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Sustainable Civil Construction: Incorporating Discarded Face Masks with Recycled Concrete Aggregate and Silica Fume

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Abstract: *This study investigates the use of Shredded Face Mask (SFM) fibers, made from polypropylene, as a sustainable additive in concrete. The results show that incorporating SFM fibers at an optimal content of 1% enhances the mechanical properties of concrete, particularly compressive strength, due to the crack-bridging effect of the fibers. The addition of silica fume further reduces porosity, improving the overall densification of the concrete matrix. However, higher fiber content (2% and 3%) leads to increased porosity and decreased strength, highlighting the need for optimal fiber content to balance performance and material density. The combination of SFM fibers with Recycled Concrete Aggregate (RCA) also shows promise for creating more sustainable construction materials, supporting waste reduction and environmental conservation. Durability tests under sulfuric acid exposure confirm the concrete's resilience to aggressive environmental conditions, particularly at the optimal fiber content. This research paves the way for incorporating waste materials, such as face masks, into construction, contributing to a circular economy.*

Keywords: Shredded Face Mask (SFM), polypropylene, concrete, mechanical properties, compressive strength

1. Introduction

The growing environmental concern regarding single-use plastics, particularly face masks, has prompted the exploration of innovative ways to repurpose these materials [1]. This study focuses on the incorporation of Shredded Face Mask (SFM) fibers, primarily made from polypropylene, into concrete as a sustainable alternative. The objective is to investigate how SFM fibers can enhance the mechanical properties of concrete while contributing to waste reduction and environmental conservation. Given the large quantities of single-use face masks disposed of globally, recycling them into construction materials offers a potential solution to mitigate plastic waste. The study explores the effect of varying SFM fiber content on concrete's compressive strength, porosity, and overall durability. The use of silica fume in combination with SFM fibers is also examined for its impact on reducing porosity and enhancing the concrete matrix's densification. Furthermore, the addition of Recycled Concrete Aggregate (RCA) is investigated for its potential to create more sustainable construction materials [2]. The durability of the concrete is assessed under exposure to sulfuric acid, providing insights into its performance under harsh environmental conditions. This research aims to contribute to a circular economy by integrating waste materials into concrete production.

2. Literature Review

The increasing environmental challenges posed by plastic waste and single-use materials have led to the exploration of sustainable solutions in the construction industry. Recent studies, such as those by Zhang et al. (2024) and Rajput et al. (2023), focus on repurposing waste materials like face masks and plastic fibers in concrete production. This literature highlights the potential of incorporating recycled materials, such as polypropylene fibers and recycled concrete aggregates (RCA), to enhance the mechanical properties, durability, and environmental impact of concrete, while contributing to waste management and sustainability goals.

Table 1: Summary of Literature Review

Author's	Work Done	Findings
Zhang, X. (2024)	Investigated the use o Shredded Face Mas (SFM) fibers in concret production as sustainable solution fo waste management.	SFM fibers at 1% enhance concrete compressiv strength, while higher content led to increased porosity an reduced strength.
Sharma, A. (2023)	Explored the use o waste plastic fibers i concrete to improv strength and durability.	Waste plastic fiber improved concrete properties especially in terms of strengt and crack resistance.
Kim, S. (2022)	Reviewed th incorporation o recycled materials i concrete, analyzin environmental an economic impacts.	Recycled materials ca reduce environmental impact but require careful integratio to maintain concret performance.
Gupta, S. (2022)	Focused on integratin plastic waste int concrete as a sustainabl construction material.	Integration of plastic wast improved mechanica properties but was limited b the fiber content.
Yadav, R. (2021)	Provided comprehensive revie on the effects o polypropylene an plastic fibers o concrete.	Polypropylene fiber enhanced mechanica properties but showed decline in performance wit excessive content.
Taha, M. (2021)	Reviewed the role o polypropylene fibers i concrete production.	Polypropylene fiber enhanced strength, durability and crack resistance i concrete, especially in lo percentages.
Abbas, M. (2021)	Examined polypropylene fibers a a sustainable additive fo concrete.	Polypropylene fiber positively impacted th concrete's compressiv strength and durability whe used in moderation.
Khan, I. (2020)	Studied the effect o waste polypropylen fibers on the mechanica behavior of concrete.	Waste polypropylene fiber improved mechanica properties, with optimal fibe content significantl enhancing performance.
Joshi, M. (2019)	Reviewed the use o waste materials i concrete, focusing o construction an demolition wast recycling.	Recycling of constructio and demolition waste int concrete is feasible an sustainable, though it require balancing performance.
Fathy, A. (2018)	Investigated th mechanical propertie and durability o concrete containin polypropylene fibers.	Polypropylene fiber improved both mechanica strength and durability, thoug higher content may reduc overall performance.

2.1 Research Gap

Despite the growing interest in recycling single-use plastics, there is a limited exploration of incorporating Shredded Face Mask (SFM) fibers into concrete. While studies have examined the effects of various additives on concrete properties, the specific impact of SFM fibers, particularly at optimal content levels, remains under-researched. Additionally, the combined effect of SFM fibers with silica fume and Recycled Concrete Aggregate (RCA) on concrete's mechanical performance and durability, particularly under aggressive environmental conditions, has yet to be fully explored. This study addresses these gaps.

3. Problem Statement

The disposal of single-use face masks, particularly those made from polypropylene, contributes significantly to plastic waste. This study aims to investigate the repurposing of Shredded Face Mask (SFM) fibers in concrete, enhancing its properties while addressing environmental sustainability and waste reduction.

4. Methodology

The primary material considered for investigation in this study is concrete incorporating Shredded Face Mask (SFM) fibers made of polypropylene. The study utilized new single-use face masks due to COVID-19 precautions [1]. This section first outlines the properties of the materials used (SFM, Recycled Concrete Aggregate (RCA), Silica Fume, and Concrete). In the second part, the experimental design and composition of the concrete mixture for the research are provided. To ensure the accuracy of the results, three samples were tested for each outcome, and the numerical findings represent the average of these three samples.

Shredded Face Mask (SFM): For this research, new disposable surgical face masks, made of polypropylene fibers arranged in a random orientation and fused into small, closely spaced welds, were used. Prior to incorporation into the concrete mixture, the face masks required preparation.

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Initially, the ear straps and any metal components were manually removed. The masks were then cut into smaller pieces by hand [2]. The polypropylene fibers from the masks were used in two forms: short fibers and long fibers. In this study, short fibers were selected due to their ease of handling and better dispersion within the concrete mix. These short fibers had dimensions of 20 mm in length, 5 mm in width, and 0.46 mm in thickness. The aspect ratio, defined as the length-to-diameter ratio of the fibers, ranged from 20 to 60 for the short fibers, while for long fibers, it exceeded 200. According to Naaman (2003), the aspect ratio of a fiber with a non-circular cross-section can be calculated as follows:

$$\text{Aspect ratio} = \frac{l}{d\text{FIER}} = \frac{l}{4\frac{A}{\Psi}}$$

where l is the length, d_{FIER} is the equivalent diameter, A is the cross-sectional area, and Ψ is the perimeter of the f_{ber} cross-section. Te aspect ratio was approximately [3].

5. Result & Discussion

The density of a single-use face mask was determined using a water displacement method. A cylinder was filled with water up to 600 ml, and a 30 gm (0.030 kg) sample of the face mask was immersed in the water for 24 hours. After 24 hours, all air voids were removed, and the water level in the cylinder increased to 680 ml. The volume change was recorded as 80 ml (0.00008 m³). Using the formula for mass per unit volume, the density of the face mask was calculated, as shown in Table 2. The procedure for calculating the density is illustrated in Figs. 1 and 2 [4].

Table 2 Density of single-use facemask

Ingredients	**Mass (gm)**	**Volume of Cylinder (ml)**
Water	-	600
Water and Facemask	-	680
Change in Volume	-	80
Facemask	30	80
Density (kg/m³)	-	370

Figure 1 SFM fbers.

Figure 2 Cylinder with facemask depth.

Recycled Concrete Aggregates (RCA): This research utilized materials including water, cement, and aggregates. The RCA was sourced from demolished road shoulders used for sewage work in Abbott bad and was manually crushed to a nominal size of 19 mm from old concrete debris [5]. The strength of the demolished concrete ranged from 20–25 MPa. It is well-established that normal concrete consists of approximately 75% coarse aggregates, for which certain mechanical and physical properties need to be determined. These properties for both natural and recycled concrete aggregates were assessed in accordance with the relevant ASTM standards, as shown in Table 3.

Table 2 Physical and mechanical properties of aggregates

Properties of Aggregates	**Aggregate Size**	**Standards**	**Natural Aggregates**	**Recycled Concrete Aggregates**
Specific Gravity (gm/cm³)	Fine	ASTM C128-15	2.66	2.42
	Coarse	ASTM C127-15	2.65	-
Water Absorption	Fine	ASTM C128-15	3%	7.40%
	Coarse	ASTM C127-15	0.81%	-
Moisture Content	Fine	ASTM C566-13	3.28%	6.70%
	Coarse	ASTM C566-13	1.99%	-
Impact Test	Coarse	ASTM-D256	18.51%	16.17%
Fineness Modulus	Fine	ASTM C117-05	3.12	-

Silica Fume: Considering the beneficial effects of silica fume in enhancing concrete properties and its environmental benefits by substituting disposal with its use in construction, 10% by weight of ordinary Portland cement was added to the concrete mix. A large portion of the silica fume particles (95%) are finer than 1 µm. This particle size and nature of silica fume help densify the concrete mix by filling voids created by the inclusion of SFM fibers. The reduction in porosity is more pronounced when silica fume is added up to a 10% level, with little effect on porosity reduction beyond this percentage [6].

Concrete: Concrete typically consists of 75% coarse aggregates, the properties of which are outlined in Table 3. The remaining 25% comprises water, cement, and fine aggregates. Water for concrete production and curing was sourced from COMSATS University Abbottabad. Ordinary

Portland cement, with physical and chemical properties listed in Table 4 and a specific gravity of 3.15, was used [7]. Natural aggregates were obtained from Tandiani near Abbottabad, and their properties are also presented in Table 4.

Table 4 Physical and mechanical properties of aggregates

Properties of Aggregates	Aggregate Size	Standards	Natural Aggregates	Recycled Concrete Aggregates
Specific Gravity (gm/cm³)	Fine	ASTM C128-15	2.66	2.42
	Coarse	ASTM C127-15	2.65	-
Water Absorption	Fine	ASTM C128-15	3%	7.40%
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Moisture Content	Fine	ASTM C566-13	3.28%	6.70%
	Coarse	ASTM C566-13	1.99%	-
Impact Test	Coarse	ASTM-D256	18.51%	16.17%
Fineness Modulus	Fine	ASTM C117-05	3.12	-

Table 5 Chemical compositions of the cement (%), and mechanical and physical properties

Property	Range
SiO_2	20–20.5%
Al_2O_3	5.5–6%
Fe_2O_3	4.5–6%
CaO	63–64%
MgO	3–5%
C_3A	7.5–8%
SO_3	2.5–3%
Cl	0.1–1%
Compressive Strength (MPa)	3 Day: 120–170
	7 Day: 200–280
	28 Day: 325+
Initial Setting (min.)	45
Final Setting (min.)	360

To achieve a target compressive strength of 25 MPa, a recommended slump value of 20–30 mm, and a maximum aggregate size of 19 mm, a control concrete mix design was created using a water-to-cement (W/C) ratio of 0.62, based on the ACI method. In the experimental mixes, natural aggregates were replaced with 15%, 25%, and 50% recycled concrete aggregates (RCAs). Due to the higher water absorption rate of RCAs compared to natural aggregates, an increased amount of water was factored into the mix [8]. Additionally, 10% silica fume by weight of cement and shredded face masks (SFM) at 1%, 2%, and 3% by volume of concrete were incorporated into the mixes. The trial mixes and control sample mix design are detailed in Table 6.

Table 6 Mix design

Mix No.	w/c	Water (kg/sample)	Cement (kg/sample)	Silica Fume (kg/sample)	Fine Agg. (kg/sample)	Coarse Agg. (kg/sample)	Recycled Concrete Agg. (%)	Weight (kg/sample)	Vol. Facemask (%)	Weight (g/sample)
A1	1	0.62	1.007	2.097	3.93	5.08	–	–	–	–
	2	0.62	1.007	2.097	0.209	3.93	5.08	–	1	19.6
	3	0.62	1.007	2.097	0.209	3.93	5.08	–	2	39.2
	4	0.62	1.007	2.097	0.209	3.93	5.08	–	3	58.8
B1	5	0.62	1.007	2.097	0.209	3.93	4.32	15	0.76	19.6
	6	0.62	1.007	2.097	0.209	3.93	3.816	25	1.27	19.6
	7	0.62	1.007	2.097	0.209	3.93	2.54	50	2.54	19.6

Compressive Strength Test: The compressive strength tests were conducted on cylindrical samples with dimensions of 150 mm in diameter and 300 mm in height, following ASTM C39 standards. The samples were cured and tested at 7, 14, and 28 days. Loading was applied until the samples fractured, and the corresponding compressive strengths were recorded (as illustrated in Fig. 3) [9].

Splitting Tensile Strength: Based on the compressive strength test results, the samples with the highest compressive strength were further subjected to diametral loading to determine their splitting tensile strength after 28 days, in accordance with ASTM C496. Cylindrical specimens of 150 mm in diameter and 300 mm in height were loaded diametrically at a rate of 1.2–2.4 MPa/min until they split apart, as depicted in Fig. 4.

Figure 4 Bridging effect of fiber.

Durability Assessment: The durability of the concrete samples was evaluated under aggressive sulfuric acid attack as per ASTM D3744. A 5% sulfuric acid solution was used to test the samples' resistance over a 24-hour exposure period [10]. Loss in compressive strength and visual degradation of the samples were assessed (as shown in Fig. 5).

Figure 5 Durability test sample

Compressive Strength: The compressive strength results, presented in Fig. 6 and Table 6, indicate that increasing the percentage of discarded face mask (SFM) fibers from 0% to 1% improves the strength significantly, with the maximum strength observed at 1% SFM. This enhancement is attributed to the crack-bridging effect of the fibers. However, beyond 1% SFM, the compressive strength declines due to increased porosity and voids in the concrete mix. A 1% SFM addition, combined with 10% silica fume (by weight of cement), resulted in a 9.97% increase in compressive strength [11]. In contrast, higher SFM percentages (2% and 3%) introduced excessive voids, reducing the overall density and strength of the concrete. The optimum percentage of SFM was identified as 1%, which provided the highest compressive strength.

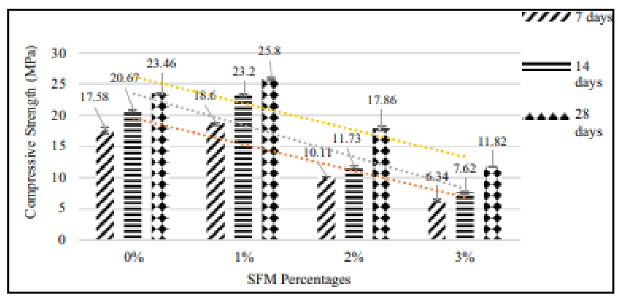

Figure 6 Compressive strength vs SFM percentages.

Table 7 Compressive strength vs SFM percentages.

Mix No.	SFM (%)	RCA (%)	Compressive Strength (MPa)
			7 Days
1	0	0	17.58
2	1	0	18.6
3	2	0	10.11
4	3	0	6.34

Further Trials: Additional trials incorporated 1% SFM, varying percentages of recycled concrete aggregate (RCA), and 10% silica fume by weight of cement. These trials aimed to explore the combined impact of SFM and RCA on compressive strength.

Compressive Strength: From Fig. 7, which includes error bars based on standard deviation, and Table 7, it is concluded that the combination of 1% discarded face mask (SFM) fibers and 0% recycled concrete aggregate (RCA) yielded the maximum compressive strength of 25.8 MPa [12]. As the RCA percentage increased from 0% to 50%, a decline in strength was observed. This reduction is attributed to the weak and porous characteristics of RCA compared to natural aggregates. However, all compressive strengths remained above the minimum allowable limit of 20 MPa for rigid pavements. Thus, for cost-efficiency, a higher RCA content of up to 50% can be utilized while still meeting structural requirements.

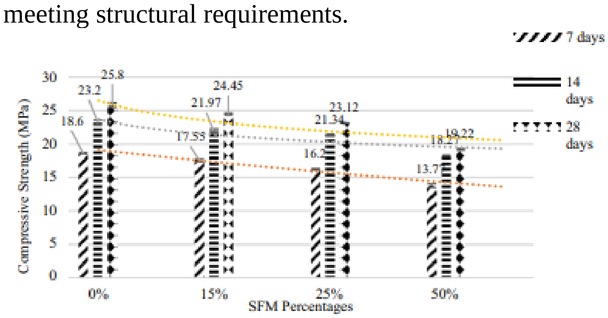

Figure 7 Compressive strengths vs RCA percentages

Splitting Tensile Strength: The sample with the highest compressive strength (from Table 7) was subjected to splitting tensile strength testing and compared to the control sample. As illustrated in Fig. 8, the tensile strength of the optimized sample increased significantly compared to the control sample without SFM fibers. This enhancement is attributed to the reinforcing, crack resistance, and bridging effects provided by the SFM fibers. Additionally, the improved tensile strength is linked to the greater flexibility of SFM fibers compared to RCA particles. Classified as short and discontinuous fibers, the SFM fibers contribute to better overall strength and stiffness in the concrete [13]. This study emphasizes the dual benefits of incorporating SFM fibers and RCA in concrete for both strength enhancement and economic sustainability in rigid pavement applications.

Table 8 Compressive strength vs RCA percentages

Mix No.	SFM (%)	RCA (%)	Compressive Strength (MPa)
			7 Days
1	1	0	18.6
2	1	15	17.55
3	1	25	16.2
4	1	50	13.77

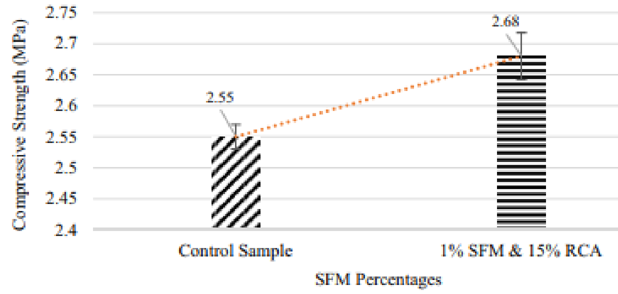

Figure 8 Split tensile strength vs SFM percentage

Durability Test: Concrete samples were subjected to a 5% sulfuric acid solution for 24 hours to evaluate their durability under harsh acidic conditions. Samples with RCA levels of 0%, 15%, 25%, and 50% were compared to control samples containing the optimal amount of SFM fibers. The test assessed strength loss and visually inspected the degraded samples. As reported in Fig. 9 and Table 8, no significant strength loss was observed. The maximum recorded strength loss was 0.7 MPa out of 25.8 MPa, a negligible reduction. Visual inspection revealed a slight color change in the concrete from its original shade to a lighter hue, consistent with findings from Anish Banerjee's research, which also noted color deterioration in acidic environments.

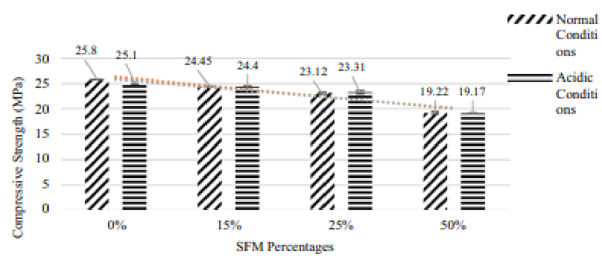

Figure 9 Durability of various specimens containing various RCA percentages.

Table 9 Durability test results

Trial No.	SFM% (%)	RCA% (%)	Compressive Strength at 28 Days (MPa)
			Normal Condition
1	1	0	25.8
2	1	15	24.45
3	1	25	23.31
4	1	50	19.22

Comparison with Previous Studies: Fiber-reinforced concrete offers notable improvements in compressive strength, split tensile strength, and ductility compared to regular concrete. Research by Cory High demonstrated that incorporating chopped basalt fibers and basalt fiber-reinforced bars as additives increased compressive strength by up to 6% at 28 days. Similarly, Biradar's study found a 9% increase in compressive strength at 28 days with 0.3% fibers by volume. Sivakumar's research showed that using 0.6 kg/m³ of fibers improved 28-day compressive strength by 3% for GFRC, 1.8% for polyester, and 6.3% for nylon. Pelisser's research indicated that incorporating polyethylene terephthalate (PET) fibers by volume increased compressive strength by 1% at 28 days [14]. However, these improvements are less pronounced than the compressive strength enhancement achieved with 1% SFM fibers by volume. The superior mechanical properties, environmental benefits, ease of availability, and cost-effectiveness of SFM fibers make them a preferable choice for concrete and rigid pavement applications. The comparative results of these studies are summarized.

Strength and Durability Observations: Compared to the control sample, the split tensile strength of SFM fiber-reinforced concrete showed significant improvement, as illustrated in Fig. 8. This increase is attributed to the reinforcing, crack-resistance, and bridging effects of SFM fibers, consistent with findings by Shannon Kilmartin-Lynch. In the durability test, the control sample experienced a minimal strength loss of 0.7 MPa, amounting to 2.71% of the total strength, after exposure to a 5% sulfuric acid solution. This aligns with research by Arash Arjomandi, who observed strength degradation in concrete with prolonged exposure to acidic conditions. His study, which used a similar 5% sulfuric acid solution, highlighted the durability of concrete incorporating steel fibers and nylon granules under acidic environments.

6. Conclusion

In conclusion, the study demonstrated the feasibility of incorporating Shredded Face Mask (SFM) fibers, derived from polypropylene, into concrete as a sustainable and innovative approach to repurposing single-use face masks. The experimental results revealed that the inclusion of SFM fibers at an optimal percentage (1%) significantly enhanced the mechanical properties of concrete, particularly compressive strength, due to the crack-bridging effect provided by the fibers. This improvement, coupled with the addition of silica fume, reduced porosity and further contributed to the densification of the concrete matrix. The investigation also highlighted the limitations of excessive SFM fiber content (2% and 3%), which led to increased porosity and decreased strength. This underscores the importance of optimizing fiber content to balance mechanical performance and material density. Furthermore, the use of Recycled Concrete Aggregate (RCA) in combination with SFM fibers demonstrated the potential for creating more sustainable construction materials, aligning with waste reduction and environmental conservation goals. Durability assessments under sulfuric acid exposure affirmed the concrete's resistance to aggressive environmental conditions, especially at the optimal SFM content. This indicates that SFM fibers can contribute to enhancing both the structural integrity and longevity of concrete structures. In conclusion, this research provides a promising framework for integrating waste materials, such as single-use face masks, into construction practices, fostering a circular economy. Future studies could explore the scalability of this approach, investigate long-term performance under varied environmental conditions, and assess its economic viability in practical applications.

Future Scope

- Investigate the industrial-scale integration of SFM fibers in concrete production.
- Assess concrete performance over extended periods under various environmental conditions.
- Fine-tune SFM fiber percentage for enhanced mechanical properties and durability.
- Explore the cost-effectiveness of SFM fiber-based concrete compared to traditional materials.

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