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An Environmentally Friendly Solution for Waste Facial Masks Recycled in Construction Materials

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Abstract: In response to the COVID-19 pandemic, single-use disposable masks saw a dramatic rise in production. Facial masks that are not properly disposed of will expose the environment to a form of non-biodegradable plastic waste that will take hundreds of years to degrade. Therefore, recycling such waste in an eco-friendly manner is imperative. Fibered or shredded waste masks can be used to make green concrete that is an environmentally friendly solution to dispose the facial masks. This study prepared six classes of concrete samples, three of which contained fibers from masks and three of which contained shredded masks at the ages of seven days and 28 days. The results show that in the seven-day and 28-day samples, mask fiber added to the mixes resulted in increased compressive strength. For seven-day and 28-day samples, the compressive strength increased by 7.2% and 10%, respectively. Despite that, the results of the shredded mask addition to concrete indicate that the increase in shredded mask volume has a minor impact on the compressive strength of the seven-day samples. An increase in shredded mask from 0.75 to 1% increased 28-day compressive strength by 14%. However, the compressive strength of the mask fiber decreased by 8 after 1% volume. According to a thermal analysis of 28-day concrete samples, as the fiber percentage increases, the mass loss percentage increases. The mass loss rate for samples containing fibers is higher than that for samples containing shredded mask pieces. In general, based on the results mentioned above, the use of fiber in concrete in its fiber state enhances its strength properties. As a result, using shredded mask pieces in concrete leads to better curing due to the reduction of residual capillary pore water loss in construction materials.

Keywords: facial masks; mask fiber; shredded mask; compressive strength; tensile strength

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1. Introduction

The amount and composition of hospital waste, and even municipal and household waste, has changed with the COVID-19 crisis [1]. Consumption of individuals and families has increased dramatically following the spread of COVID-19 worldwide. The spread of COVID-19 heart disease has led to an increase in global demand for disinfectants, detergents, masks, and other health items [2,3]. The increase of these detergents and masks increases the pollution of water and wetlands and the environment and has adverse negative effects on living organisms [4].

It is believed that the segregation of wastes causes the virus to spread further and, therefore, all of them should be buried in the same way that they are collected. Some developed countries have prepared instructions and have asked the people to divide their waste into three categories: wet, dry, and non-recyclable [5–7].

Restrictions on the segregation and recycling of municipal waste in many countries around the world are among the most influential factors on the environment after the outbreak of COVID-19. Household waste, hospital waste, plastic, paper, and glass have all been dumped into large chunks [8]. Landfilling all waste will be a major disaster because, in addition to wasting returnable capital, it contaminates soil and water, and large areas of land are spent on landfilling. Garbage is referred to as dirty gold [9]. In addition to wasting material, burying garbage makes land into a landfill. While this waste can be recycled and put into the production cycle, waste that is not recyclable should also be converted into compact materials that take up the least space [10–12].

Another new problem and consequence of the COVID-19 crisis that needs to be managed is the use of disposable gloves and masks and their release into the environment and public thoroughfares [13]. Plastics and disposable materials do not decompose in the environment and will have long-term consequences [14]. In recent years, methods to reduce the use of plastic materials have been implemented in many countries, but now, due to greater caution and fear of increasing epidemics of the past, coronavirus-like measures are being implemented [15–18]. Concerns about the safety and contamination of the virus have led to the lifting of the ban on the use of disposable plastics, and as a result, the demand for water bottles, plastic bags, plastic packaging, and mask masks has increased. The use of protective products such as masks, gloves, and other plastic medical devices and their release into the environment cause these materials to enter and also close the waterways [19,20].

An analysis of samples taken from major rivers in Europe shows that masks are being abandoned in these rivers at an increasing rate. The polypropylene used in disposable protective masks breaks down quickly [21,22].

Another important point is that in order to achieve sustainable development, the economy must be considered along with the environment. The COVID-19 dealt a heavy blow to the world economy and spread poverty [23,24]. Under such circumstances, governments will move forward to meet the basic needs of society and will not be strict on industries. COVID-19 has caused many social and economic disorders, and attention to the environment will not be a priority [25]. At the same time, the environment, along with society and the economy, is an important three-pronged approach to achieving sustainable development. In a world where COVID-19 is killing people in society and destroying the economy, the discourse of the environment will not be heeded [26].

The recycling of face masks and their reutilization in building materials could be a feasible way to solve these issues. As a result, it reduces waste generated worldwide by the face mask and may improve various attributes of the concrete it contains [27]. Although concrete is a widely used material in construction materials, it has disadvantages such as: low tensile strength, low ductility, shrinkage of concrete and subsequent cracking due to it, and cracks caused by improper processing and hardening of concrete. Due to the properties that are expected from plastic materials, these weaknesses of concrete can be eliminated to a large extent. In addition, by using this solution, it is possible to correct the defects in concrete and to create a more suitable environment for living [25].

Research conducted on concretes containing polypropylene fibers of different types shows that the strength and thermal resistance of concrete specimens have increased using polypropylene fibers. After seven and 28 days, the 250 × 250 × 250 mm cubic samples were removed from the water basin and the samples containing polypropylene fibers were placed in a 450 °C oven for 8 h for thermal testing. Compressive strength tests were then performed on them [28]. Chandramouli et al. [29] believe that with 1.5% of fiberglass to the weight of concrete, the modulus of rupture increases by about 20% and toughness by about 50%. Moreover, by increasing the force required to deform the concrete and increase the toughness, the fibers prevent the spread of more cracks [29]. Pakravan et al. [30] investigated the compressive and flexural strength of concrete specimens containing steel fibers and polypropylene. They used 150 × 150 × 150 mm cube molds to test the compressive strength and rectangular cube molds of 100 × 100 × 500 mm molds to test the flexural strength. They conducted these experiments and concluded that the best combination of steel fibers and polypropylene is a combination of 75% steel fibers and 25% polypropylene fibers [30]. Hamad [31] in their research, by making three designs of mixing concrete with fiber fibers and performing compressive, flexural, and tensile strength tests at the ages of 3, 7, and 28 days on concrete samples containing fibers, concluded that fibers in concrete increase the compressive, flexural, and tensile strength of concrete [31]. Noushini et al. [32] in their research concluded, by making 19 concrete mixing designs with steel fibers and glass fiber and performing compression testing on cubic and cylindrical specimens and flexural strength test on rectangular cubic specimens at the ages of 7, 14, and 28 days on concrete specimens containing fibers, that fibers in concrete increase the compressive and flexural strength of concrete [32]. Zhang et al. [33], in a laboratory study, investigated the combined effect of nano-silica and different fibers on toughness, fracture energy, and flexural strength of self-compacting concrete. For this purpose, they have 40 mixing designs including four series, which include 0, 2, 4, and 6% by weight of cement, nano-silica, which were examined as alternatives to cement. The results showed that the combined presence of fibers and the optimal percentage of nano-silica improves the toughness, fracture energy, and flexural strength of concrete [33]. Nuaklong et al. [34] investigated the effect of polypropylene fibers on mechanical properties and permeability of concrete. Their results indicate that the compressive strength of fibrous concrete prototypes is lower than the control samples, but with increasing the age of the samples, the results were reversed and the highest increase in compressive strength of 28 days was related to the amount of fibers used 0.8%. They observed the highest increase in tensile strength at 28 days of age in concrete samples containing 0.4% fiber [34].

The purpose of this paper is to address the issue of waste facial masks, which is a severe environmental issue worldwide. Moreover, this research aims at finding a way to reuse facial masks by utilizing them in construction materials. In addition, concrete can be made more cheaply by reusing used waste facial masks in fiber form. Therefore, utilizing them in construction material is an environmentally friendly solution. Moreover, their use may improve concrete's mechanical properties.

2. Materials and Methods

In this study, Portland Cement conforming to ASTM-C150 (Farmington Hills, MI, USA) was used. As fine aggregate, 2.42 fineness modulus sand was used.

2.1. Preparing of Fibereed and Shredded Masks

To ensure that the masks were not pathogenic, the collected masks were quarantined for 10 days and then their metal parts were removed. To be more sure, alcohol spray was used for disinfection. Finally, to produce concrete, the collected masks were shredded in two methods: fiber and squared-shredded. This study used three-ply waste masks because they are inexpensive and often used by people. Spin-bond polypropylene fabric is used both on the inner and outer surfaces of the mask, and melt-blown polypropylene fabric is used on the middle layer. In Figure 1, samples of weighed fibers and shredded mask for the mixing design are shown in this study. Table 1 shows the chemical composition of the masks used in this study.

After reviewing the results of previous research, to achieve better results, the mask was used in two forms [35–40]. As shown in Table 2, fibred masks were included in 1.0, 1.5, and 2.0% of concrete volume (CS1–CS3). Meanwhile, the squared masks were cut into 1–2 mm pieces using a cutting machine. Shredded masks were used as 0.75, 1, and 1.5% of the total concrete volume (CS4–CS6).

(**a**)

(**b**)

Figure 1. Samples of shredded (**a**) and fibers (**b**) mask (fibers prepared from Shandong Luming New Materials Co., Ltd., Weifang, China) for the mixing design.

Table 1. Chemical composition of the masks.

Element	Weight (%)
Mg	2.94
Al	9.99
Ca	25.85
Si	59.11
K	2.11

2.2. Preparation of Sample Concretes

In this study, the crushed stone as coarse material and sand as fine aggregate materials were used in the experiments performed. Coarse-grained and fine-grained materials were combined in equal proportions. In addition, the ratio of water to cement is 0.5. In this study, first by selecting the mixing plan of sand, cement, sand, and water, sample control concrete (CS0) was prepared and after 24 h when the samples were dried, they were placed in a normal water pool.

For mixing concrete in this research, the standard method of ACI-211 regulation was used. First, a mixer mixed sand, cement, and water for two minutes, and then fiber and shredded masks were gradually added to the mixer. Finally, the mixer worked for another 3 min to obtain a uniform mixture. To distribute the mask pieces evenly and prevent balling, the pieces were added to the mixture in a completely dry manner and CONPLAST SP432MS superplasticizer was used. It is a chloride-free superplasticizer based on naphthalene sulfonate polymers and is a brown solution that dissolves rapidly in water. CONPLAST SP432MS super lubricant complies with BSEN 934-2 and ASTM C494 as Type B, Type D, and Type G additives (depending on consumption) [23].

Table 2. Sample and mixing properties.

Mixture ID	Fiber (% Vol)	Cement (kg/m^3)	Water (kg/m^3)	Superplasticizer (kg/m^3)	Coarse Aggregate (kg/m^3)	Fine Aggregate (kg/m^3)	W/C
CS0	–	350	182	5.25	857	859	0.5
CS1	1 (Fibered)	350	182	5.25	857	859	0.5
CS2	1.5 (Fibered)	350	182	5.25	857	859	0.5
CS3	2 (Fibered)	350	182	5.25	857	859	0.5
CS4	0.75 (shredded)	350	182	5.25	857	859	0.5
CS5	1 (shredded)	350	182	5.25	857	859	0.5
CS6	1.5 (shredded)	350	182	5.25	857	859	0.5

Table 2 presents the values and components of the mixing data used in this study. As shown in Table 2, the ratio of water to cement in all mixing designs is 0.5. The amount of superplasticizer for all fiber concrete mixing designs is equal to 1.5% by weight of cement. In the process of making concrete samples with mask parts, the amount and type of cement, sand, sand and water has been fixed and only the amount and type of fibers change.

2.3. Compressive and Tensile Strength Tests

In the process of making concrete specimens for compression testing of standard cubic molds of 150 × 100 × 150 mm and for making concrete specimens for tensile strength testing of standard cylinders with dimensions of 150 (diameter) × 300 mm was used (Figure 2).

In the compressive strength test, the specimens are pressurized by a concrete crusher. The load is applied uniformly to the specimens by the upper and lower jaws of the device. It is essential that the load be applied to the specimens without sudden and continuous change. The concrete crusher must be equipped with devices that can record the rupture force after loading. In this device, the rupture force is displayed on a monitor screen. The vertical axis of the piston must coincide with the vertical axis of the device and be located along the vertical axis of the device when loading to move the piston, so that the result of the forces passes right through the center of the sample. The lower cylinder surface of the machine must be perpendicular to its axis and remain perpendicular during loading. The center of the spherical seat of the upper jaw should have a tolerance of ±1 mm at the point of collision of the vertical axis of the device with the lower surface of the upper jaw.

Split cylinder tensile strength tests (based on ASTMC496) were performed [41]. In this test, the specimen is placed between the plates of the concrete breaker jack so that its axis is horizontal and then the load is increased so that the rupture occurs in two halves on the plate containing the vertical diameter of the specimen. The load is applied continuously, uniformly, and without sudden changes at a constant speed of about 400 to 700 kPa until the test rupture (Figure 2).

2.4. Detection of Thermal Properties

Shimadzu's TGA-50 thermogravimetric analyzer was utilized to define thermal factors [42,43]. The samples were measured by aluminum pans containing 8–11 mg of each sample. In the tests, temperatures ranged from 30 °C to 600 °C at a 10 °C/min rate. The pan containing samples was placed in the TGA oven. Using Shimadzu's thermal analysis software, mass loss was measured and analyzed following an increase in temperature.

2.5. Durability Tests

The rapid chloride permeability test (RCPT) is a reliable indicator of permeability. More permeability implies more durability concerns [37,38]. At larger RCPT levels, corrosion process in concrete is more prevalent. As a consequence, in accordance with ASTM C 1202, the RCPT apparatus was used to determine the permeability of various mixes. In harsh environments, the durability of concrete deteriorates [44]. Freeze-thaw is a condition that affects people all around the world. Synthetic fibers improve freeze-thaw resistance [45]. As a consequence, the effect of waste mask fiber on the freeze-thaw resistance of concrete was studied.

(**a**)

(**b**)

Figure 2. Compressive (**a**) and tensile strength (**b**) tests.

3. Results and Discussion

In this section, the results of waste masks usage in concrete are investigated for their effects on concrete properties.

In order to validate the results of this study, the results of laboratory research of Małek et al. [28] were used. Table 3 shows a comparison of the compressive strength results of a cubic sample in the case without fiber additive, and 1% fiber additive. According to Table 3, the results of both studies are well matched (RMSE = 0.89).

Table 3. A comparison between results of compressive strength in present study and in Małek et al. [28].

Fiber (% Vol)	Compressive Strength (Mpa)							
	Present Study				Małek et al. [28]			
	7 Days	SD	28 Days	SD	7 Days	SD	28 Days	SD
–	17.2	1.12	27.3	0.65	18.3	0.76	27.9	0.15
1%	16.7	0.81	28	0.96	17.3	0.29	28.2	2.16

3.1. The Effect of Waste Masks on Compressive Strength

In order to evaluate the effect of waste masks on compressive strength, the mixes at seven and 28 days were investigated. The results of compressive strength of the mixes incorporated mask fiber and shredded mask can be seen in Figure 3a,b, respectively. As shown in this figure, compressive strength increased by addition of mask fiber in the seven-days and 28-days samples. Compressive strength of samples increased by values of 7.2% and 10%, for seven-days and 28-days samples, respectively. This increase is up to 2% for concrete mix with fiber additive. However, Park [46] and Pourbaba et al. [47] showed that compressive strength decrease by increasing the fiber in the concrete mix after 2%. The results of shredded mask addition to the mixes are a bit complicated. For example, the increase in shredded mask volume in the mixes has a minor effect on the compressive strength of the seven-days samples, while increase in shredded mask from 0.75 to 1% increase 14% compressive strength of the 28-days sample. However, after 1% volume of shredded masks, the compressive strength decreases by the value of 8%. This is because concrete cannot be homogeneous due to inadequate mixing and interlocking of fibers. A higher fiber content usually leads to a lower compressive strength. Lower fiber counts mean fibers do not entangle or conglobate and there are no issues with homogeneity. Table 4 shows the results of compressive strength variation in the different samples in comparison with CS0. According to Table 4, the effect on compressive strength by masks incorporated into concrete appears in 28-days concrete significantly.

Table 4. The results of compressive strength variation in the different samples in comparison with CS0.

Sample ID	Sample Age	Compressive Strength Increase (%)
CS1	7-days	−6.14
	28-days	0.36
CS2	7-days	−1.12
	28-days	5.73
CS3	7-days	7.82
	28-days	11.70
CS4	7-days	−3.19
	28-days	3.58
CS5	7-days	−2.79
	28-days	18.28
CS6	7-days	−3.46
	28-days	−3.94

Figure 4 shows the tensile strength of the mixes at seven days and 28 days. Figure 4a shows the results of tensile strength mask fibers addition to concrete and Figure 4b shows the results of tensile strength of shredded mask. According to Figure 4a, increase in mask fiber in concrete, tensile strength increases both in the seven-days and 28 days samples. Tensile strength of samples increased by values of 7% and 14%, for seven-days and 28-days samples, respectively. Compared to ordinary concrete, by adding mask fiber to concrete, it has a higher tensile strength and, therefore, better crack resistance. However, the tensile strength for mixes with shredded mask at seven days have no significant variation in tensile strength (Figure 4b), while an increase in mask element from 0.75 to 1% increase 1% compressive strength of the 28-days sample. However, after 1% volume of shredded mask the compressive strength decreases by the value of 15%. In fact, when the tensile strength test was conducted, mask elements acted as a block and allowed the sample to quickly separate. It seems that the performance of the shredded mask addition into concrete was not remarkable.

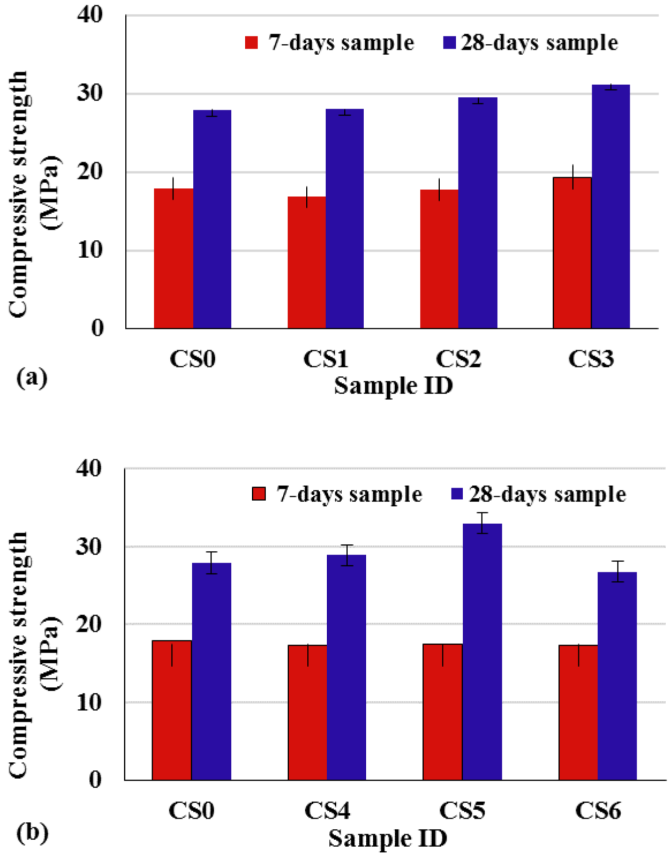


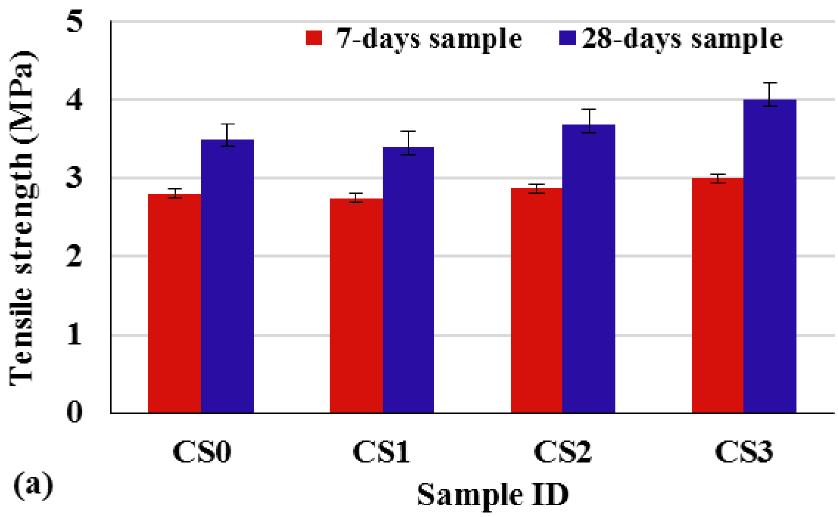
Figure 3. Compressive strength of (**a**) waste fiber mask and (**b**) shredded mask at seven days and 28 days.

3.2. The Effect of Waste Masks on Tensile Strength

Table 5 shows the results of tensile strength variation in the different samples in comparison with CS0. According to Table 5, waste mask use in mixes increase the tensile strength in comparison with the control sample (CS0); however, the use of 1.5% shredded mask into concrete decreases the tensile strength by the value of 14.57%.

Table 5. The results of tensile strength variation in the different samples in comparison with CS0.

Sample ID	Sample Age	Tensile Strength Increase (%)
CS1	7 days	−1.78
	28 days	−2.85
CS2	7 days	2.50
	28 days	5.14
CS3	7 days	7.14
	28 days	14.57
CS4	7 days	0.36
	28 days	0.00
CS5	7 days	−0.36
	28 days	1.14
CS6	7 days	−2.50
	28 days	−14.57



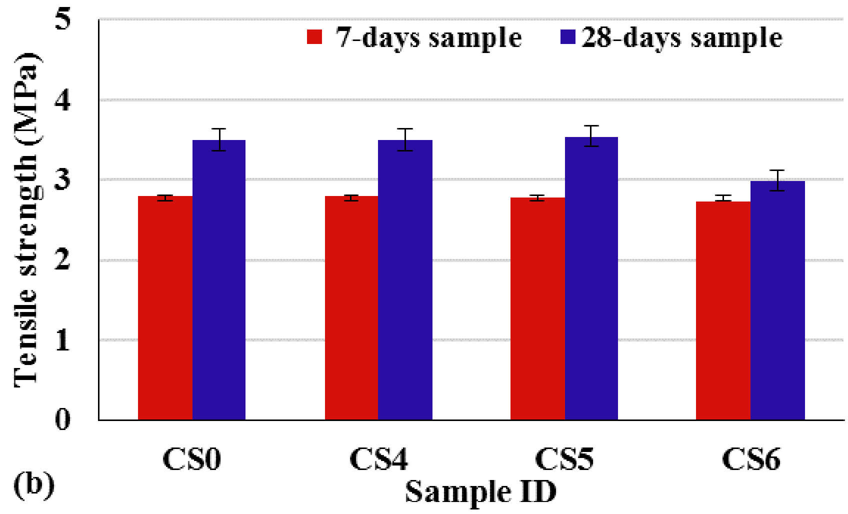


Figure 4. Tensile strength of (**a**) waste fiber mask and (**b**) shredded mask at 7-days and 28 days.

3.3. Thermogravimetric Analysis

As mentioned in Section 2.3, TGA is used to test for thermal degradation in concrete with fibers from the used mask. Figure 5 shows that polypropylene in concrete is not degrading significantly. The lack of transition could be explained by the fact that polypropylene is not widely used in concrete. Polypropylene begins to decompose at about 400 °C, which is lower than the average degradation temperature of 300 °C. Concrete loses mass as it dries out residual capillary pore water lower than 70 °C and as it hydrates calcium hydroxide over 450 °C. A loss of mass of 1.0% was observed in concrete with waste mask fibers after drying of residual capillary pore water. By allowing concrete to dry for longer, it retains more water during curing state and it is better for concrete. At high temperatures, concrete produces no gas, so it is safe, because polypropylene fibers do not degrade significantly at elevated temperatures. According to Figure 5, with increasing fiber percentage in 28-day concrete samples, the mass loss percentage in concrete becomes more intense. However, samples containing shredded mask pieces have a lower mass loss percentage than samples containing fibers. Given the nature of the decomposition of the materials mentioned above, this is justifiable.

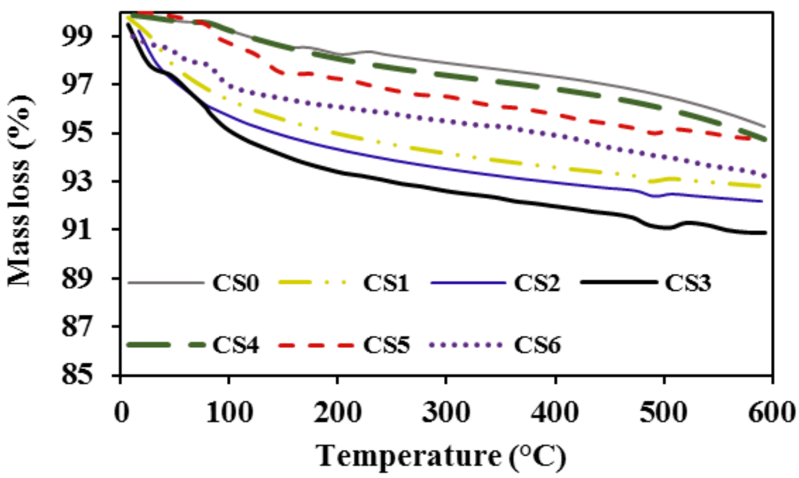


Figure 5. Thermogravimetric analysis of 28-day samples.

3.4. Microstructure of the Concrete

The microstructure of the concrete was studied using scanning electron microscopy (SEM). Polypropylene fibers were discovered to be heavily encrusted with hydration products and barely visible. The irregular rectangular growths in the image reflect C-S-H overlapping/wrapping on the mask fibers. Figure 6 demonstrates that C-S-H has primarily enveloped fiber cotton, as shown by its cotton-like appearance. On the other hand, hydration products begin to travel along longer fibers. Because masks are made up of spunbound polypropylene and melt-brown polypropylene layers, they may react differently as hydration product sites.

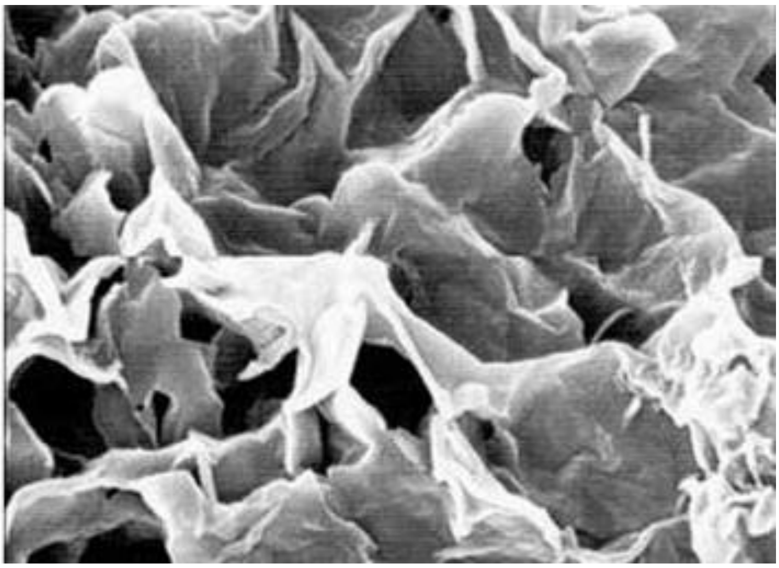


Figure 6. SEM images (at 300 nm).

3.5. RCPT Test Result

The samples' chloride permeability was determined. Reduced chloride permeability indicates better corrosion resistance (Figure 7). According to Figure 7a, the permeability was first reduced by incorporating up to 1.5% waste mask fiber into the concrete. However, after 1.5% mask fiber, the permeability increases. It can be deduced that 1.5% is the best value for reducing permeability by 23.2%. Lower percentages of polypropylene fiber reduce permeability and increase resistance to chloride penetration by filling the effect in pores.

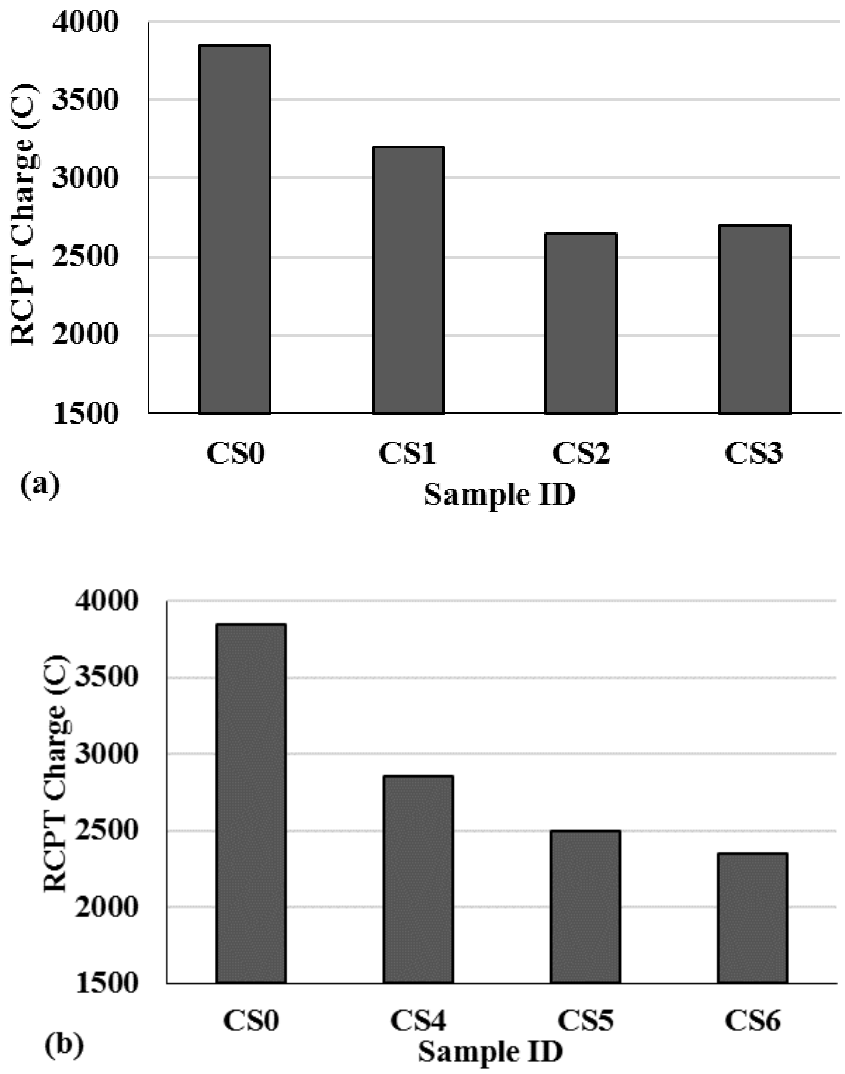


Figure 7. RCPT test results: (**a**) waste fiber mask and (**b**) shredded mask at 28 days.

Permeability is reduced almost by 41.3% when the shredded mask (1% of concrete volume) is used (Figure 7b). The masks are impermeable, and the square-cut pieces prevent water or ions from passing through, resulting in a significant reduction in the concrete sample's permeability.

4. Conclusions

The spread of COVID-19 has led to the widespread use and production of disposable facial masks worldwide. Waste from this production and mass consumption of facial masks in the next few years is an important environmental challenge for humans. Therefore, finding a solution to dispose of this massive waste is a very important issue. In this research, the use of disposable facial masks in construction materials and its effect on the strength of concrete used in structures has been evaluated. For this purpose, concrete samples were prepared in six classes, including three classes containing mask fiber in concrete and three concrete classes containing shredded mask at the age of seven days and 28 days. The results of the samples of each class were compared with the results of the control sample. The main results of this study are presented as following:

The results of compressive strength of the mixes incorporated mask fiber showed that compressive strength increased by addition of mask fiber in the seven-days and 28-days samples. Compressive strength of samples increased by values of 7.2% and 10% for seven-days and 28-days samples, respectively. This increase is up to 2% for concrete mix with fiber additive. However, the results of shredded mask addition to concrete showed that the increase in shredded mask volume in the mixes has s minor effect on the compressive strength of the seven-days samples, while increase in shredded masks from 0.75 to 1% increase compressive strength by 14% in the 28-days sample. However, after 1% volume of mask fiber, the compressive strength decreases by the value of 8%.

Tensile strength tests show that adding mask fiber to concrete increases both the seven-day and 28-day tensile strength of the samples. As a result, the tensile strength of samples increased by 7 and 14% for seven-day and 28-day samples, respectively. When compared to control sample concrete, adding mask fiber to concrete increases tensile strength and, thus, crack resistance. Tensile strength for shredded fiber mixes, on the other hand, shows no significant variation after seven days, while increasing the mask element from 0.75 to 1%, the compressive strength of the 28-day sample increased by 1%. However, after 1%volume of mask fiber, the tensile strength was reduced by 15%. According to thermal analysis with increasing fiber percentage in 28-day age concrete samples, the mass loss percentage in concrete becomes more intense. However, samples containing shredded mask pieces have a lower mass loss percentage than samples containing fibers.

Overall, based on the results mentioned above, the use of facial masks in concrete in their fiber state improves the strength performance. In contrast, the use of shredded mask pieces in concrete leads to better curing due to the residual capillary pore water loss in construction materials, which increases its efficiency.

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