asphalt mixtures. Many researchers have focused a great deal on enhancing the asphalt bond's rheological characteristics through the addition of powders, fibers, or certain chemical compounds [21]. On the other hand, some focused on improving aggregate interlock. The majority of the ingredients forming the asphalt mixture are aggregates. About 80% of the shear strength came from the internal friction angle [22]. Additionally, reinforcing pavement structures using fibers in HMA mixtures can extend the pavement's lifespan and increase its adaptability to a variety of environmental factors, including traffic volume over time, effects, and changes in the climate.

Fibers are successful when they increase tensile strength while also providing adequate lateral tightness for the reinforcement mechanism [23]. It ensures stability and mechanical strength when adding fibers to the binder or bituminous mixes [24].

The properties of asphalt mixtures that use fibers as reinforcement had been the subject of numerous investigations. Moghadas et al. [25] assessed 1, 2, and 3 cm lengths of carbon fibers with three different percentages of 0.02, 0.025, and 0.035% by total weight; they concluded the percentage of 0.035% and 3 cm, which led to a significant increase in Marshall properties and rutting resistance. Alfalah et al. [26] showed, a 0.16% of carbon fibers by total weight led to an enhancement in the mechanical properties of asphalt mixtures.

Eisa et al. [27] showed 0.25% of glass fiber by total weight led to an increase in stability of about 10% and a decreased flow of 13.5%; furthermore, a decrease in rutting depth of 19.7% compared to the conventional mixture.

Enieb and Yang [28] investigated glass fibers that had two lengths of 6 and 12 mm, with two percentages of 0.3 and 0.6% by the total weight of the mixture. The study showed an increase in asphalt mixture properties, Marshall, fatigue, and resilient modulus. Glass fibers were utilized as strengthening materials for asphalt mixtures containing 50% reclaimed asphalt pavement [29], [30]. Ceramic fibers could be added to the asphalt cement or mixtures as modifiers, because of the high specific surface area of ceramic fibers which increased the contact area, the percentage of 0.4% by the total weight of the mixture led to an increase in stability about 17.5%, with a slight increase in flow and improved rotting performance [31]. It also enhanced rutting, fatigue, and stiffness when the asphalt binder was modified by 3% of ceramic fibers [32].

Basalt fibers had prominences between polyester and lignin as they had a superior effect, which was preferable when strengthening asphalt mixtures compared to their counterparts [33], [34].

The research aimed to study the Marshall and volumetric properties of asphalt mixtures as a result of the addition of recycled concrete aggregate to improve the aggregate interlock, and reinforced these mixtures with carbon fiber to improve stiffness which is considered the novelty in this paper.

The research hypothesis was that recycled concrete aggregates are classified as weak elements under heavy loads and have high absorbability. Therefore, the quantities of cement asphalt absorbed by the pores of the aggregate play an important role in the performance of asphalt mixtures.

II. MATERIALS AND METHODS

Various sources supplied the raw materials, which involved asphalt cement, virgin (coarse, and fine) aggregate, recycled concrete aggregate, carbon fibers, and filler.

a. Asphalt Cement

In Iraq, the common type of asphalt cement used in asphalt pavement is 40–50 penetration grade. It was obtained from the Dourah refinery inside Baghdad Province. Table 1 demonstrates the physical properties of the asphalt cement used.

Table 1: Physical properties of asphalt cement.

Test	Unit	Test Method	Result	SCRB Requirements
Penetration (25˚C,100gm, 5 sec).	1/10 mm	ASTM D-5	43	40-50
Ductility (25 °C, 5 cm/min).	cm	ASTM D-113	167	≥ 100
Flash point (Cleveland open cup).	ºC	ASTM D-92	>232	232 Min
Specific gravity at 25˚C	-	ASTM D-70	1.02	-
Kinematics viscosity, at 135 °C.	cSt	ASTM D-2170	405	-
Softening point (Ring and Ball).	ºC	ASTM D-36	51	-
Residue from thin film oven test.		ASTM D-1754		
-Retained penetration, % of original.	%	ASTM D-5	77	>55
-Ductility (25˚C, 5 cm/min).	cm	ASTM D-113	92	>25

Source: Own elaboration.

b. Aggregates

Virgin crushed fine and coarse aggregate was obtained from the (al Nabaie) quarry, which lies north of Baghdad. Tables 2 to 3 demonstrate the physical properties of the fine and coarse aggregate used, respectively.

With the objective of accomplishing the task, the mid-range of gradation limits according to the SCRB 2003 standard for wearing course Type IIIA was selected. Figure 1 demonstrates the gradation of the aggregate selected.

Table 2: Physical properties of fine aggregate.

Test	Test Method	Result	SCRB Requirements for Type IIIA
Bulk Specific Gravity, gm/cm^3	ASTM C-128	2.58	-
Water Absorption, %.	ASTM C-128	0.83	-

Source: Own elaboration.

Table 3: Physical properties of coarse aggregate.

Test	Test Method	Result	SCRB Requirements for Type IIIA
Bulk Specific gravity, gm/cm^3	ASTM C-127	2.55	-
Water Absorption, %.	ASTM C-127	0.45	-
Abrasion by Los Angeles Machine, % loss.	ASTM C-131	13	30% Max
Degree of Crushing, %.	ASTM D-5821	92	90% Min has one or more fractured faces.
Flat and Elongated pieces more than (5:1) between Max and Min Dimension, %.	ASTM D-4791	0	10% Max.

Source: Own elaboration.

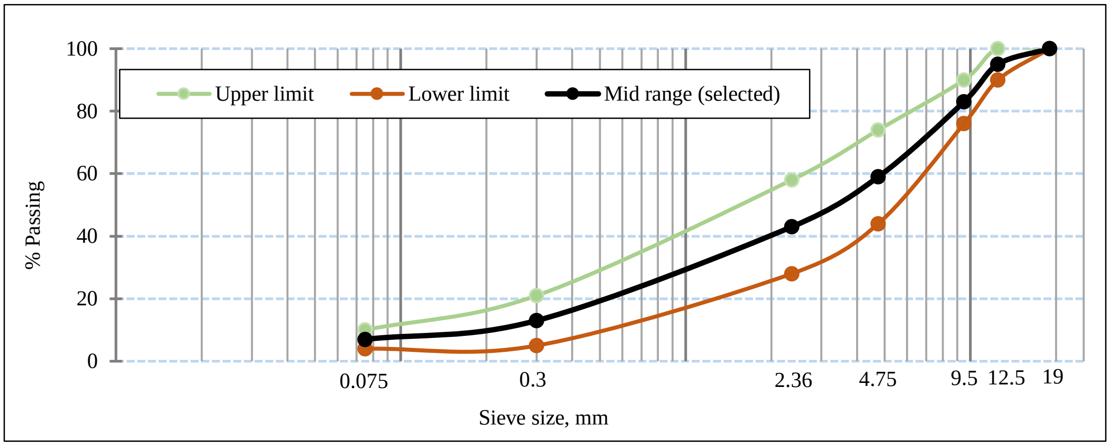


Figure 1: Grain size distribution of aggregate.
Source: Own elaboration.

c. Filler

The SCRB 2003 Iraqi standard, requires that the filler be either limestone dust or Portland cement. In this study, ordinary Portland cement was used; it was obtained from a cement concrete plant inside Baghdad Province. Table 4 demonstrates the physical properties of the filler used.

Table 4: Physical properties of the filler.

Test	Result	SCRB Requirement
Sieve Analysis.		
% passing sieve (No 30).	100	100
% passing sieve (No 50).	100	95-100
% passing sieve (No 200).	98	70-100
Specific gravity, gm/cm^3	3.14	-

Source: Own elaboration.

d. Recycled concrete aggregate

It was obtained by assembling and crushing the small pieces of a crumbling New Jersey barrier. It was crushed manually by a Hummer weighing 3 kg. After that, the grains were sieved according to SCRB 2003 Iraqi requirements for wearing course type IIIA gradation and dried, then stored in separate containers. Table 5 demonstrates the physical properties of the recycled concrete aggregate used.

Table 5: Physical properties of recycled concrete aggregate (RCA).

Test	Test Method	Result	SCRB Requirements for Type IIIA
Bulk Specific Gravity, gm/cm^3	ASTM C127	2.32	-
Water absorption, %.	ASTM C127	2.94	-
Abrasion by Los Angeles Machine, % loss.	ASTM C-131	22	30% Max

Source: Own elaboration.

e. Carbon fibers

It was obtained from a local supplier. The type used was Wrap C-300 unidirectional bundles of woven carbon fiber fabric. The physical properties of this material were 4000 N/mm2 dry tensile strength, and dry density 1.82 gm/cm3.

III. METHODOLOGY OF TESTING

The basic test adopted was the Marshall test for asphalt mix design according to ASTM D6926. The standard (4×2.5-inch) cylindrical specimens were prepared by mixing and compacting (75 blows for each face). 1200 gm of asphalt mixture containing different amounts of recycled concrete aggregate (0, 20, 40, 60, 80, 100%) of coarse aggregate to identify the optimum asphalt contents and Marshall properties. The ASTM D2726 standard was adopted to identify the bulk-specific gravity for each specimen. The ASTM D2041 standard was adopted to determine the theoretical maximum specific gravity (Gmm) for each mix. The ASTM D6927 standard was adopted to identify resistance to plastic flow.

After identifying the optimum asphalt contents and other volumetric properties for each mix, carbon fibers were embedded with three different contents (0.15, 0.25, and 0.35%) by the total weight of the mixture at two lengths of 10, and 20 mm separately by dry method i.e., addition carbon fibers to the total aggregate before mixing with the asphalt binder to provide significant dispersion.

The same context of work mentioned above was followed to identify resistance to plastic flow and volumetric analysis for reinforced mixtures. Figure 2 demonstrates the Marshall specimens prepared.

Figure 2: Marshall Test.
Source: Own elaboration.

IV. RESULTS AND DISCUSSION

Results of the Marshall test for mixtures that contained RCA, and carbon fibers, which were handled in various amounts are shown in Table 6 and Figures 3 to 8.

When comparing the test results summarized in Table 6 with the SCRB 2003 requirements demonstrated in Table 7, it is obvious that all mixtures satisfy the requirements of the aforementioned specification.

Table 6: Marshall test results.

RCA, %	O.A.C, %	% C.F.	C.F.L, mm	Stability, kN	Flow, mm	MQ, kN/mm	VMA, %	VTM, %
0	4.93	-	-	11.03	3.3	3.35	14.97	3.92
20	5	0	0	11.8	3.85	3.5	15.09	3.94
		0.15	10	12.9	3.25	3.97	15.32	4.13
		0.15	20	13.11	3.16	4.15		
		0.25	10	13.3	3.2	4.16	15.43	4.26
		0.25	20	13.58	3.12	4.36		
		0.35	10	13.6	3.23	4.22	15.54	4.38
		0.35	20	13.9	3.14	4.43		
40	5.08	0	0	12.43	3.92	3.61	15.2	3.92
		0.15	10	13.88	3.35	4.15	15.36	4.21
		0.15	20	14.03	3.26	4.31		
		0.25	10	14.12	3.28	4.31	15.44	4.21
		0.25	20	14.66	3.22	4.56		
		0.35	10	14.52	3.33	4.37	15.51	4.29
		0.35	20	14.76	3.13	4.74		
60	5.17	0	0	12.66	3.93	3.55	15.11	3.93
		0.15	10	13.83	3.38	4.1	15.27	4.15
		0.15	20	14.5	3.31	4.39		
		0.25	10	14.73	3.32	4.44	15.34	4.23
		0.25	20	15.1	3.27	4.62		
		0.35	10	14.9	3.35	4.45	15.42	4.32
		0.35	20	15.32	3.3	4.65		
80	5.27	0	0	12.27	3.95	3.38	15.07	3.93
		0.15	10	13.25	3.41	3.89	15.21	4.05
		0.15	20	13.7	3.35	4.09		
		0.25	10	13.72	3.36	4.09	15.25	4.09
		0.25	20	14.65	3.31	4.43		
		0.35	10	14.42	3.38	4.27	15.32	4.18
		0.35	20	14.82	3.33	4.46		
100	5.45	0	0	11.95	3.98	3.15	15.06	3.93
		0.15	10	12.93	3.45	3.75	15.22	3.99
		0.15	20	13.3	3.39	3.93		
		0.25	10	13.5	3.4	3.98	15.34	4.12
		0.25	20	14.45	3.36	4.31		
		0.35	10	14.2	3.43	4.14	15.45	4.25
		0.35	20	14.8	3.36	4.41		

Source: Own elaboration.

Table 7: SCRB limits requirements.

Property	SCRB Limits for wearing course Type IIIA
Resistance to plastic flow: Marshall Stability, kN Marshall Flow, mm	 8 Min 2-4
Voids in Marshall specimen (VTM), %	3 - 5
Voids in mineral aggregate (VMA), %	14 Min
Asphalt Cement (by total weight of Mix), %	4 - 6

Source: Own elaboration.

Figure 3 illustrates the effect of recycled concrete aggregate on optimum asphalt contents. It is obvious that the increased content of recycled concrete aggregate led to an increase in the content of asphalt. Due to the cement mortar adhering to the aggregate, it had sucked some asphalt cement through its pores.

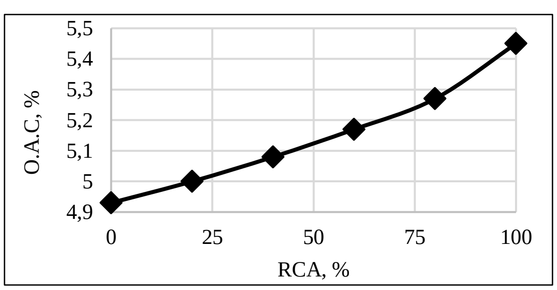


Figure 3: Effect of RCA on O.A.C.
Source: Own elaboration.

Figure 4 (a to e) illustrates the effect of recycled concrete aggregate and carbon fibers on Marshall's stability. It is clear that all mixtures containing recycled concrete aggregate had higher Marshall stability than the reference mixture. This is due to the fact that recycled concrete aggregate had more crushed faces than virgin aggregate, which increased the contact area. In addition, the roughness of the surface of the recycled aggregate as a result of the adhesion of cement mortar led to increased adhesion between asphalt and recycled aggregate. It can be noted that the addition of carbon fibers led to an additional increase in Marshall stability. Maybe it happened due to the increased contact area, or the mixture gained more stiffness as a result of the addition of carbon fiber. It is clear to note that all 20 mm carbon fiber-reinforced mixtures have higher Marshall stability than their counterparts with lengths of 10 mm. It is likely due to an increase in the number of fibers with a length of 10 mm, which led to the overlap or agglomeration of some of them as they reduced the contact areas. The maximum increase was recorded in the mixture containing 60% recycled concrete aggregate and 0.35% carbon fibers with a length of 20mm.

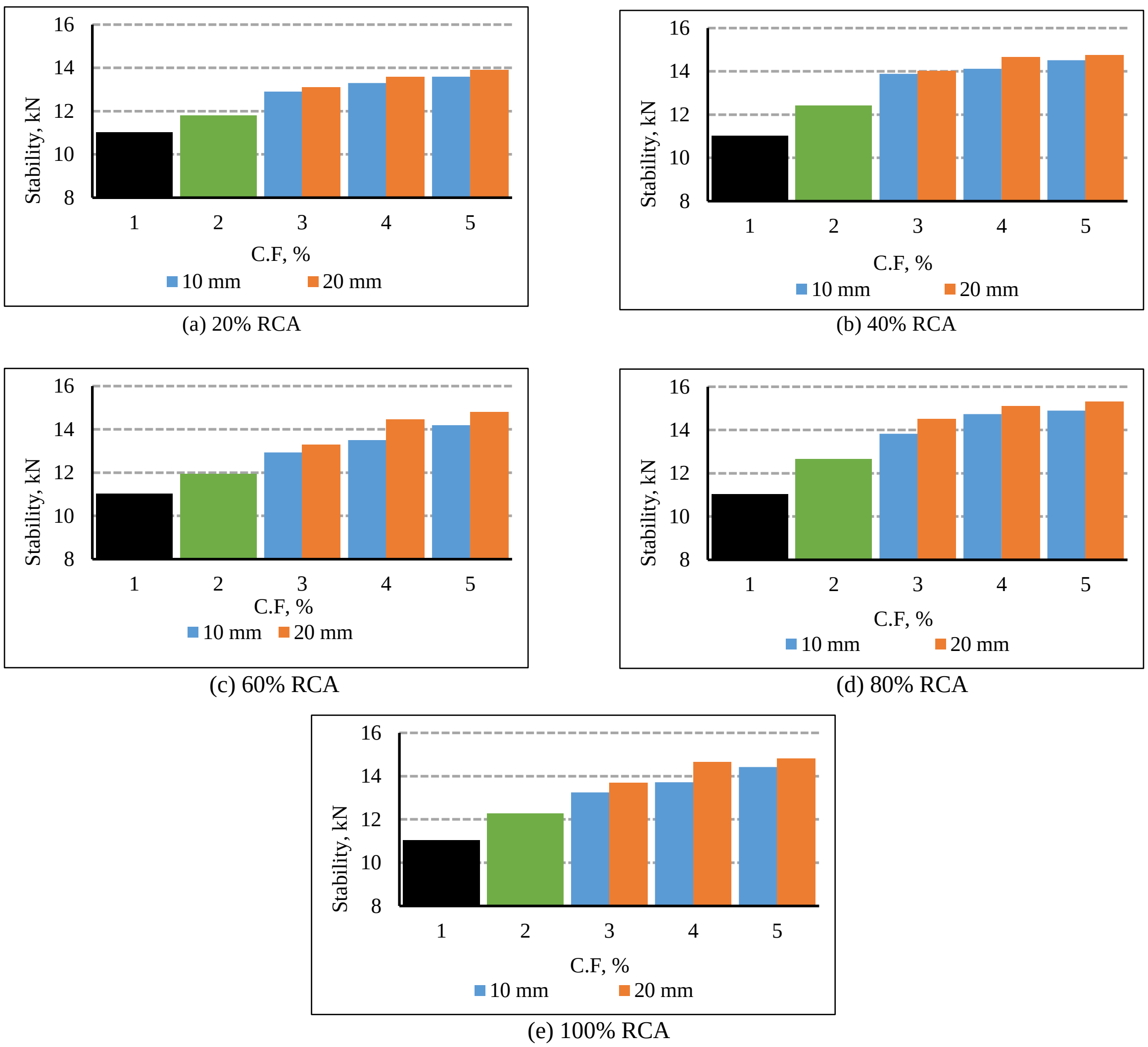
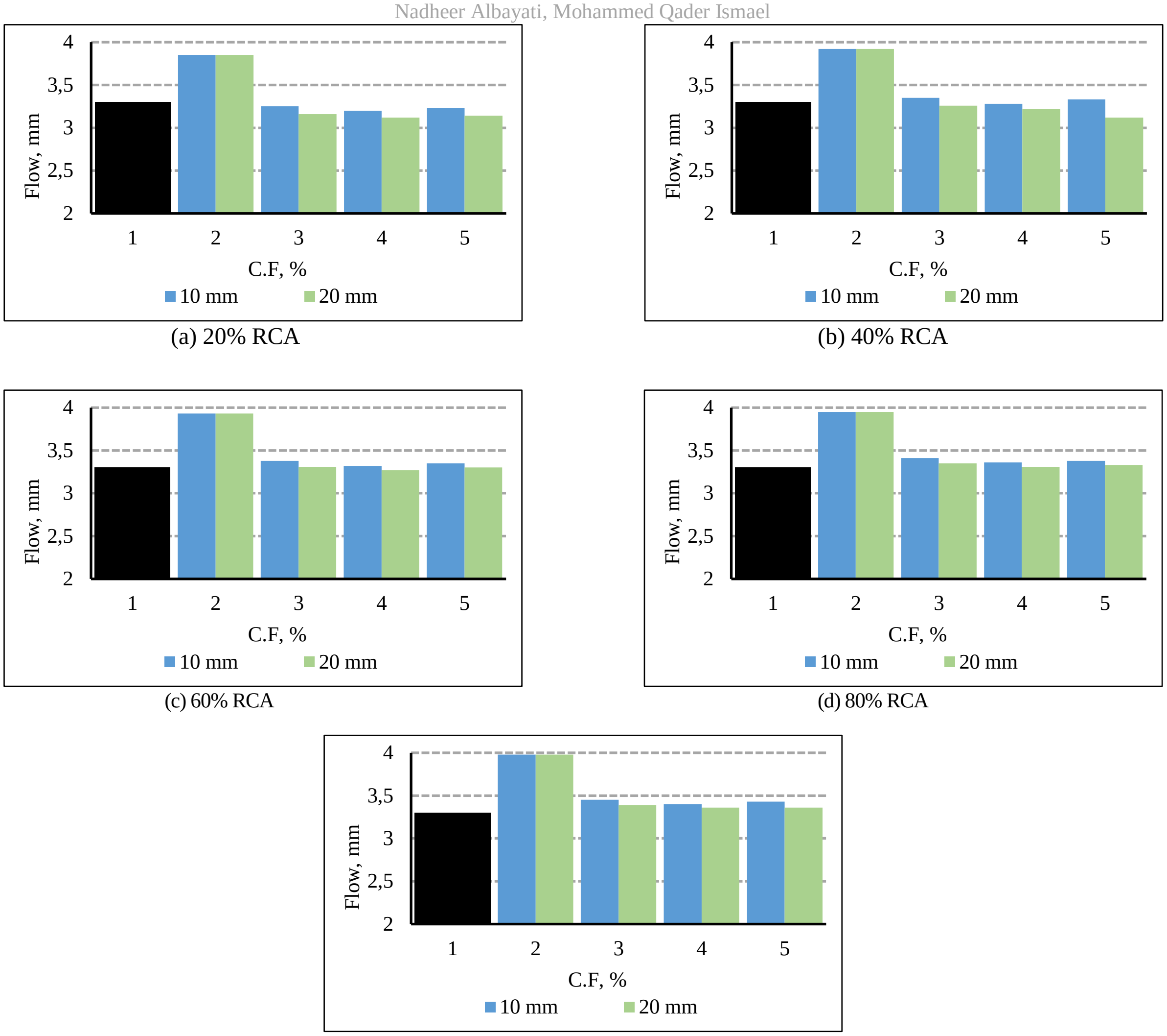


Figure 4: Effect of RCA and Carbon Fibers on Stability.
Source: Own elaboration.

Figure 5 (a to e) illustrates the effect of recycled concrete aggregate and carbon fibers on Marshall's flow. It is possible to note that the addition of recycled concrete aggregate led to an increase in Marshall flow. This might be due to the content of asphalt. The highest flow increase was 20.61% over the control mixture for the mixture containing 100% recycled concrete aggregate. While the addition of carbon fiber reduced the flow in all proportions and two lengths, the mixture containing 20% recycled concrete aggregate and reinforced by 0.25% carbon fiber with a length of 20 mm recorded a lower flow of 5.45% than the control mixture.



(a) 20% RCA

(b) 40% RCA

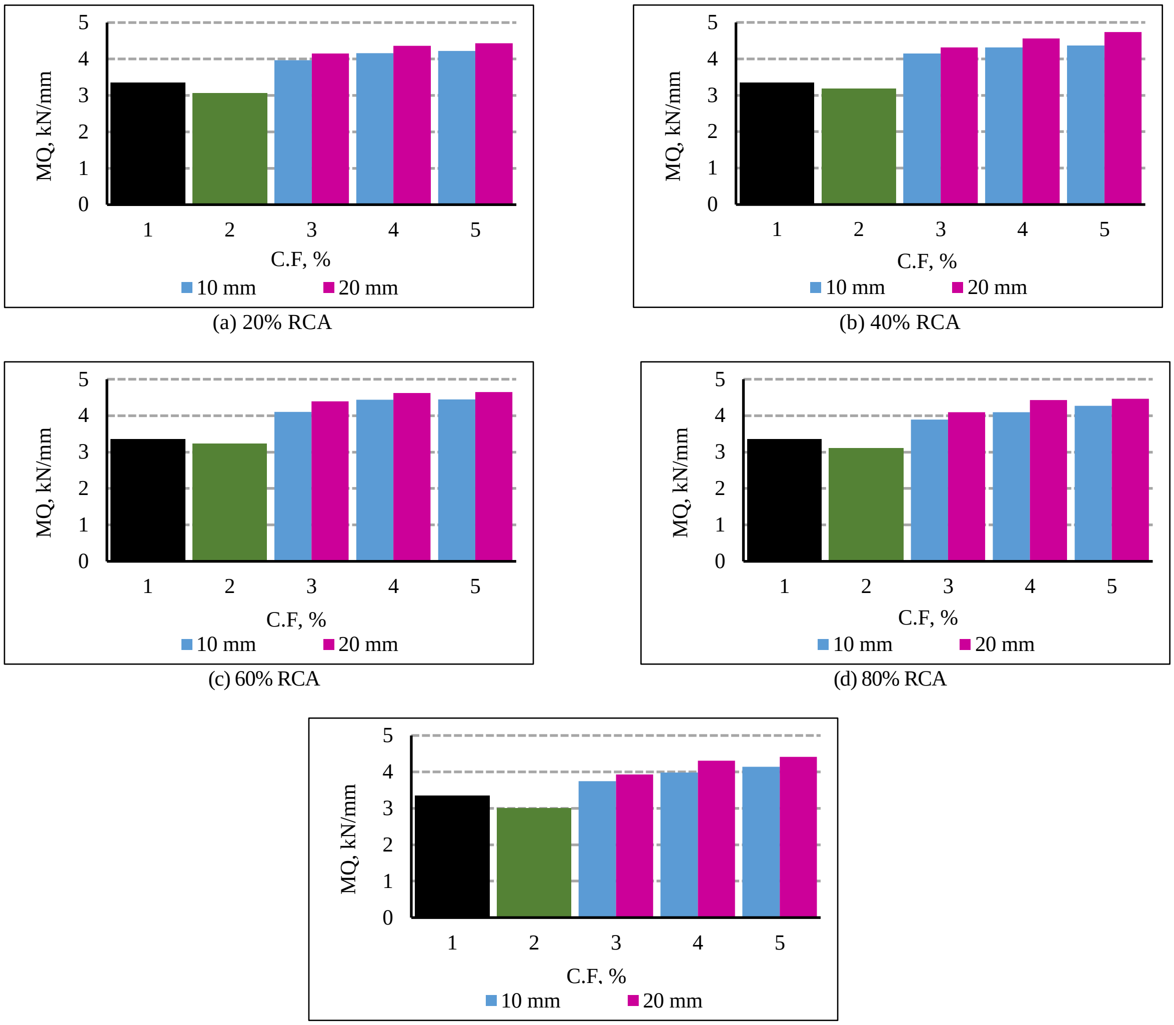
(c) 60% RCA

(d) 80% RCA

(e) 100% RCA

Figure 5: Effect of RCA and Carbon Fibers on Flow.
Source: Own elaboration.

The plastic stiffness index is known as the Marshall quotient or Marshall stiffness. It is determined by dividing stability by flow. It provides information about a mixture's resistance to long-term deformation [35], [36]. Figure 6 (a to e) illustrates the effect of recycled concrete aggregate and carbon fibers on the Marshall quotient. It is very clear that mixtures containing recycled concrete aggregate had a lower Marshall quotient than reference mixtures for all contents. However, adding carbon fibers significantly improved Marshall's quotient for both lengths and all the contents. The mixture containing 40% recycled concrete aggregate and reinforced by 0.35% carbon fibers, recorded the highest increase of 41.5% over the reference mixture.



(e) 100% RCA

Figure 6: Effect of RCA and Carbon Fibers on Marshall Quotient.
Source: Own elaboration.

V. CONCLUSION

On the basis of the results of the tests conducted and the characteristics of the materials used that have been emphasized, the following significant elements can be added to the summary of this research:

1. When virgin material was swapped out with recycled concrete aggregate, the asphalt cement content increased. The maximum increase occurred at the content of 100% recycled concrete aggregate, where the increase in asphalt content was 10.55% over the control mixture.
2. The addition of recycled concrete aggregate increased Marshall's stability and flow. The highest increase was 14.78% over the control mixture for the mixture containing 60% recycled concrete aggregate. While the maximum increase in flow was 20.61% over the control mixture for the mixture containing 100% recycled concrete aggregate.
3. The addition of carbon fibers led to an increase in Marshall's stability and decreased flow. The maximum increase in stability was at the mixture consisting of 60% recycled concrete aggregate and reinforced by 0.35% carbon fibers with a length of 20mm, where the increase was 38.89% over the control mixture. While the maximum decrease in flow was 5.45% lower than the control mixture, it was recorded in the mixture containing 20% recycled concrete aggregate and 0.25% carbon fibers with a length of 20mm.
4. The Marshall quotient or stiffness is significantly improved when carbon fibers are added to asphalt mixtures as a result of increasing Marshall stability and reducing flow, which leads to increased resistance to permanent deformation. The highest increase in Marshall quotient was found in mixtures containing 40% recycled concrete aggregate reinforced with 0.35% carbon fiber with lengths of 20 mm.
5. The length of the carbon fibers did not lead to a significant difference in Marshall properties when added to asphalt mixtures.
6. The addition of recycled concrete aggregate led to prolonged mixing time and the need to maintain a high temperature during mixing, which was not less than 163 °C as well as an increase in asphalt content. Therefore, the addition of carbon fiber did not lead to the need to increase the asphalt content for mixing.

VI. REFERENCES

[1] Henao-Pereira, J. P., Tovar-León, A. E., Castillo-Landinez, S. P., & Caicedo-Rodriguez, P. E. "Traffic accidents from the perspective of data mining A review of the literature," AiBi Revista de Investigación, Administración e Ingeniería, vol. 8. No. 2, pp. 133-141, 2020.
[2] Rozo-Verjel, E. J., & Pérez-Fernández, B. J. "Decalogue of road safety for the reduction of risks in road users, motorcycle drivers, belonging to a Colombian company," AiBi Revista de Investigación, Administración e Ingeniería, vol. 9, no. 2, pp. 40-52, 2021.
[3] Samantha, A. A, "The skeletal structure of hot mix asphalt and the effects of fiber additives." M.S. Thesis, The University of Texas Rio Grande Valley, USA, 2021.
[4] Ali, S., & Ismael, M. Q, "Improvement of Marshall properties for hot mix asphalt by using ceramic fiber," Kufa Journal of Engineering, vol. 12, no. 1, pp. 48-58, 2021.
[5] Al-Saad, A. A, & Ismael, M. Q, "Rutting prediction of hot mix asphalt mixtures reinforced by ceramic fibers," Journal of Applied Engineering Science, vol. 20, no. 4, pp. 1345-1354, 2022.
[6] Taher, Z. K, & Ismael, M. Q, "Moisture Susceptibility of Hot Mix Asphalt Mixtures Modified by Nano Silica and Subjected to Aging Process," Journal of Engineering, vol. 29, no. 4, pp. 128-143, 2023.
[7] Jasim, S., & Ismael, M. Q, "Marshall performance and volumetric properties of styrene-butadiene-styrene modified asphalt mixtures," Civil Engineering Journal, vol. 7, no. 6, pp. 1050-1059, 2021.
[8] Hashim, R. R, "Piezoresistive Hot Mix Asphalt (HMA) Mixtures modified with Carbon Nano-fibers Development and Application as Smart HMA," Ph.D. dissertation, University of Louisiana, USA, 2016.
[9] Albayati, A. H, "Influence of temperature upon permanent deformation parameters of asphalt concrete mixes," Journal of Engineering, vol. 23, no. 7, pp. 14-32, 2017.
[10] Al-Bayati, H., Tighe, S., & Achebe, J., "Influence of recycled concrete aggregate on volumetric properties of hot mix asphalt. Resources," Conservation and Recycling, vol. 130, pp. 200-214, 2018.
[11] AL-Mosawe, G. A., & Al-Mosawe, H. M, "Study the Effect of using RAP in Warm Mix Asphalt Pavement," Journal of Engineering, vol. 29, no. 7, pp. 153-168, 2023.
[12] Siriwardane, H., Gondle, R., & Kutuk, B, "Analysis of flexible pavements reinforced with geogrids," Geotechnical and Geological Engineering, vol. 28, pp. 287-297, 2010.
[13] Nazal, H., & Ismael, M. Q, "Evaluation the moisture susceptibility of asphalt mixtures containing demolished concrete waste materials," Civil Engineering Journal, vol. 5, no. 4, pp. 845-855, 2019.
[14] Ismael, M. Q, Joni, H., & Fattah, M, "Neural network modeling of rutting performance for sustainable asphalt mixtures modified by industrial waste alumina," Ain Shams Engineering Journal, vol. 14, no. 5, 101972, 2023.
[15] Mills-Beale, J., & You, Z, "The mechanical properties of asphalt mixtures with recycled concrete aggregates," Construction and Building Materials, vol. 24, no. 3, pp. 230-235, 2010.
[16] Gul, W. A., "Effect of recycled cement concrete content on rutting behavior of asphalt concrete," Civil Engineering Department, M.S. Thesis, Middle East Technical University, Turkey, 2008.
[17] Gedik, A, "A review on the evaluation of the potential utilization of construction and demolition waste in hot mix asphalt pavements," Resources, Conservation and Recycling, vol. 161, 104956, 2020.
[18] Gómez-Meijide, B., & Pérez, I, "Effects of the use of construction and demolition waste aggregates in cold asphalt mixtures," Construction and Building Materials, vol. 51, pp. 267-277, 2014.
[19] Pasandín, A. R., & Pérez, I, "Laboratory evaluation of hot-mix asphalt containing construction and demolition waste," Construction and Building Materials, vol. 43, pp. 497-505, 2013.
[20] Al-Bayati, H. K. A, & Tighe, S. L, "Effect of recycled concrete aggregate on rutting and stiffness characteristics of asphalt mixtures," Journal of Materials in Civil Engineering, vol. 31, no. 10, 2019.
[21] Du, Y., Chen, J., Han, Z., & Liu, W, "A review on solutions for improving rutting resistance of asphalt pavement and test methods," Construction and Building Materials, vol. 168, pp. 893-905, 2013.
[22] Wang, H., Liu, X., & Hao, P, "Evaluating the shear resistance of hot mix asphalt by the direct shear test," Journal of testing and evaluation, vol. 36, no. 6, pp. 485-491, 2008.
[23] Ashraf, A, "Fiber dosage effects in asphalt binders and hot mix asphalt mixtures," M.S. thesis, Arizona State University, USA, 2012.
[24] Mawat, H., & Ismael, M. Q, "Assessment of moisture susceptibility for asphalt mixtures modified by carbon fibers," Civil Engineering Journal, vol. 6, no. 2, pp. 304-317, 2020.
[25] Moghadas Nejad, F., Vadood, M., & Baeetabar, S, "Investigating the mechanical properties of carbon fibre-reinforced asphalt concrete," Road materials and pavement design, vol. 15, no. 2, pp. 465-475, 2014.
[26] Alfalah, A., Offenbacker, D., Ali, A., Decarlo, C., Lein, W., Mehta, Y., & Elshaer, M, "Assessment of the impact of fiber types on the performance of fiber-reinforced hot mix asphalt," Transportation Research Record, vol. 2674, no. 4, pp. 337-347, 2020.
[27] Eisa, M. S., Basiouny, M. E., & Daloob, M. I, "Effect of adding glass fiber on the properties of asphalt mix," International Journal of Pavement Research and Technology, vol. 14, pp. 403-409, 2021.
[28] Enieb, M., Diab, A., & Yang, X, "Short-and long-term properties of glass fiber reinforced asphalt mixtures," International Journal of Pavement Engineering, vol. 22, no. 1, pp. 64-76, 2021.
[29] Park, K. S., Shoukat, T., Yoo, P. J., & Lee, S. H, "Strengthening of hybrid glass fiber reinforced recycled hot-mix asphalt mixtures," Construction and Building Materials, vol. 258, 118947, 2020.
[30] Ziari, H., Aliha, M. R. M., Moniri, A., & Saghafi, Y, "Crack resistance of hot mix asphalt containing different percentages of reclaimed asphalt pavement and glass fiber," Construction and Building Materials, vol. 230, 117015, 2020.
[31] Wang, X., Zhou, H., Hu, X., Shen, S., & Dong, B, "Investigation of the performance of ceramic fiber modified asphalt mixture," Advances in Civil Engineering, vol. 2021, pp. 1-10, 2021.
[32] Arabani, M., & Shabani, A, "Evaluation of the ceramic fiber modified asphalt binder," Construction and Building Materials, vol. 205, pp. 377-386, 2019.
[33] Zhao, H., Guan, B., Xiong, R., & Zhang, A, "Investigation of the performance of basalt fiber reinforced asphalt mixture," Applied Sciences, vol. 10, no. 5, 1561, 2020.
[34] Guo, F., Li, R., Lu, S., Bi, Y., & He, H, "Evaluation of the effect of fiber type, length, and content on asphalt properties and asphalt mixture performance," Materials, vol. 13, no. 7, 1556, 2020.

[35] Ismael, M. Q, Fattah, M., & Jasim, A, “Permanent deformation characterization of stone matrix asphalt reinforced by different types of fibers,” Journal of Engineering, vol. 28, no. 2, pp. 99-116, 2022.

[36] Geckil, T., & Ahmedzade, P, “Effects of carbon fibre on performance properties of asphalt mixtures,” Baltic Journal of Road and Bridge Engineering, vol. 15, no. 2, pp. 49-65, 2020.