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Research Article

Studies on strength aspect and effective use of medical face mask to make a sustainable green fiber reinforced concrete

Karthiga Shenbagam NATARAJAN[1], Raja PRİYA P[2], Kannan V[3,*]

[1]*Department of Civil Engineering, Bannari Amman Institute of Technology, Sathyamangalam, Erode District, 638401, India*
[2]*Department of Civil Engineering, Francis Xavier Engineering College, Tirunelveli, Tamilnadu, 627003, India*
[3]*Department of Civil Engineering, National Engineering College, Kovilpatti, Thoothukudi, 628503, India*

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ABSTRACT

In the current scenario, face masks (FMs) are widely employed for personal protection against diseases, and similar materials find applications in the medical industry. However, the non-biodegradable nature of face masks poses challenges in their disposal. This study primarily focuses on the effective utilization of face masks in concrete manufacturing as a supplementary material to enhance flexural properties. Two types of fibers, namely medical face mask fiber (FMF) and basalt fiber (BF), were incorporated into the casting of concrete specimens using reused aggregates. FMFs were utilized in varying proportions of 0%, 0.05%, 0.1%, 0.15%, 0.2%, and 0.25%, while BFs were employed in proportions of 0%, 0.25%, and 0.5%. To mitigate the environmental impact of CO_2 emissions during cement production, the research involves partial replacement of cement with waste materials from industries. The test results revealed that the incorporation of these waste materials in concrete significantly increased compressive strength by approximately 14%, split tensile strength by 27%, and flexural strength by 63%. Microstructural analysis indicated an improvement in the quality of the inter-transition zone by using these waste materials.

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INTRODUCTION

The global landscape and its regular operations have been profoundly impacted by the effects of COVID-19 from 2019 until the present. This crisis has resulted in a staggering loss of lives worldwide, despite the introduction of vaccinations. The emergence of various Covid variants has further contributed to an increased death toll of approximately 5.5 million globally [1-3]. During the peak of the crisis, the lack of proper regulations and methodologies for the disposal of used masks led to a widespread issue of improper mask disposal by the public, exacerbating the environmental consequences [4, 5]. Due to the plastic content in masks, environmental pollution has become a concerning issue [6-8]. Surveys indicate that substantial quantities of masks are being discarded in landfills across

***Corresponding author.**
*E-mail address: kannanvpandian@gmail.com

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various countries, including Chile [9-14]. The waste generated from mask disposal has been estimated to range from 0.005 to 0.3 per square meter [15, 16], contributing to the escalating problem of plastic waste, which persists alongside unresolved issues from previous decades [17-20].

Historically, before the onset of the COVID-19 pandemic, masks were typically disposed of in landfills or incinerated to address environmental concerns [21-24]. The prevalent use of polypropylene material in mask manufacturing [25] prompted exploration into its application in concrete as a reinforcement material. This approach has proven effective in enhancing impact strength, ductility, creep resistance, early shrinkage, and fostering an eco-friendly environment [26-29]. However, past research has indicated that the use of polypropylene fibers can negatively impact workability and compressive strength in concrete [30-33], necessitating the recommendation of admixtures to mitigate these effects [34, 35].

This research extends beyond traditional cement usage by incorporating mineral admixtures such as fly ash (FA) and ground granulated blast furnace slag (GGBS) in small proportions. The concrete specimens are prepared using coarse and fine aggregates in addition to specific percentages of face mask fibers (FM) and basalt fibers (BF). Mechanical and durability tests, including compressive strength, split tensile strength, flexural strength, ultrasonic pulse velocity, density, and water adsorption tests, were conducted on the cast specimens. Furthermore, scanning electron microscopy (SEM) analysis was employed to assess the quality and compatibility of face mask fibers when integrated into concrete. By incorporating waste materials from mask production into concrete, this research aims to contribute to a more sustainable environment by reducing the disposal of plastic masks in landfills, thus mitigating the environmental impact.

MATERIALS AND METHODS

Materials

Facial mask (FM)

The facial masks (FMs) utilized in this study were sourced from China. These masks, with dimensions of 175mm in length and 95mm in width, were constructed using polypropylene fibers in a non-woven configuration. The central filtering area incorporated melt-blown fabric, following the specifications outlined by Dowd et al. (2020). To ensure fiber homogeneity, the ear straps and nose wire frame were removed. The FM material was then precisely cut into small segments measuring 20mm in length and 5mm in width. A summary of the sample and mechanical properties of the FM fibers is presented in Table 1.

Table 1. Mechanical properties of facial mask (FM) and basalt fiber (BF)

Property	Facial Mask fiber (FMF)	Basalt fiber (BF)
Length	20mm	18mm
Width	5mm	Not specified
Composition	Polypropylene fiber	Basalt
Filtering Material	Melt-blown fabric	Not applicable
Source	China	China
Diameter (if applicable)	Not specified	17.4μm

Figure 1. FM and BF.

Table 2. Mechanical properties of FM and BF.

Properties	FM	BF
Length (mm)	20	18
Width (mm)	5	
Diameter (mm)		17.4
Specific gravity	0.90	2.7
Tensile strength (MPa)	^{3}4.0	^{3}2000

Basalt fiber (BF)

Basalt fiber (BF) was chosen for its capacity to provide high strength, excellent thermal properties, small diameter, and chemical stability, as highlighted by Ahmed and Lim (2020). The BF used in this research was procured from China, possessing a length of 18mm and a diameter of approximately 17.4µm. Additional details regarding the sample and mechanical properties of the BF are summarized in Table 2.

Concrete materials

ASTM and BIS standards are used to prepare the concrete samples CC (controlled concrete) with Ordinary Portland cement, then other concrete samples with 20 % replacement with two admixtures FA, GGBS. Water cement ratio was maintained at 0.42 for all prepared specimens. Polycarboxylic ether super plasticizer was used in order to maintain the workability of prepared concrete samples. The chemical properties of the materials used are tabulated in Table 2 below.

Mix proportioning and specimen preparation

Mix proportioning of concrete with usage of binder material in various proportions of OPC, FA, GGBS, with addition of BF and FMF in mix design of concrete were

Table 2. Chemical composition of materials used in research

Chemical composition (in %)	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	Specific Gravity	Colour
OPC	22.4	6.1	2.89	0.24	64.7	0.77	0.11	3.2	Grey
Fly ash	54.11	26.59	9.69	0.88	3.61	1.78	2.42	2.39	Grey
GGBS	36.20	12.70	0.33	0.79	42.24	7.98	0.15	2.39	white

Table 3. Mix proportion of concrete specimens

Mix proportion ID	Fiber content in %		Binder Material (kg/m^3)			MS (kg/m^3)	CA (kg/m^3)	Water (kg/m^3)	SP (%)
	FMF	BF	OPC	FA	GGBS				
CC	0.00	0.00	490	-	-	727	865	208	1.00
CM1	0.00	0.00	392	32	66	727	865	208	1.00
CM2	0.05	0.00	392	32	66	727	865	208	1.00
CM3	0.10	0.00	392	32	66	727	865	208	1.00
CM4	0.15	0.00	392	32	66	727	865	208	1.00
CM5	0.20	0.00	392	32	66	727	865	208	1.00
CM6	0.25	0.00	392	32	66	727	865	208	1.00
CM7	0.00	0.25	392	32	66	727	865	208	1.00
CM8	0.05	0.25	392	32	66	727	865	208	1.00
CM9	0.10	0.25	392	32	66	727	865	208	1.00
CM10	0.15	0.25	392	32	66	727	865	208	1.00
CM11	0.20	0.25	392	32	66	727	865	208	1.00
CM12	0.25	0.25	392	32	66	727	865	208	1.00
CM13	0.00	0.50	392	32	66	727	865	208	1.00
CM14	0.05	0.50	392	32	66	727	865	208	1.00
CM15	0.10	0.50	392	32	66	727	865	208	1.00
CM16	0.15	0.50	392	32	66	727	865	208	1.00
CM17	0.20	0.50	392	32	66	727	865	208	1.00
CM18	0.25	0.50	392	32	66	727	865	208	1.00

studied in detail and 19 specimens were cast. Controlled concrete is a specimen in which there is no amount of FA and GGBS added. CM1-CM6 has 0% of BF and 0, 0.05, 0.1, 0.15, 0.2, 0.25 % of FMF. CM7-CM12 has 0.25% of BF and 0, 0.05, 0.1, 0.15, 0.2, 0.25 % of FMF. CM13-CM18 has 0.5% of BF and 0, 0.05, 0.1, 0.15, 0.2, 0.25 % of FMF respectively.

Abbreviations used in Table 3: CC controlled concrete, CM concrete mix proportion, FMF face mask fiber, BF Basalt fiber, OPC Ordinary Portland cement, FA Fly ash, GGBS Ground granulated blast furnace slag, MS manufactured sand, CA Coarse aggregate, SP Super plasticizer.

In order to study the strength aspects of concrete, various experimental tests were conducted on three samples each and the average strength of the three samples were determined to find out the physical and mechanical properties of concrete when FMF, BF were used. Compressive strength was carried out in 150mm cubes, split tensile strength in cylinders with 150x300mm size. The even distribution of concrete was tested using ultra sonic pulse velocity tests with the help 100mm cube specimens. The water absorption tests were also done to calculate the durability strength of prepared samples. All the above said tests were carries out in accordance to the “ASTM C39”, “ASTMC496”, “ASTM C78”, “ASTM C597”, “ASTM 642-06” codal provisions.

RESULTS AND DISCUSSION

Compressive Strength

Following a 28-day curing period for both the controlled concrete (CC) and the various specimens, the compressive strength was assessed using a Compression Testing Machine (CTM), and the results are illustrated in Figure 2. Remarkably, the inclusion of fibers and mineral admixtures contributed to an enhancement in compressive strength. The observed increase in strength can be attributed to the additional formation of essential compounds such as calcium silicate hydrate gel (C-S-H) and Calcium Alumino Silicate Hydrate (C-A-S-H), aligning with findings from previous studies [36].

Moreover, a positive correlation between the compressive strength and the incorporation of fiber contents (Facial Mask Fiber - FMF and Basalt Fiber - BF) was noted in specific proportions. Notably, the combination denoted as CM15, with 10% FMF and 50% BF, exhibited a substantial increase in compressive strength by approximately 13.4% when compared to the controlled concrete (CC). The selection of BF in this research was strategic, as it possesses the capability to bridge cracks and functions as a reinforcing material [37, 38]. Upon comparing the compressive strength of each mixture, it was evident that CM3 (10% FMF), CM10 (15% FMF and 50% BF), and CM15 (10% FMF and 15% BF) achieved the highest compressive strengths. However, it’s crucial to note that an excessive increase in fiber content resulted in a decline in compressive strength. This trend emphasizes the importance of a balanced composition to optimize the performance of the concrete mixtures.

Split Tensile Strength

After a 28-day curing period, the split tensile strength of concrete specimens was evaluated using a Compression Testing Machine (CTM). Specimens incorporating Facial Mask Fiber (FMF) demonstrated higher tensile strength values, measuring approximately 3.3 MPa, 3.4 MPa, and 3.6 MPa, as illustrated in Figure 3. This increase in strength

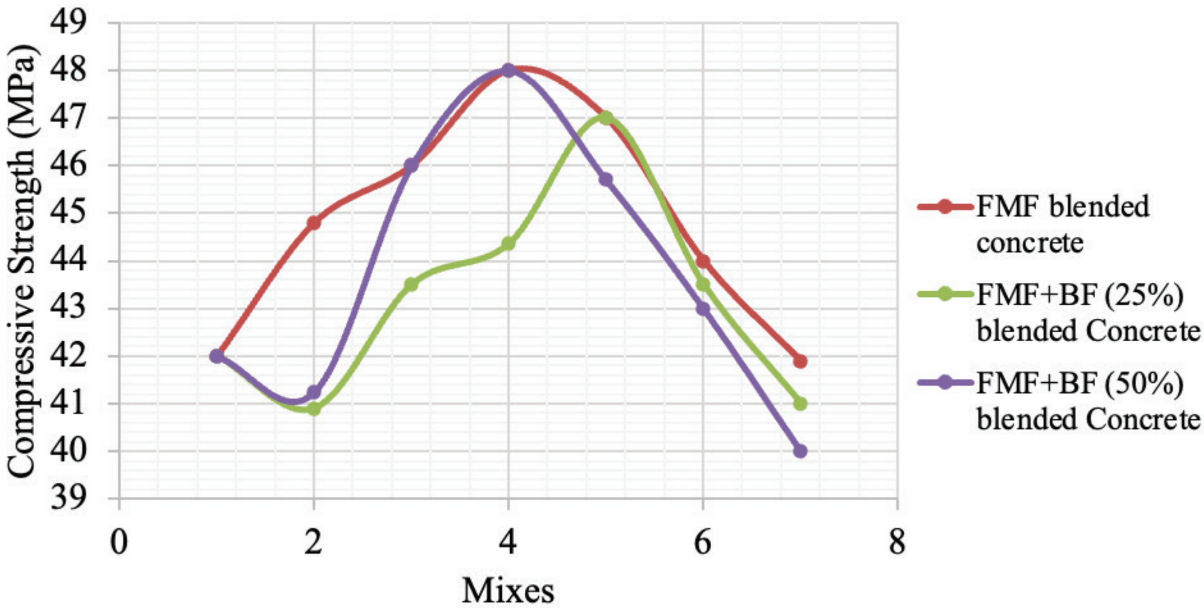

Figure 2. Compressive strength of FMF and BF blended concrete.

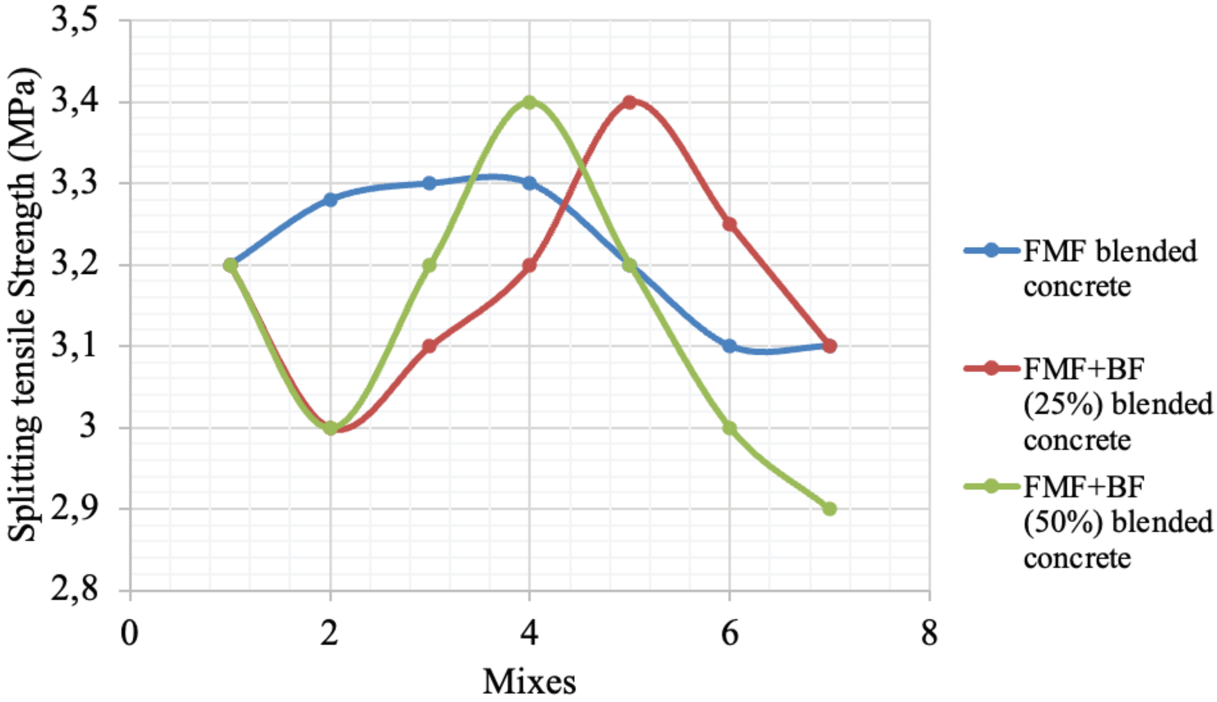

Figure 3. Splitting tensile strength of concrete for FMF and BF blended concrete.

is attributed to the improved cracking resistance of concrete resulting from the addition of FMF fiber and mineral admixtures. The introduction of Basalt Fiber (BF) at 2.5% in specimens (CM7-CM12) further amplified tensile strength, showcasing enhancements of 11.4%, 14.2%, 16.8%, 19.2%, and 21.6%, respectively. Elevating the BF content to 5.0% in specimens (CM13-CM18) resulted in even higher tensile strength improvements, reaching values of 23.2%, 25.5%, 27.7%, 25.2%, and 22.9%, respectively. Similar to the trend observed in compressive strength, CM15 exhibited superior tensile strength compared to the controlled concrete (CC).

SEM analysis of the cast specimens revealed a robust bond between the binder and the fibers used in the concrete. This finding suggests that the integration of FMF and BF in the concrete matrix effectively enhances the interfacial bonding, contributing to the overall improvement in split tensile strength. The observed results underscore the potential of incorporating these fibers and mineral admixtures for enhancing the mechanical properties of concrete, particularly in terms of tensile strength and cracking resistance.

Ultra-sonic Pulse Velocity Tests

A comprehensive evaluation of the concrete mix quality and material homogeneity was conducted through density and Ultrasonic Pulse Velocity (UPV) tests. For the controlled concrete (CC), the density and UPV were determined to be 2404 kg/m^3 and 4489.17 m/s, respectively (Fig. 4). Comparatively, specimens reinforced with Facial Mask Fiber (FMF) and Basalt Fiber (BF) exhibited slightly enhanced values, measuring 2419.27 kg/m^3 and 4524.32 m/s. The SEM analysis (Fig. 5 and 6) provided insights into the composition of specimens reinforced with fibers and mineral admixtures. The findings indicated a notable improvement in quality, evidenced by higher values of density and UPV. This enhancement can be attributed to the reduction in pore and void content, signifying improved material homogeneity.

The SEM images further support the conclusion that the incorporation of fibers and mineral admixtures contributes to a more uniform and denser microstructure, enhancing the overall quality of the concrete mix. These results affirm the positive impact of fiber reinforcement and mineral admixtures on the structural integrity and homogeneity of the concrete material.

Water Absorption

Water absorption testing was conducted to assess the permeability and porosity of concrete specimens, particularly those incorporating FMF and BF. The specimens containing FMF and BF exhibited lower water absorption values, indicating a reduction in the formation of voids and pores within the concrete mix. The use of FMF and BF in concrete is known to promote the formation of calcium silicate hydrate gel (C-S-H) and Calcium Alumino Silicate Hydrate (C-A-S-H), contributing to increased density and reduced void space, as corroborated by studies such as "Provis et al" (2012) and "Shaban et al." (2019).

However, a noteworthy exception was observed in the specimen CM17, which included 0.2% Facial Mask Fiber

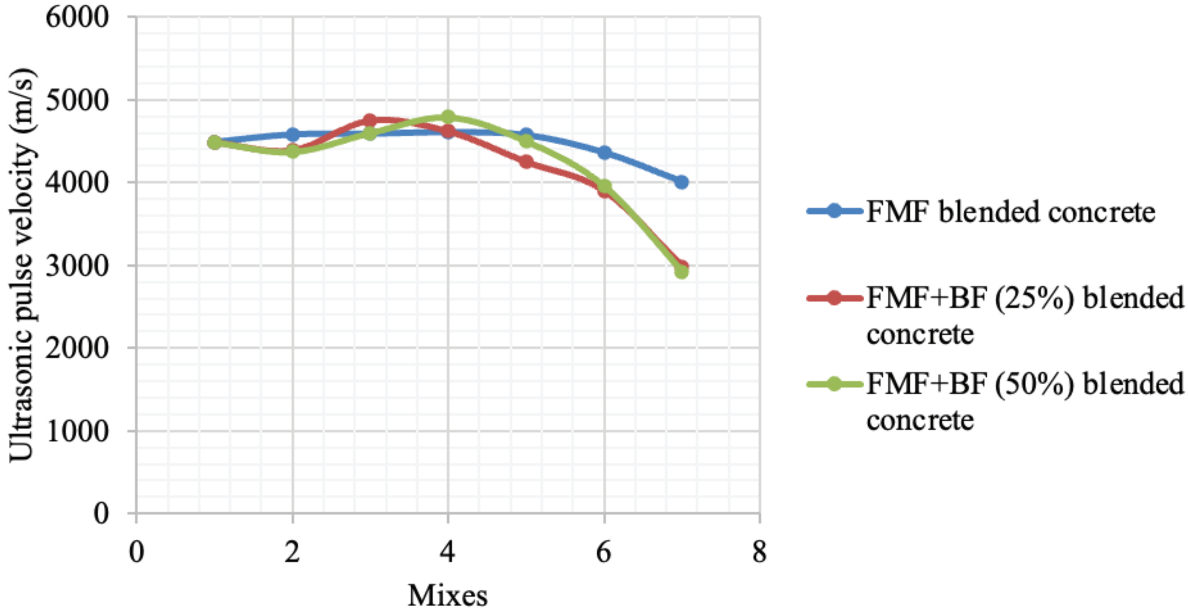

Figure 4. Ultrasonic pulse velocity for FMF ad BF blended concrete.

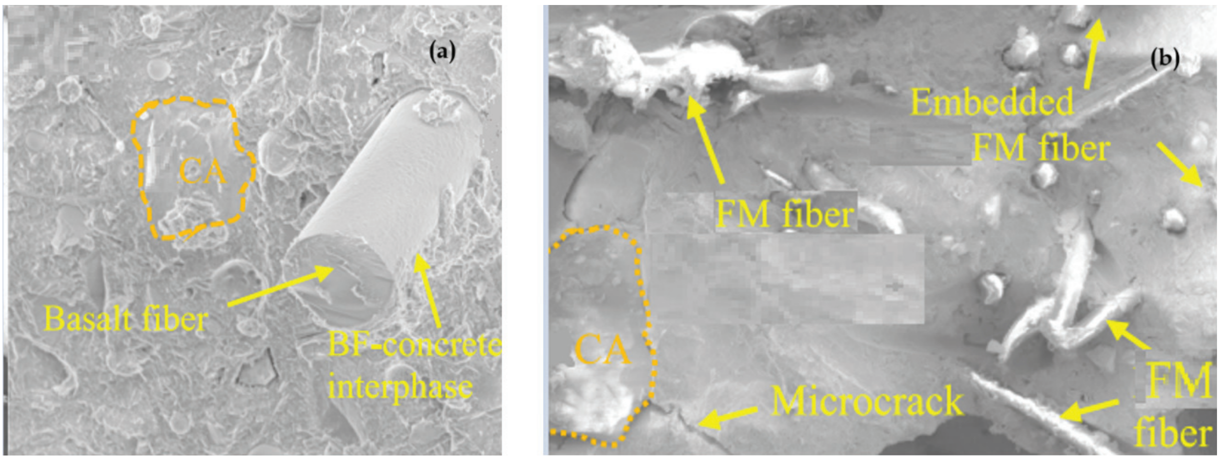

Figure 5. SEM images of a) FMF and b) BF in cast specimens.

(FMF) and 0.5% Basalt Fiber (BF). This particular mixture resulted in higher water-cement absorption, reaching approximately 3.72%. The elevated water absorption can be attributed to an excessive amount of FMF in the concrete, leading to the formation of unwanted pores and cavities within the material. This observation underscores the importance of maintaining a balanced fiber content to optimize the performance of the concrete mix and prevent the unintended negative effects on water absorption.

SEM Analysis

Facial mask fiber (FMF): In the SEM analysis, FMF exhibited inner layers with a smooth texture, showcasing a random distribution. The thin layer observed displayed gaps and voids, attributed to the arrangement of polypropylene fibers within the FMF. This unique texture suggests the potential for effective bonding within the concrete matrix.

Basalt fiber (BF): The SEM analysis of BF revealed a smooth circular cross-section in filament type, devoid of voids and pores. The absence of irregularities in the cross-sectional structure suggests BF's capability to contribute to a more uniform and denser microstructure within the concrete. This characteristic is indicative of the reinforcing potential of BF in enhancing the overall structural integrity. Understanding the morphological details of the fibers is crucial for comprehending their interaction within the concrete matrix. These SEM observations provide valuable insights into the surface characteristics and arrangement of FMF and BF, aiding in the assessment of their contributions

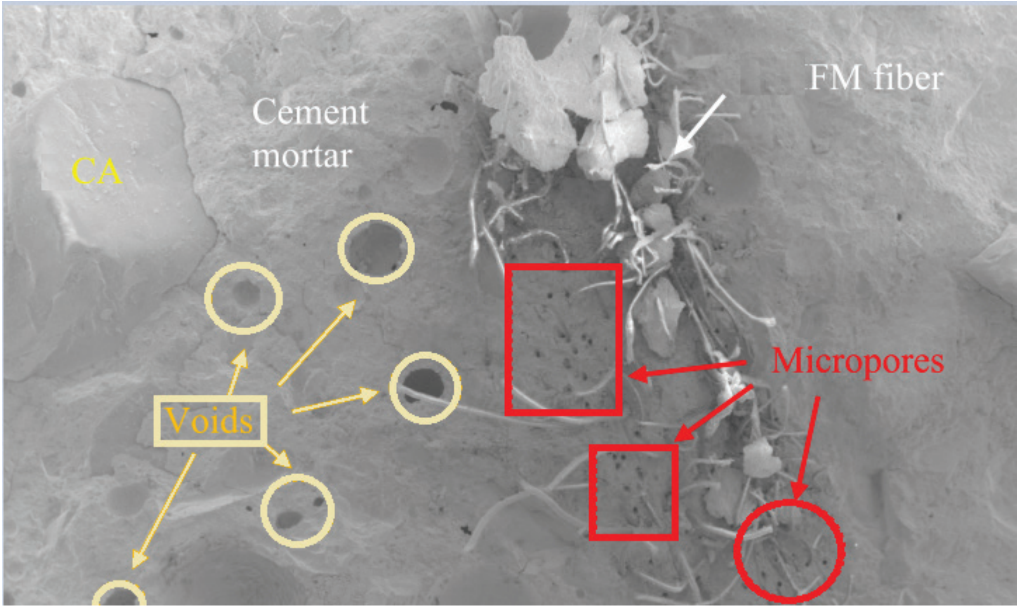

Figure 6. SEM image of CM17 specimen after water absorption test.

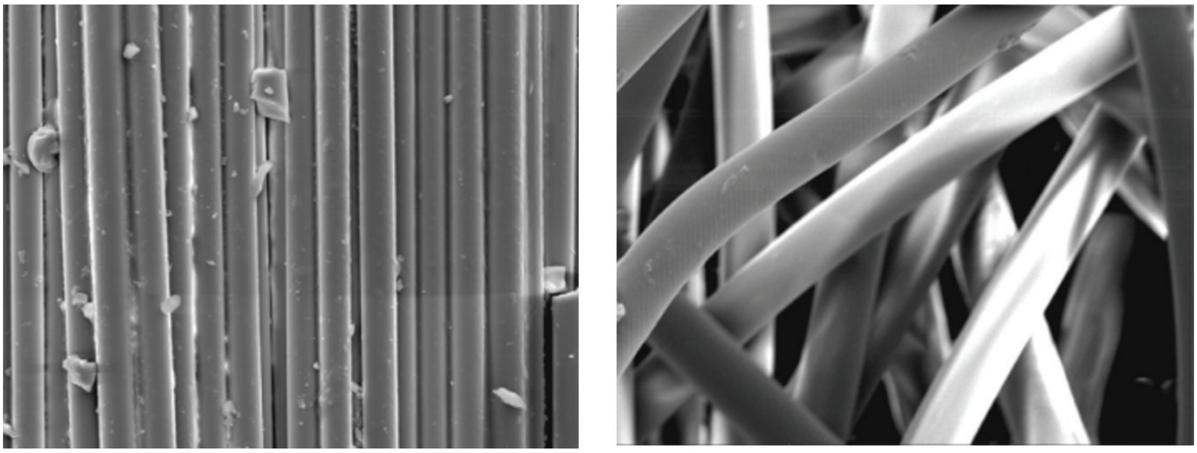

Figure 7. SEM image of BF and FMF.

to the mechanical properties and overall performance of the concrete.

CONCLUSION

- The CM15 mix proportion, incorporating 0.1% FMF and 0.5% BF, exhibited a remarkable increase of approximately 14% in compressive strength, showcasing the potential of this combination for enhancing the durability and structural performance of the concrete.
- The split tensile strength of concrete, particularly in the CM15 mix with 0.1% FMF and 0.5% BF, showed a substantial improvement, reaching 27.7%. This finding underscores the positive impact of the selected fiber combination on the tensile properties of the concrete, contributing to enhanced cracking resistance.
- The Ultrasonic Pulse Velocity (UPV) values exceeding 4500 m/s indicate a very good quality of the concrete mix. This suggests that the developed concrete compositions, incorporating FMF and BF, are suitable for structural applications, reflecting their high-quality and durable nature.
- SEM analysis provided insights into the morphological details of the fibers. FMF exhibited inner layers with a smooth texture and a random distribution, with a thin layer displaying gaps and voids due to the arrangement of polypropylene fibers. In contrast, BF displayed a smooth circular cross-section with a filament type, characterized by the absence of voids and pores. These

observations suggest that FMF and BF contribute to a more uniform and dense microstructure within the concrete.

In conclusion, the utilization of disposed facial masks in concrete, along with carefully chosen mineral admixtures and fibers, proved to be an environmentally friendly approach while simultaneously enhancing the mechanical and durable properties of the concrete. The study supports the potential for sustainable and innovative practices in the construction industry, contributing to both structural resilience and environmental conservation.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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