Utilizing Recycled Face Mask Fiber to Enhance Concrete Strength

Dosti T. M. Malazada[a,*] and Abdullkader G. Anwar[b]

[a] Department of Civil Engineering/ Faculty of Engineering/ Koya University/ Kurdistan Region – F.R. Iraq.

Email: dosty.talib@gmail.com; ORCID: https://orcid.org/0009-0000-0582-7339

Email: abdulkader.gaylan@koyauniversity.org; ORCID: https://orcid.org/0000-0002-0440-2723

Abstract

The COVID-19 pandemic has introduced a pressing environmental challenge with the widespread use of disposable face masks (DFMs). Millions of face masks (FMs) are discarded, increasing the risk of environmental pollution through microplastic accumulation. This study presents a recycling method for converting DFMs into fibers for addition to concrete. Before the addition, the DFMs underwent a five-day sunlight disinfection process to ensure COVID-19 negativity. The study investigated the effect of recycled face mask fibers (RFMFs) on concrete strength. 270 concrete samples, consisting of various volume contents (0%, 0.15%, 0.30%, and 0.45%) of RFMFs as an additional volume of concrete, were subjected to compression, splitting tensile, and flexural strength tests. The RFMFs, measuring 20 mm, 30 mm, and 40 mm in length and 5 mm in width, were utilized in the concrete. The specimens were cured for different durations (3, 7, and 28 days). The results indicated a significant enhancement in the concrete strength with the addition of RFMFs after 3 days of curing. An optimum increase of 17.47% in compressive strength was observed at 0.15% volume content and 20 mm length of RFMF. Moreover, an 18.52% increase in splitting tensile strength was achieved at 0.15% volume content and 40 mm length of RFMF. Additionally, at 0.45% volume content and 30 mm length of RFMF, a significant 36.62% increase in flexural strength was recorded. This study presents an innovative approach to strengthening concrete at an early age, providing a practical solution to mitigate the environmental impact and waste management challenges

***Keywords*:** Compressive Strength, Concrete, Environmental Impact, Flexural Strength, Recycled Face Mask Fiber, Splitting Tensile Strength, Waste Management

Highlights

- Addressing environmental impacts and waste management challenges for disposable face masks (DFMs).
- The process of disinfection and recycling that turns DFMs into recycled face mask fibers (RFMFs), which are used as reinforcement in concrete.
- The investigate compression, splitting tensile, and flexural strength, evaluating optimal enhancements across various factors, including curing (3, 7, and 28 days), lengths (20 mm, 30 mm, and 40 mm), and volume contents (0%, 0.15%, 0.30%, and 0.45%) of RFMF

1. Introduction

The incorporation of environmentally friendly materials in the field of engineering is highly important. The COVID-19 pandemic has witnessed a surge in the usage of disposable face masks (DFMs) worldwide as a preventive measure to limit the spread of the virus. Followed several coronaviruses variants viruses, including (Alpha, Beta, Gamma, Delta, and Omicron …etc). The WHO recommends the use of face masks (FMs) to aid in the prevention of infectious virus transmission. FMs act as a physical barrier, reducing the transmission of respiratory droplets from an infected individual to others around them [1]. Based on the investigation by Suman et al. [2] the danger of contracting COVID-19 from surfaces is significantly lower, approximately 100 times less, compared to direct transmission from an infected individual.

Disposable three-ply FMs are the most common type. They are primarily composed of polypropylene and significant threat to the environment. This is due to their slow decomposition rate, which can exceed 25 years [3, 4].

Consequently, the already critical issue of environmental pollution has been made worse by this increased usage, which has resulted in a notable increase in DFM waste. Ecosystems, wildlife, and human health are all at risk from the incorrect disposal and accumulation of DFMs [5]. The viruses have resulted in the production of 6.88 billion FMs every day globally discarded, due to their non-biodegradable nature, which poses a hazard to the environment and marine life [6]. Moreover, Asia continent uses more than 2.2 billion DFMs daily [7]. The majority of DFMs are observable on parks, streets, and beaches because of their lightweight, which allows wind and water to move them. Very few DFMs are thrown away, burnt, or buried [8]. The recycling technique offers a potential key for effectively utilizing the vast quantities of DFMs available [9]. Recycled Face Masks (RFMs) provide a promising response to the environmental problems that DFMs raise by managing waste, reducing resource demand, and promoting a circular economy by recycling materials that would otherwise end up in landfills or incinerators. With this strategy, fewer new raw materials are needed, resources are conserved, and a sustainable waste management system is promoted [3, 10]. Concrete, being the most widely used construction material, offers an opportunity for incorporating recycled materials as an eco-friendly alternative. RFMs as reinforcement in concrete improve mechanical properties, mitigate environmental impact, and extend the life cycle of DFMs, offering a sustainable solution to DFM pollution [11, 12].

Numerous studies have focused on disinfection and RFMs, but limited research has been conducted on recycling used DFMs. Some studies have characterized the DFM advise recycling after heat treatment utilizing morphological and chemical analysis [13]. Others have investigated the pore structure of surgical DFMs following treatment with various methods such as UV light, steam, washing machine and ethyl alcohol [14]. Idrees et al. [15] investigated that the DFMs were collected and stored for 7 days before being further protected through disinfection using an alcohol-based disinfectant spray. Incorporating DFMs in concrete reduces the transmission of COVID-19, as the virus struggles to survive on surfaces with a high pH level, thereby hindering its viability [16].

In a study shown by Saberian et al. [17], the use of shredded FMs as an additive in recycled concrete aggregate (RCA) for road bases and subbases was investigated.

The study found that incorporating different proportions of shredded FMs (1%, 2%, and 3% by weight of RCA) met the required stiffness and ductility of the pavement. The results indicated that a shredded FM content of 1% produced the highest values, while increasing the FM content beyond 2% lead to in a reduction in stiffness.

Kilmartin-Lynch et al. [18] investigated the use of pandemic RFMs in concrete. The FMs were converted into fibers measuring 2 cm by 0.5 cm and were then incorporated into different concrete mixtures at volume proportions of 0%, 0.10%, 0.15%, 0.20%, and 0.25%. The mechanical properties of the concrete were evaluated, and the findings revealed that adding RFMFs at a volume content of 0.20% yielded optimal results in terms of both strength and durability.

The advantages of incorporating RFMF into concrete are multi-fold. There are several benefits to adding RFMF to concrete. Firstly, it allows for the sustainable use of DFMs, preventing them from ending up in landfills and reducing their environmental impact. Secondly, the addition of RFMFs may improve the mechanical properties of the concrete, thereby enhancing its performance as a construction material.

Lastly, the utilization of RFMs in concrete manufacturing promotes waste reduction and resource efficiency, two key principles of a circular economy [10, 16].Limited studies have been conducted on the incorporation of RFMFs into concrete, particularly regarding their strength over time at different lengths and volume content. Existing studies have not thoroughly investigated concrete strength with RFMs, nor the determination of strength at different ages and fiber lengths for DFM. Addressing environmental issues brought on by unregulated DFMs in the ecosystem is the primary aim of this research. The objective of this experimental study is to examine the impact of RFMFs on the strength of concrete.

It determines the optimum strength of concrete containing RFMFs, considering different lengths, volume contents, and curing ages, as well as pre-treatment of DFMs by sunlight.

The findings of this study have significantly contributed to improving the strength of concrete at an early age and waste management practice, thereby mitigating the environmental impact.

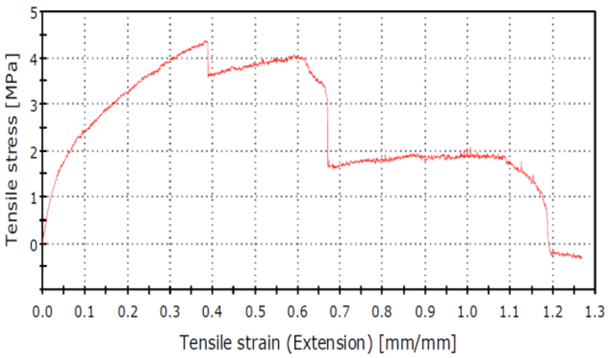
2.Experimental Program And Methodology

2.1.Recycled Face Mask Fiber (RFMF)

This study explores the incorporation of RFMFs from DFMs into concrete. To prepare the RFMF for the experimental study, an initial treatment of the DFMs was conducted. The DFMs underwent disinfection using a technique involving exposure to direct sunlight. However, due to the current stage of coronavirus restrictions, the use of DFMs was not permissible in this study to mitigate the risk of community transmission and infection. In this study, three-ply FMs were utilized. The investigation conducted at the Central Laboratory in Koya revealed that all FMs were initially contaminated with positive coronaviruses and had been stored and frozen at a temperature -85 Celsius. However, after disinfection, the results indicated a negative presence of the coronavirus after 5 days from contamination day. Samples were taken for inspection every day.

After completing the disinfection process, specific components of the DFMs, such as the elastic ear loops, nose bridge, and the frame around the DFMs, were manually removed to acquire a uniform material. Subsequently, the DFMs were transformed into fiber form using a paper cutter instrument, as shown in Fig. 2-(d). However, if an automated process is considered more effective than the manual method for cutting DFMs into fibers. Three distinct lengths of RFMFs (20, 30, and 40) mm were obtained, each with a width of 5 mm. The RFMF exhibited a lightweight characteristic lower specific gravity compared to concrete ingredients. The water absorption of the RFMF was measured, indicating its ability to absorb water. Additionally, a digital caliper was used to measure the thickness, size, and manufacturer details of the RFMFs. The aspect ratio was then calculated and presented in Table 1. To evaluate the tensile strength of the RFMF, tests were performed at the Strength of Materials Laboratory in the Faculty of Engineering at Koya University. Fig. 1 displays the analysis results of the tensile strength of the RFMFs, accompanied by a diagram illustrating the stress-strain relationship. The diagram illustrates distinct tensile strength characteristics for each layer of the three-ply RFMF. The initial decline in the stress-strain curve represents the rupture of the middle layer, while the subsequent declines correspond to the inner and outer layers of the RFMF. The analysis aimed to assess several key parameters, including maximum tensile strength, maximum strain, maximum elongation, and elongation at break. These tests provided valuable insights into the mechanical properties of the RFMF and helped understand its behavior under tensile forces. The summary physical properties of RFM, are outlined in Table 1. Overall, this methodology ensured the preparation of the RFMF and incorporation into the concrete mixture, as displayed in Fig. 2.

(a)



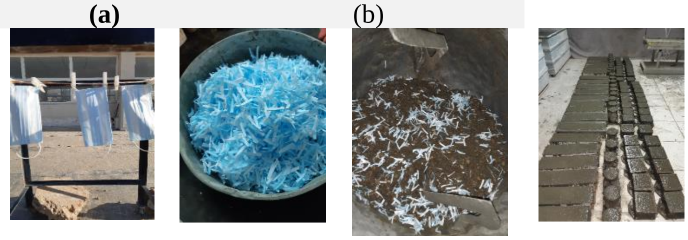
(b)

Fig. 1 Tensile Strength Test of RFMF: (a) The RFMF is Subjected to a Tensile Strength Test. (b) Tensile Stress-Strain Diagram of the RFMF.

Table 1 Physical Properties of RFMF

Physical properties	Units	Results	Standard test method
Thickness	Mm	0.25-0.32	ACI 544.4R [19]
Specific Gravity		0.91	ASTM D792 [20]
Size of FM	Mm	195*95	
Manufacturer of FM	%	JINKAI	
Water Absorption	%	85	ASTM D570 [21]
Maximum Tensile Strength	MPa	4.14	ASTM D638 [22]
Maximum Strain		0.56	ASTM D638 [22]
Tensile Extension at Break	Mm	117	ASTM D638 [22]
Aspect ratio for RFMF lengths (20 mm, 30 mm, and 40 mm)		39, 58 and 78	ACI 544.4R [19]

(a) (b)



(c) (d) (e) (f)

Fig. 2 The Process Methodology for Incorporating RFMF into Concrete Involved the Following Steps: (a) DFMs at a Landfill. (b) Collection of DFMs. (c) Disinfection of DFMs Using Sunlight. (d) Cutting up the RFMs To Obtain RFMF. (e) Mixing the RFMFs With Concrete in a Mixer. (f) Casting the RFMF Concrete into Molds.

2.2.Materials and Methods

Normally, water, coarse and fine aggregate, and cement are used to make concrete. According to ASTM the ingredients of concrete are specified. The main binder ingredient is ordinary portland cement (OPC), which is sourced from Tasluja Company. Tables 2 and 3 provide a summary of the physical and chemical properties of the cement utilized, in accordance with ASTM C150M [23].

Natural river sand with a specific gravity of 2.7 was the fine aggregate used in this study. Gravel with a maximum size of 12.5 mm and a specific gravity of 2.67 consisted of coarse aggregate, which was obtained from the Kaniby quarry. The fine and coarse aggregate particle size distributions, together following ASTM limitations, are displayed in Fig. 3 [24].

To evaluate the effect of RFMF on concrete strength, ten concrete mixtures, and 243 samples were prepared. These mixtures included different volume contents of RFMF as an addition to the concrete mix (0.15%, 0.30%, and 0.45%). Additionally, for each RFMF volume content, one of three distinct RFMF lengths (20 mm, 30 mm, and 40 mm) was used, and for each RFMF length, three samples were employed. The selection of the length and volume content of RFMF was based on ACI limits and multiple trials use [19]. Moreover, the samples were cured by immersing them in a water tank for durations of 3, 7, and 28 days. In addition to control concrete samples (0%), a total of 27 specimens were set for the study. Table 4 provides the mix proportions needed to produce 1 m3 of concrete. All the mix designs were based on the guidelines provided by ACI 211 mix design [25]. To evaluate concrete strength, specimens in the form of cubes, cylinders, and prisms were prepared from each concrete mix. Cube specimens measuring 100 mm x 100 mm x 100 mm, cylinder specimens measuring 100 mm x 200 mm, and prism specimens measuring 100 mm x 100 mm x 500 mm were utilized. The samples were cured for 3, 7, and 28 days by submerging them in a water container. The ASTM C1116/C1116M standard was utilized for the mixing, proportioning, placement, and curing [26].

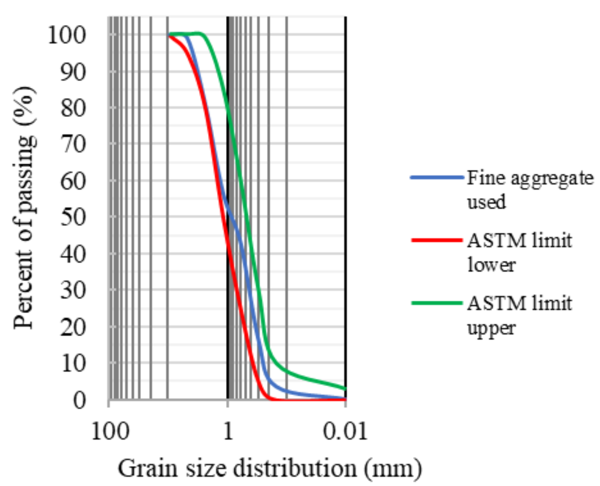
Overall, this methodology allowed for the investigation of the effect of RFMF on concrete strength, including its compressive, splitting tensile, and flexural strength. To evaluate the optimal mix and assess the effect of RFMFs on concrete strength, different combinations were investigated. The tests were conducted at the Materials of Construction Laboratory, which is located within the Faculty of Engineering at Koya University. The methodology employed for incorporating RFMF into the concrete is shown in Fig. 2. The process involved, the collection of DFMs, disinfections, cutting them into fiber form, mixing the RFMFs with concrete in a mixer, and finally casting the molds. Additionally, the multi-trial mixing and the preparation of samples for strength tests were conducted. Cube specimens were employed for compression testing, cylinder specimens for splitting tensile testing, and prism specimens for flexural testing. Tests were carried out according to (BSEN 12390), (ASTM C496) and (BSEN 12390-5), respectively [27-29].

Table 2 Physical Properties of Cement.

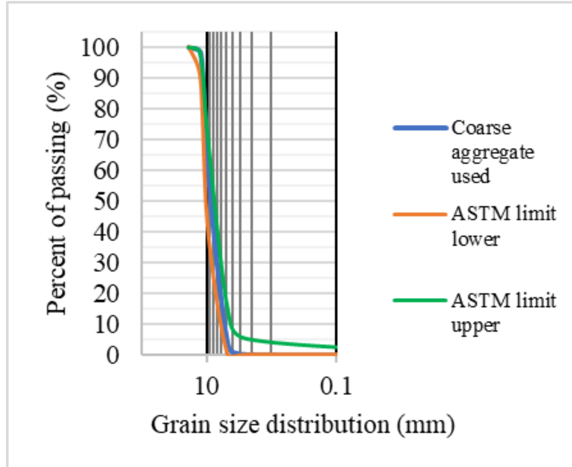
Physical properties	Unit	Test results
Specific Gravity		3.17
Initial Setting Time	minute	120
Final Setting Time	minute	270
3 Days Compressive Strength	MPa	23
28 Days Compressive Strength	MPa	52.4
Fineness	m^2/kg	394

Table 3 *Chemical Properties of Cement.*

Chemical properties	Unit	Test results
Loss of ignition	%	2.45
Insoluble material	%	0.67
SiO2	%	19.62
CaO	%	62.89
Al2O3	%	4.15
Fe2O3	%	3.78
MgO	%	1.59
SO3	%	2.22



(a)



(b)

Fig. 1 *Grain Size Distribution For: (a) Fine Aggregate with ASTM Limits. (b) Coarse Aggregate with ASTM Limits.*

Table 4 *Mix Proportions for 1 m^3 Concrete.*

RFMF length (mm)	Volume content of RFMF (%)	Cement (kg)	Sand (kg)	Gravel (kg)	Water (kg)
-	0	450	700	1000	225
20	0.15	450	700	1000	225
	0.30	450	700	1000	225
	0.45	450	700	1000	225
30	0.15	450	700	1000	225
	0.30	450	700	1000	225
	0.45	450	700	1000	225
40	0.15	450	700	1000	225
	0.30	450	700	1000	225
	0.45	450	700	1000	225

3.Results And Descussion

Compressive, splitting tensile, and flexural strength of the concrete were examined. Table 5 presents the results for each volume content (0%, 0.15%, 0.30%, and 0.45%), each RFMF length (20 mm, 30 mm, and 40 mm), and each curing (3, 7, and 28 days), showcasing the effects of incorporating RFMFs.

Table 5 Result of Concrete Strength Containing RFMFs

RFMF length	Volume content of RFMF	Compression strength (MPa)			Splitting Tensile strength (MPa)			Flexural strength (MPa)		
		3 days	7 days	28 days	3 days	7 days	28 days	3 days	7 days	28 days
-	0%	23.36	31.32	39.45	3.51	3.86	4.92	2.84	4.47	5.51
20 mm	0.15%	27.44	33.78	43.77	3.63	4.21	4.94	2.92	4.94	5.50
	0.30%	23.10	28.65	37.90	3.67	3.97	4.98	3.13	5.18	5.71
	0.45%	21.24	27.93	37.50	3.34	3.99	4.92	3.83	4.69	5.17
30 mm	0.15%	26.34	32.62	39.53	4.08	4.22	5.05	2.97	4.52	5.48
	0.30%	23.86	30.31	38.70	3.47	4.11	4.98	2.86	4.68	5.53
	0.45%	21.69	30.05	37.79	3.26	4.10	4.86	3.88	4.79	5.08
40 mm	0.15%	25.41	30.69	39.79	4.16	4.23	5.02	2.93	4.84	5.55
	0.30%	23.18	30.37	38.61	3.67	4.11	4.91	3.00	4.81	5.48
	0.45%	23.38	30.19	38.12	3.83	4.11	5.01	3.79	4.83	5.04

3.1.Compression Strength

Fig. 4 displays the results of the compressive strength of the concrete. The control specimen displayed compressive strengths of 23.36 MPa, 31.32 MPa, and 39.45 MPa after 3, 7, and 28 days, respectively. The findings revealed that the optimal result was achieved with a 0.15% volume addition of RFMFs. However, at 0.30% and higher volume content, the compressive strength declines compared to the control specimen.

At the 3 days of curing, Fig. 4-(a) shows that adding 0.15%, 0.30%, and 0.45% volume contents of RFMFs resulted in an increase of 17.47%, then decreased to 1.11%, and 9.07%, respectively, for 20 mm length. The improvements for 30 mm length were 12.76%, 2.14%, and a decrease to 7.15%. There was an 8.79% increase for 40 mm length, a 0.77% decline, and finally a 0.1% minor increase, respectively, compared to the control specimen. The optimal combination of 20 mm length and 0.15% volume content of RFMFs resulted in the biggest compressive strength.

At 7 days of curing (Fig. 4-(b)), the addition of 0.15%, 0.30%, and 0.45% volume contents of RFMFs resulted in an increase of 7.85%, a decrease to 8.52%, and 10.82%, respectively, for 20 mm length. For 30 mm length, the increase was 4.15%, decreased to 3.22%, and 4.05%, respectively. However, for the 40 mm length, there were decreases of 2.01%, 3.04%, and 3.62%, respectively, compared to the control specimen. The highest results were obtained using 20 mm length at the volume content of 0.15% of RFMFs.

At 28 days of curing (Fig. 4-(c)), the addition of 0.15%, 0.30%, and 0.45% volume contents of RFMFs increased the compressive strength by 10.95%, followed by decreases to 3.93%, and 4.94%, respectively, for 20 mm length. An increase was 0.20 %, decreases were 1.9 % and 4.2 % for 30 mm length. An increase was 0.87%, declines to 2.13% and 3.37% for 40 mm length, respectively, compared to the control specimen. The study found that the best results were obtained when using 20 mm at the volume content of 0.15% of RFMFs.

The compressive strength improvements varied depending on the fiber length, volume content, and curing age. Specifically, the concrete samples with 20 mm length at a 0.15 % volume content exhibited the highest increase in compressive strength at the 3-day curing age. The observed enhanced compressive strength is attributed to the microcrack restriction effect by RFMFs. Furthermore, during the early ages of concrete curing when the hydration process is still ongoing, RFMFs can serve as nucleation sites for the hydration reactions. However, at a volume content of 0.30% and beyond, as the length of RFMF increases, various factors come into play, contributing to a reduction in compressive strength.

Firstly, the increase in voids occurs with the higher volume content and length of RFMFs. Secondly, as the volume content of RFMFs increases, the water content in the concrete mix decreases. This reduction in water content can result in an inadequate amount of water for the full cement hydration process, reducing workability and impacting compressive strength development. Similar research studies have reported similar findings under comparable conditions [12, 18].

These factors collectively contribute to the decrease in compressive strength as the volume content and length of RFMFs increase. Careful consideration and optimization of these factors are necessary to mitigate the negative impact and achieve the desired strength.

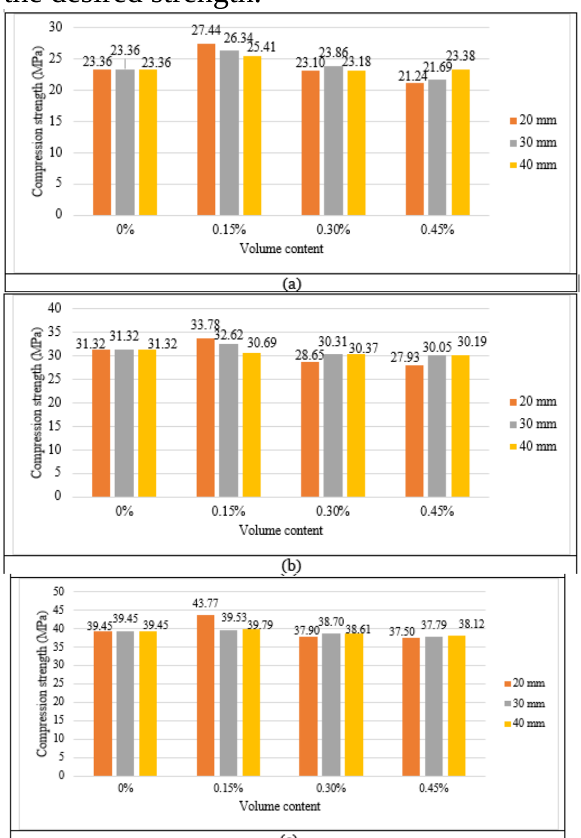


Fig. 2 Compressive Strength of Concrete Containing Different Volume Contents and Lengths of RFMF at: (a) 3 Days of Curing. (b) 7 Days of Curing. (c) 28 Days of Curing.

3.2.Splitting Tensile Strength

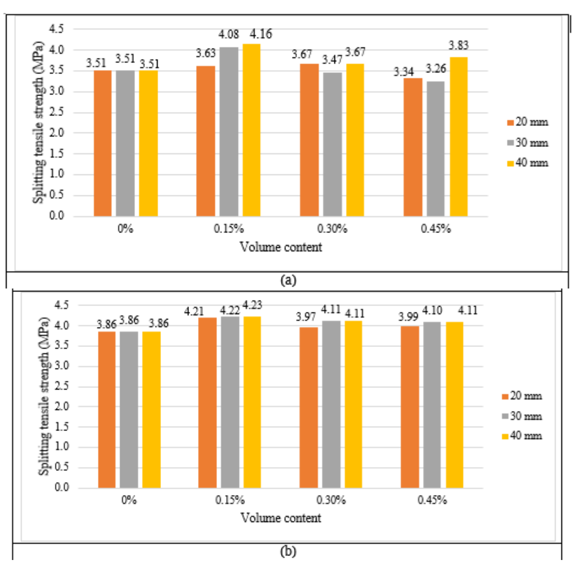
The effect of incorporating RFMFs into the concrete mix was assessed through the splitting tensile strength test, as shown in Fig. 5. The control concrete, without any RFMF addition, exhibited indirect tensile strengths of 3.51 MPa, 3.86 MPa, and 4.92 MPa at 3, 7, and 28 days are curing age, respectively.

At the 3 days of curing, Fig. 5-(a) showed that adding 0.15%, 0.30%, and 0.45% volume contents of RFMFs resulted in increases of 3.28% and 4.63%, followed by a decrease to 4.94%, respectively, compared to the control concrete, for 20 mm length. Similarly, for 30 mm length, the increase was 16.10%, decreased to 1.28%, and 7.19%, respectively. Additional, for 40 mm length, the increases were 18.52%, 4.56%, and 9.12%, respectively, compared to the control concrete. Overall, the highest improvement in splitting tensile strength was achieved with 40 mm length RFMFs at a volume content of 0.15%.

The splitting tensile strength during the 7 days of curing (Fig. 5-(b)) was dependent on the volume content and length of RFMFs. The addition of 0.15%, 0.30%, and 0.45% volume contents of RFMFs resulted in increases of 9.12%, 2.85%, and 3.37%, respectively, for 20 mm length. For 30 mm length, the increases were 9.26%, 6.52%, and 6.18%, respectively. For 40 mm RFMF length, the increases were 9.63%, 6.48%, and 6.35%, respectively, compared to the control specimen. Notably, the 40 mm length RFMFs with 0.15% volume content shown the highest achievement in splitting tensile strength.

At the 28-day of curing (Fig. 5-(c)), the splitting tensile strength were influenced by the length and volume content. The addition of 0.15%, 0.30%, and 0.45% volume contents of RFMFs resulted in increases of 0.36% and 1.17%, and followed by a decrease to 0.07%, respectively, for 20 mm length. While, for 30 mm length, the increases were 2.54%, 1.17%, and a decrease of 1.22%, respectively. Furthermore, for 40 mm length, an increase was 1.96%, a decrease to 0.24%, and then an increase to 1.73%, respectively, compared to the control specimen. Overall, the 30 mm length RFMF at a volume content of 0.15% resulted in the most increased in splitting tensile strength.

The study found that a 0.15% volume content of RFMFs combined with 40 mm length resulted in the greatest splitting tensile strength, especially at 3 days of curing. Longer fibers can bridge microcracks and enhance tensile strength. However, higher volume contents can introduce voids and weaken the bond between fibers and cement, leading to reduced tensile strength, particularly when volume content exceeds 0.30%. Overall, RFMFs positively influenced tensile strength at early ages, although a slight increase was observed at 28 days of curing.



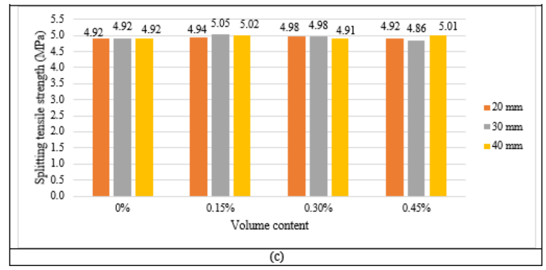


Fig. 5 Splitting Tensile Strength of Concrete Containing Different Volume Contents and Lengths of RFMF at: (a) 3 Days of Curing. (b) 7 Days of Curing. (c) 28 Days of Curing.

3.3.Flexural Strength

The flexural strength test results, shown in Fig. 6, show the effect of adding RFMFs to the concrete mixture. At (3, 7, and 28) days of curing ages, the control concrete had flexural strengths of 2.84 MPa, 4.87 MPa, and 5.51 MPa, respectively. When compared to the control concrete, the findings indicate a variety of trends in strength with some combinations showing the enhancement and others showing declines.

Figure. 6-(a) shows the incorporating different volume contents of RFMFs on the flexural strength at the 3 days of curing. For the length of 20 mm, the addition of 0.15%, 0.30%, and 0.45% volume contents resulted in increases of 2.82%, 10.33%, and 34.79%, respectively, compared to the control specimen. Similarly, for the length of 30 mm, the increases were 4.65%, 0.7%, and 36.62%, respectively. Moreover, for the length of 40 mm, the increases were 3.24%, 5.63%, and 33.38%, respectively. The highest increase is 36.62%, which results from the volume content of 0.45% and 30 mm length of RFMF.

Affecting the 7 days of curing, as shows in Fig. 6-(b), the addition of 0.15%, 0.30%, and 0.45% volume contents of RFMFs resulted in increases of 10.51%, 15.88%, and 4.97%, respectively, for RFMF length of 20 mm. However, for a length of 30 mm, the increases were 1.12%, 4.70%, and 7.11%, respectively. Furthermore, for 40 mm length, the increases were 8.28%, 7.65%, and 8.01%, respectively, compared to the control concrete. The best enhancement is 15.88%, which results in the addition of 0.30% volume contents for a 20 mm length RFMF.

Figure. 6-(c) presents the results at the 28 days of curing. The addition of 0.15%, 0.30%, and 0.45% volume contents of RFMFs resulted in a decrease of 0.18%, followed by an increase to 3.59%, and then a decrease to 6.13%, respectively, for the RFMF length of 20 mm. However, for the RFMF length of 30 mm, a decrease was 0.54%, followed by an increase to 0.40%, and a decrease to 7.80%, respectively. For a RFMF length of 40 mm, an increase was 0.69%, followed by decreases to 0.54%, and 8.50%, respectively, compared to the control concrete. The highest increment in strength is 3.59%, which is achieved by adding 0.30% volume contents for the RFMF length of 20 mm.

The addition of RFMFs had a significant enhance in flexural strength, particularly during 3 days of curing compared to 7 and 28 days. Some factors contributed to the increase in flexural strength at an early age. The tensile strength of concrete is crucial in the early age as it grapples with resisting substantial loads during the continuous hydration process. At this early age, RFMFs exhibit higher tensile strength than concrete, resulting in enhanced performance, notably evident at the 3-day curing point. The observed enhancement in flexural strength is attributed to the microcrack restriction effect induced by RFMFs.

However, variations and irregularities in the flexural strength results were noted due to the random orientation and distribution of RFMFs within the concrete mix.

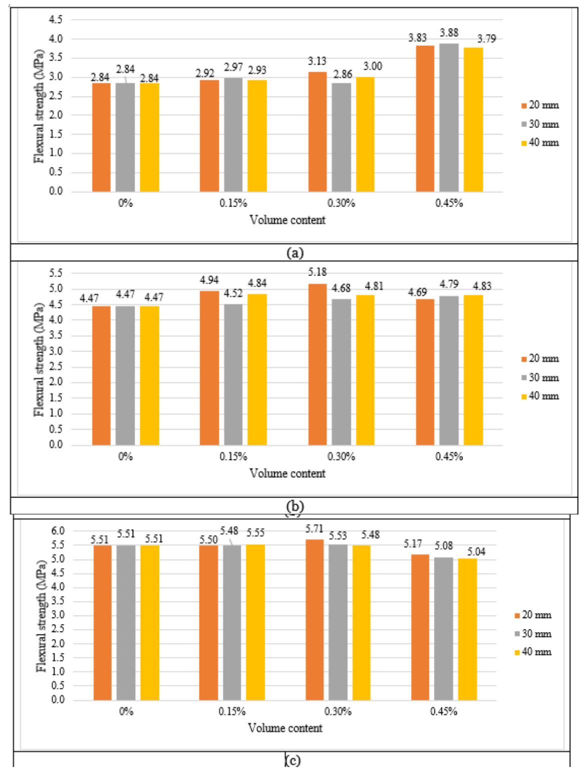


Fig. 6 *Flexural Strength of Concrete Containing Different Volume Contents and Lengths of RFMF at: (a) 3 Days of Curing. (b) 7 Days of Curing. (c) 28 Days of Curing.*

4.CONCLUSIONS

The study emphasizes the importance of optimizing the RFMF length (20 mm, 30 mm, and 40 mm), volume content (0%, 0.15%, 0.30%, and 0.45%), and curing (3, 7, 28 days) for different strength parameters. This research contributes to sustainable waste management by offering an innovative solution to recycle and incorporate RFMFs into concrete, thereby addressing environmental impacts. The following key findings were obtained:

- Incorporating RFMFs into concrete offers a significant solution to mitigate the environmental impact caused by DFM waste and waste management.
- The disinfection method, which is cost-effective and eco-friendly through 5-day sunlight exposure, successfully yielded negative COVID-19 test results. However, it does require time consumption, but this is essential for safety reasons.
- RFMF addition to concrete significantly improved compressive strength at 3 days of curing. Specifically, when the RFMF volume content was set at 0.15% and the length was optimized at 20 mm, there was a remarkable 17.47% increase in compression strength.
- The splitting tensile strength of concrete was optimized by adding 40 mm RFMFs at a volume content of 0.15%. After 3 days of curing, it achieved a strength of 18.52%.
- The concrete's flexural strength experienced the most significant increase when using RFMF with a length of 30 mm and a volume content of 0.45%. After 3 days of curing, the highest value recorded was 36.62%, surpassing that of the control specimen.
- The results indicate that at 3 days of curing the most significant enhancement in the concrete strength containing RFMFs compared to 7 and 28 days.
- To address the negative effects of reduced water content, decreased workability, and compromised compacting ability in concrete mixtures containing RFMF, it is recommended to incorporate a superplasticizer.
- It is recommended to investigate the influence of incorporating RFMFs on the impact resistance strength of concrete, as a thorough understanding of impact strength is crucial for assessing concrete quality.
- It is recommended to investigate the influence of incorporating RFMFs on the impact strength of concrete.

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