Sustainable disposal of face masks in concrete: an investigation of mechanical properties and environmental impact

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Abstract. The COVID-19 pandemic has resulted in the excessive use of personal protective equipment used by people to safeguard themselves from contracting viruses. The use of plastic gloves and face masks has raised environmental concerns. The undue accumulation of this personal protective equipment has resulted in the degradation of land and water and contributed to the spread of the virus. Thus, this research paper is divided into two parts. The first phase entails completing thorough literature research to compile data on the mechanical, chemical, and physical properties of face masks. The second phase involves the potential reusing of face masks as an additive in concrete. This study’s findings can have a significant implication for the construction industry concerning environmental pollution management. This paper also highlights the effects of improper disposal of these face masks in terms of health and safety to the common public. Moreover, the study’s results can encourage further research on the potential application of face masks in other construction materials, leading to the development of more environmentally friendly building materials.

Keywords. sustainability, green concrete, disposal, recycle, and reuse.

1 Introduction
The addition of fiber, such as polypropylene fiber, to concrete helps to improve the uniformity of the mix, strength, and durability of the material. This is due to the mechanical properties of these fibers, which can transmit stress without breaking or slipping. However, there can be issues with the workability of the mixture. Increasing the water/cement ratio to improve the workability of the mixture may result in a decrease in strength. Therefore, new innovative solutions are being looked at to resolve the undue accumulation of such face masks.

By using face masks in concrete, it not only helps the environment by reducing the disposal of plastic waste, but it also has the potential to improve mechanical properties when an excessive buildup of them on the face is observed. This is because the fibers help to distribute voids evenly, leading to an increase in void volume during placement. The use of polypropylene fiber has a negative impact on the environment.

Improper use of disposable face masks in construction is on the rise due to the rapid spread of the COVID-19 pandemic. The demand for disposable face masks in healthcare, personal protection, and the construction industry has grown sharply. The production of face masks releases 59g of CO₂, which harmed the environment. According to [5], the demand for disposable face masks in the UK is estimated at 24.37 billion [6]. As the manufacture of these masks has increased, the waste that has accumulated in landfills has become a cause for concern. The marine life was strangled when such masks entered water bodies. Therefore, improper disposal of such face masks can be a major concern.

The polypropylene fiber in concrete has been a new concept. It can be used to make advances in sustainability in the construction industry. The research studies of the past few years have helped to understand the rising demand for disposable face masks in the market. To resolve the ongoing problems caused by the pandemic, the use of polypropylene fiber has a negative impact on the environment. Hence, there is a need for new innovative solutions that can resolve the issues and help to reduce the excessive use of disposable face masks in the construction industry.
2 Methodology
Table 1. Mix proportions for casting one cube

<table>
<thead>
<tr>
<th>Proportion (%)</th>
<th>Cement (kg)</th>
<th>Fine Aggregate (kg)</th>
<th>Coarse Aggregate (kg)</th>
<th>Mask (kg)</th>
<th>Water (L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.025</td>
<td>2.025</td>
<td>4.050</td>
<td>0</td>
<td>0.910</td>
</tr>
<tr>
<td>0.25</td>
<td>2.022</td>
<td>2.022</td>
<td>4.045</td>
<td>0.009</td>
<td>1.010</td>
</tr>
<tr>
<td>0.50</td>
<td>2.020</td>
<td>2.020</td>
<td>4.040</td>
<td>0.231</td>
<td>1.010</td>
</tr>
<tr>
<td>0.75</td>
<td>2.017</td>
<td>2.017</td>
<td>4.035</td>
<td>0.028</td>
<td>1.110</td>
</tr>
</tbody>
</table>

For the concrete mix design, cement of grade OPC43 was used, and the following tests were conducted to confirm the quality check of the cement bags:
- Field testing of cement,
- Fineness test of cement,
- Consistency test of cement, and Initial and Final setting time of cement.

Quality checks were also performed on the fine and coarse aggregates to ensure their proper size and quality. Fine aggregates consist of those aggregates of size smaller than 4.75mm IS Sieve and those aggregates that are retained on 4.75mm IS sieve are considered as coarse aggregates as per IS 456. To ensure that the fine and coarse aggregates used were of good quality:
- Specific gravity of aggregates,
- Fineneess modulus of aggregates,
- Aggregate impact test,
- and Los Angeles abrasion test.

The concrete mix design specified a ratio of 1:1:2 for M25 concrete, in accordance with IS 456 standards, intending to achieve a characteristic compressive strength of 25 N/mm² on the 28th day of testing using a cube.

Fig.1 represents the manufacturing process of concrete used in this experiment.
Masks were mixed thoroughly in the drum. Following this, water was gradually added to the mix in stages, until the desired consistency was achieved. This ensured that all the ingredients were uniformly blended, resulting in a homogeneous mixture suitable for use in the construction of M25-grade concrete.

To ensure that the concrete cube was extracted from the molds without any damage and to prevent it from adhering, the molds were first greased using a brush. Once the concrete slurry reached a consistent state, the drum mixer was stopped, and the concrete was extracted from the drum using a trowel and placed into the molds. During this process, compaction was carried out simultaneously, by using tamping rods to create a minimum number of void spaces in the resulting cube.

The curing process is the most critical step in the development of concrete strength since it allows the concrete to fully mature by the 28th day. To evaluate and compare the compressive strength and water absorption capacity of the concrete cubes at different stages, the cubes were kept in a curing tank for 7, 21, and 28 days.

After being demolded, the cubes were placed in a curing tank filled with potable water. This enabled concrete to undergo necessary hydration processes which resulted in a stronger and more durable concrete cube. Pond curing was used to carry out the curing process, which involved submerging the concrete cubes in a tank free from any vibration or disturbance in moist air. The curing tank maintained a temperature of 27±2°C, while the water temperature ranged between 15-18°C.

After curing for 7, 21, and 28 days, the cubes were sun-dried for approximately 1.5 hours to remove excess water. The manufacturing process took place in November in the U.A.E. with temperatures ranging between 31-36°C and low humidity levels, which prevented the concrete from deteriorating due to shrinkage and cracking. This ensured that the concrete achieved its desired strength and durability.

2.1 Tests conducted on concrete

Two tests were performed to determine the change in the strength of concrete and the percentage of water absorbed by the matrix. The tests were performed in accordance with the Indian standard which included compressive strength \([23]\) and water absorption test \([24]\). The compressive strength test was performed on a Universal Testing Machine, following the guidelines outlined in IS 516\([23]\). To ensure consistency in all the batches of concrete cubes, the duration for which concrete cubes were exposed to the sun was controlled. The cubes were placed on the Universal Testing Machine such that the top surface was smooth to ensure a gradual and uniform load would be acting on it. Three samples were tested for each case, and the average of three specimens was taken for further analysis. The concrete cubes were weighed twice, once upon removal from the curing tank and secondly after drying, to determine the water absorption of concrete.
Slump test was conducted to evaluate the consistency of each batch of concrete mix. This involved pouring the concrete into the slump cone and tamping adequately into 4 layers, which were tamped 25 times per layer to ensure that the mix filled every part of the slump cone. The screws were then loosened, the cone was immediately removed, and the value was recorded. The slump test readings were highly influenced by the water-cement ratio which was limited to less than 0.6 to achieve better workability. To achieve the required slump value, the mix was adjusted using varying water-cement ratios. The slump test for 0.75% proportion is depicted in Fig. 2, a slump value of 5 cm was obtained.

Fig. 2. Slump test

3 Data collection and analysis

The tests conducted on concrete were the slump test, water absorption test, and compressive strength test. The data was collected as shown below and further analyzed.

3.1 Slump test

Each batch of the concrete mix was subjected to the slump test, to achieve a medium workable concrete. The slump test findings were strongly influenced by the water-cement ratio. Therefore, this concrete mix can be used for real-life applications such as heavily reinforced sections in slabs, beams, walls, and columns. The slump of various proportions with water cement ratio ranging from 0.45 to 0.55 is fixed at 5 cm. Therefore, this concrete mix can be used for heavily reinforced sections in slabs, beams, walls, and columns.

Upon performing the slump test, the following values were recorded as shown in Table 2. The water-cement ratio varies for different mixes as the desired slump was between 5-8 cm. In this experiment, the water-cement ratio was increased by 0.05 in case the desired slump value was not obtained.
### 3.2 Water absorption test

Upon conducting the water absorption test in the laboratory, the following data were collected as shown in Table 3. These values represent an average of 3 specimens.

<table>
<thead>
<tr>
<th>Day tested on</th>
<th>Control volume (in %)</th>
<th>0.25% (in %)</th>
<th>0.50% (in %)</th>
<th>0.75% (in %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7th day</td>
<td>0.419</td>
<td>0.636</td>
<td>0.428</td>
<td>0.647</td>
</tr>
<tr>
<td>21st day</td>
<td>0.628</td>
<td>0.645</td>
<td>0.632</td>
<td>0.655</td>
</tr>
<tr>
<td>28th day</td>
<td>0.421</td>
<td>0.642</td>
<td>0.633</td>
<td>0.868</td>
</tr>
</tbody>
</table>

From Table 3, it can be observed that as the quantity of face masks present in concrete increases, the resultant water absorption increases as well.

### 3.3 Compressive strength

The compressive strength test was carried out on the Universal Testing Machine and the following values were calculated (Table 4).

<table>
<thead>
<tr>
<th>Average of 3 cubes tested on</th>
<th>Control volume</th>
<th>0.25%</th>
<th>0.50%</th>
<th>0.75%</th>
</tr>
</thead>
<tbody>
<tr>
<td>7th day</td>
<td>26.930</td>
<td>28.995</td>
<td>25.495</td>
<td>20.820</td>
</tr>
<tr>
<td>21st day</td>
<td>30.633</td>
<td>29.612</td>
<td>29.155</td>
<td>25.569</td>
</tr>
<tr>
<td>28th day</td>
<td>32.696</td>
<td>29.983</td>
<td>30.646</td>
<td>24.183</td>
</tr>
</tbody>
</table>

Table 2: Values for slump test (cm)

<table>
<thead>
<tr>
<th>S.no</th>
<th>Proportions</th>
<th>W/C ratio</th>
<th>Slump (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Standard (0%)</td>
<td>0.45</td>
<td>5</td>
</tr>
<tr>
<td>2.</td>
<td>0.25%</td>
<td>0.5</td>
<td>0</td>
</tr>
<tr>
<td>3.</td>
<td>0.50%</td>
<td>0.5</td>
<td>0</td>
</tr>
<tr>
<td>4.</td>
<td>0.75%</td>
<td>0.55</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 3: Values for water absorption (%)

Table 4: Values for compressive strength in N/mm²
Fig. 3 and Fig. 4 depict the formation of cracks taking place when the cubes were subjected to compressive load. Fig. 3 shows the formation of cracks in control volume cubes tested on the 21st day and Fig. 4 shows the formation of cracks for 0.25% proportion of face masks tested on the 28th day in the concrete cubes. The comparison of these two cubes revealed that the cubes with face masks had higher adhesion and the cube fragments were held better together than the control volume cubes, which displayed complete spalling of concrete. Therefore, it was analyzed upon performing the compressive strength on the specimens that the masks were holding the fragments of concrete and helped the concrete fragments to adhere even upon failure. Therefore, upon adding face masks to concrete, the resultant concrete mix showed better resistance towards cracking and improved performance of the resultant concrete. 

Fig. 3. Formation of cracks for 0% tested on the 21st day

Fig. 4. Formation of cracks for 0.25% tested on the 28th day

Fig. 5. Graph representing the variation in compressive strength for different proportions on the 7th and 28th day
The following graph was formed from the compressive strength values collected in the laboratory (Fig. 5).

Fig. 5 represents the compressive strength variation for the various proportions cast for the 7th and the 28th day. The gain of strength of 0.25% proportions is the maximum on the 7th day compared to the other proportions, whereas on the 28th day, the maximum compressive strength is seen with 0.50% proportion of face masks. The least compressive strength is seen in 0.75% proportion on the 28th day, as the quantity of masks increased in the concrete the masks began to absorb the water present in the mix. This, therefore, affected the cement present in the mix as it did not have enough water for the hydration process. This study does not highlight the cause of variation of strength as this experiment deals with the disposal of face masks.

4 Conclusion

The COVID-19 epidemic represents one of the first worldwide pandemics of an extremely contagious disease. Since the demand for personal protective equipment has drastically increased over the past few years ever since the pandemic struck, advancements in research have been carried out to understand the properties of the materials to understand how they affect the environment. To date, WHO acknowledges that “wearing a medical mask is one of the prevention measures that can limit the spread of certain respiratory viral diseases, including COVID-19.” The government, and health care authorities are looking forward to disposable personal protective equipment which in turn can be recycled or reused and help limit their detrimental effects on the environment.

The manufacture of personal protective equipment has increased in line with the sharp rise in demand. This is justifiable given that personal protective equipment, such as disposable face masks, can only be used once before being discarded. Therefore, this paper highlights the importance of proper disposal of face masks as they affect the environment and thus a comprehensive literature review that helps in understanding the various properties of face masks.

Upon conducting a comprehensive literature study, it was understood that face masks are made from polypropylene fibers. These fibers when added to concrete may improve physical properties of the matrix such as increased crack resistance, tensile strength, and improved wear resistance. On performing the compressive strength test for the various proportions, it was concluded that the cubes consisting of 0.50% of face masks have considerably higher compressive strength when compared to 0.25% and 0.75% proportions of face masks. The lowest compressive strength was noted in cubes consisting of 0.75% of face masks, this may be due to the excessive quantities of face masks absorbing the water present in the mix and as a result the cement did not have sufficient water to aid the process of hydration.

The quantities of the dry constituents of concrete can be reduced when face masks are used as an additive in concrete. This therefore results in the reduction of quantities of cement by 0.19% and fine and coarse aggregates by 0.18%.

On addition of face masks in the concrete mix, it not only gives a fiber-reinforced concrete that has improved crack resistance and wear resistance but is also excellent in confining the matrices uniformity by adhering the fragments of concrete under the application of loads.

A total of 578.18 g of face masks were used in this experiment. Therefore, this experiment provides an alternative disposal solution for the accumulated face masks on the lands and water. The construction industry can adopt a more sustainable and environmentally friendly alternative.
5 Challenges

During the casting of the concrete cubes, the process of demolding the mixture, pouring the mixture into the cubes became challenging. Moreover, when it came to drying of the mixture, it was observed that as a result of the masks absorbing water during the process, this caused uneven curing of the concrete cubes. As a result of the masks absorbing water in concrete, it was found that the face masks started to absorb the water in the concrete mix, resulting in uneven curing of the concrete cubes.

This process of drying was found to affect the face masks by starting to absorb the water in the concrete mix, resulting in uneven curing of the concrete cubes. This process is challenging as it affects the casting of the concrete cubes, pouring the mixture into the cubes and drying the mixture. As a result of the masks absorbing water, it was found that this process affected the casting of the concrete cubes, pouring the mixture into the cubes and drying the mixture.

Moreover, when it came to rapid evaluation of the concrete cubes, it was observed that there was a challenge in evaluating the concrete cubes, as it was a complex process that required a significant amount of time and effort. Additionally, when it came to handling the concrete cubes, it was found that there was a challenge in handling the concrete cubes, as it was a complex process that required a significant amount of time and effort.

6 References


