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Recycling Covid-19 Personal Face Masks Used in Concrete

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ABSTRACT

Recently, Covid-19 and other pandemics have led to a surge in the production and utilization of personal face masks, resulting in high increases in waste generation. Improper disposal of such waste endangers living organisms and the environment as most of these masks contain derivatives of plastics. Moreover, conventional disposal methods, such as incineration and landfills are not sustainable for dealing with such plastic-sourced wastes. This research proposes a creative solution to address such issues by incorporating face masks into the concrete mix. In this research, face masks were cut into rectangular pieces of approximately 2cm by 4 cm and added to the concrete mix at different percentages: 2%, 2.5%, 5%, and 10% by volume. Samples of cubes and cylinders from each mix were casted and examined the effect of masks on the strength of concrete. The compression test results presented valuable insights into the impact of adding masks to concrete and suggested that adding 2% - 2.5% of face mask by volume to the concrete mix can be enhanced or at least did not negatively impact the concrete strength. Such results are beneficial in reducing the amount of generated waste masks to be used in concrete without any negative impact on concrete properties.

1. Introduction

Since the outbreak of covid19 pandemic, the world has been suffering from health, social, economic, and environmental issues. New laws and regulations were established in 2020 to battle the fast and highly-growing pandemic. One of the primary practices issued was the mandate to wear a face mask and other personal protective equipment in public. Since this law's initiation, billions of single-use face masks have been used and thrown away. During the peak of the COVID-19 pandemic in 2020, initial studies estimate that the world used an astounding 129 billion face masks globally every month - equivalent to 3 million masks every minute, most of which are disposable face masks made from plastic microfibers [1]. Due to improper disposal of masks, it is urgent to recognize this potential environmental threat and prevent it from becoming the next plastic problem [2]. Single-use disposable face masks that end up in the environment could be a new source of micro-plastics (plastic pieces with diameters ≤ 5 mm) because they can fragment or degrade into smaller pieces when exposed to environmental factors such as sunlight, rain, and wind[3]. The mismanagement of such materials challenges the environment with a new form of plastic pollution, a potential threat to the health of ecosystems and humans.

Disposable face masks are manufactured using non-woven polypropylene fabric. Two different fabrics (spun-bond polypropylene and melt-blown polypropylene) are used as raw materials for surgical and non-surgical face masks. Similarly, polyethylene, polyurethane, poly-acrylonitrile, polyester, and cotton fibers are also utilized as raw materials [4]. These raw materials require more than hundreds of years to decompose [5]. While polypropylene is easily among the world's most commonly used polymers in plastic packaging materials, only around 9% is getting recycled [6].

Due to ignorance and poor management, worn face masks are frequently seen on streets and beaches in underdeveloped nations. These face masks gradually degrade into minute particles that pollute freshwater, waterways, marine life, and the environment. Additionally, some animals cannot distinguish between food and rubbish, so they may accidentally eat the masks [7]. Thus, the pandemic is not only influencing the economy but also causing serious environmental problems.

Due to economic and lifestyle development, the UAE is among the countries with the highest per-capita face mask waste generation. In the UAE, most face mask waste is disposed of in municipal landfills or dumpsites, and little face mask waste is incinerated [8]. However, disposing of used face masks in landfills or incineration is not sustainable. While people protected themselves against the pandemic, it is crucial to do so in a manner that does not harm terrestrial and aquatic environments. Therefore, there is a need to find a safe technique and practice for managing this waste. This topic has gained significant global research attention. As the demand for single-use face masks continues to rise due to the Covid-19 pandemic and other similar health issues innovative ways to manage and recycle them must be developed and implemented to reduce their environmental impact.

To date, various waste plastics have been examined and considered for use in concrete construction to alleviate the burden of landfill disposal. For instance, research conducted to determine the mechanical properties of a concrete mix with Polyethylene terephthalate (PET) showed that using 1% of PET increased the compressive strength by 58% [9].

Waste mask added to concrete in the form of fiber at 1% by volume of concrete is found to be the optimum percentage to enhance concrete's mechanical and durability properties [10].

This research proposes a sustainable solution for addressing face mask waste by recycling it in concrete structures. Introducing this approach to the construction industry offers a creative solution for promoting green concrete. The primary objective of this study is to examine the viability of reusing single-use face masks to reduce the amount of pandemic-generated waste disposed of in landfills or littered on the streets. This research typically uses 3-ply (surgical) face masks. The masks will be cut into rectangular pieces measuring approximately 2cm by 4cm and added to the concrete mix at volumes of 2%, 2.5%, 5%, and 10%. The workability of the fresh concrete will be closely examined, and samples of cubes and cylinders will be molded to test the compressive strength after 7, 14, and 28 days of curing the concrete.

2. Methodology

The experiment is trial-and-error, with the quantities of each concrete constituent remaining constant. Adding the mask is anticipated to absorb more water, which will dry the concrete. To accommodate the water absorption by the masks, a little amount of water will be gradually added to minimize the effect of the mask on the workability and to maintain the w/c ratio since this research is mainly focused on examining the mask's impact on concrete strength. The research will be verified through the following procedures:

1. Acquire masks and cut them into smaller rectangular pieces (approximately size of 2 cm x 4 cm).
2. Prepare the quantities of concrete constituents, sand, cement, aggregates, and water according to the weight calculated.
3. Initially, place all the dry materials (sand, aggregate, and cement) in the mixer and let it mix for 2 minutes, then add water slowly and mix for 2 minutes. After that, add the masks slowly into the mixer in small amounts to avoid clumping and flying off the mixer, and add the rest of the water slowly.
4. Conduct workability of fresh concrete tests, a slump test, and a compaction factor test as soon as the mixing is even and finished.
5. Cast 9 cubes and 9 cylinders for testing the mechanical properties of the hardened concrete experiment after 7, 14, and 28 days; in each experiment, three samples of cubes and cylinders will be taken.
6. Remove the moulds after a curing period of 24 hours.
7. Weigh and mark the samples and place them into a water tank for curing.
8. Conduct compression strength test for both cube and cylinder after 7, 14, and 28 days. Each time use three samples of each cube and cylinder.
9. Compute the calculation of compressive stress from the obtained test values.
10. Repeat the process for all samples.
11. Evaluate and compare all results with the standard concrete test results and draw a conclusion.

3. Experiment

As stated, masks were introduced by volume at 0% (reference), 2%, 2.5%, 5%, and 10% to the concrete mix. A total of five mix designs were sampled. The fresh concrete for each composition was casted into cubes and cylinders in order to test the cured concrete's mechanical strength. Nine samples of cubes and cylinders were obtained from each mix for testing the strength in 7 days, 14 days, and 28 days respectively. Three groups of samples were tested, so inconsistencies or outliers in the data could be identified and accounted for, increasing the overall validity of the experiment and the statistical power of the findings.

3.1. Mix Design

The water-cement ratio (W/C) substantially impacts the workability, strength, and various other properties of concrete. Typically, the free water-cement ratio in the range from 0.3 to 0.8, with a common range of 0.5 to 0.7 W/C used in most applications [11]. Determining the appropriate ratio can be challenging, but an average value of 0.6 W/C is commonly assumed as the maximum during the mix design process. However, the actual water-cement ratio is usually established through the mix design process itself.

The design of the control concrete considers a characteristic strength of 30 MPa. However, test results may vary in practice due to factors such as batching inaccuracy, the size distribution of aggregates and sand, absorption properties, temperature, and other factors. To account for the possibility of obtaining compressive strength lower than the defined characteristic strength, BS 8500 recommends adding a margin to the characteristic strength [12]. The margin depends on the standard deviation and the assumed percentage of defectives. In this particular research , a defectives percentage of 5% is assumed, meaning that only 5% of the test results are expected to fall below the characteristic strength. In accordance with BS 8500, the statistical value (k) for 5% defectives is 1.64. This value is multiplied by the standard deviation and added to the characteristic strength to calculate the Mean Strength.

However, this assumption will not impact the research's objectives since this research aims to investigate the impact of masks on concrete by comparing the strength of concrete with masks to that of the control concrete. The fine aggregates used in the experiment consist of 70% passing through a 600 µm sieve, which aligns with the available sand at the laboratory. The coarse aggregates used are of sizes 5 mm, 10 mm, and 20 mm, distributed in a ratio of 1:1.5:3, respectively. When designing the concrete mix, all aggregate conditions, properties, absorption by face masks, and other relevant factors are considered. Although the concrete mix will contain a lower proportion of masks, the water-cement ratio (W/C) will be affected due to the mask's water absorption.

3.2. Testing

The comprehensive workability of fresh concrete was tested using two different methods: the slump test, as per the British standard [13], and the compaction factor test, also based on the British standard [14]. The slump test measures the difference in height between the top of the cone and the top of the slumped concrete. At the same time, the compaction factor is the ratio of the weights of partially compacted concrete to the fully compacted concrete of the same volume.

Compressive tests were conducted on cube and cylinder specimens at specified intervals of 3, 7, and 28 days, following the guidelines of BS EN 12390-3:2019 [15]. Compressive strength is the ability of concrete to withstand load (compression) that tends to decrease the size of the concrete. It is the most familiar and well-accepted measurement of concrete strength to estimate the performance of a concrete mixture. The cube specimens were tested utilizing the "Servo-plus evolution, Automatic Concrete Compression Machine" with a capacity of 3000kN, applying a constant loading rate of 0.4 MPa/s. In contrast, the cylinder specimens were tested using the "Universal Hydraulic Testing Machine," with a capacity of 600 kN, at a rate of 0.06 MPa/s until failure occurred. The compressive strength of the concrete from the maximum load obtained from the testing machines for all specimens using the formula fck = F/A, where "F" denotes the fracture load, and "A" denotes the specimen's cross-sectional area.

4. RESULTS AND DISCUSSION

4.1. Workability

The fresh concrete properties are summarized in Table 1. The slump measurement for the standard concrete was approximately 40 mm, with a compaction factor value of 0.93. These values indicate that the standard concrete has relatively low workability. For the other mixes containing different compositions of masks, the slump ranged from 0 to 20 mm, while the compaction factors ranged from 0.82 to 0.90. The workability of concrete incorporating shredded masks was observed to be generally lower than the standard concrete. This can be attributed to the masks' ability to absorb water and their lightweight nature.

Workability	Slump (m)	Compaction factor
Standard Concrete	40	0.93
2% masked concrete	25	0.92
2.5% masked concrete	5	0.90
5% masked concrete	0	0.87
10% masked concrete	0	0.82

Table 1. Fresh Concrete Properties

The workability of concrete is influenced by factors such as water content and the size distribution of aggregates. In this case, the variation in workability is primarily attributed to the water absorption by the masks.

4.2. Compressive Strength

The compressive strength of cube and cylinder specimens is shown in Figure 1 and Figure 2, respectively. Both graphs represent test results on 7, 14, and 28 days. Concrete's age or curing time plays a significant role in determining its strength and durability. It is important to understand the relationship between strength and time to assess the impact of loading as the concrete ages. Environmental conditions also have a considerable influence. However, generally, the rate of hydration is faster in the early stages and slows down over time. Typically, concrete achieves 65% of its strength within seven days and reaches 99% strength after 28 days [16]. Figure 3 clearly demonstrates a comparison between the masked concrete and conventional concrete at 28 days (standard length of curing for measuring the final strength of concrete).

4.2.1. Cube Compressive Strength Development

The compressive strength of the concrete mixes increases with age, demonstrating the successful execution of the experiment. The concrete mix with 2% concrete gained over 70% of its total compressive strength after seven days of curing, and it reached 38.2 MPa at 28 days, exceeding the strength of the control mix. The concrete mix with a 2.5% mask had a strength of 26.8 MPa at seven days, which increased to 29.8 MPa after 14 days, representing an 11% rise. At 28 days, it reached 34.3 MPa, just 2.3 MPa lower than the control concrete strength. Following was the experiment to explore the impact of adding 5% of the mask by volume to the concrete mix. As expected, the overall strength value was lower compared to the mixes with 2% and 2.5% masks. The average strength of cube specimens was just over 16 MPa at seven days, significantly lower than the concrete mix with a 2.5% mask. It increased to approximately 21.4 MPa at 14 days and reached 23.9 MPa when tested at 28 days.

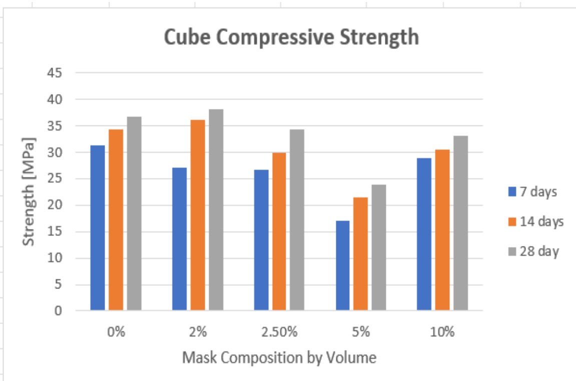

Figure 1. Compressive Strength Development of Cube Specimens

The final experiment involved a concrete mix with a 10% mask by volume. The strength of cube samples averaged 22.6 MPa at seven days, which increased to 26.5 MPa after 14 days. Surprisingly, at 28 days, the strength of the cube specimens was found to be 33.1 MPa, significantly higher than the strength of the concrete mix with a 5% mask. It is not justified from an engineering standpoint to obtain a higher strength value for the concrete containing a 10% mask than the concrete with a 5% mask. However, it is essential to note that the results obtained from the experiment with a 10% mask may not be an accurate representation. In some cases, the over-compaction of concrete can initially increase strength until segregation occurs.

4.2.2. Cylinder Compressive Strength Development

The compressive strength of concrete mixes for cylinder specimens increased over time, similar to the cube's strength, demonstrating a successful experiment. After seven days, the average strength of cylinder samples with 2% concrete was 15.9 MPa. This value increased to 23.6 MPa after 28 days of curing, with 21.6 MPa at 14 days. The compressive strength of the cylinder samples with 2% concrete was higher than the standard mix without mask composition, mirroring the cube's result. The mix with 2.5% mask had a strength of 16 MPa, which rose to 19.6 MPa after 14 days (approximately a 22 percent increase from the 7-day testing) and reached 22.7 MPa at 28 days.

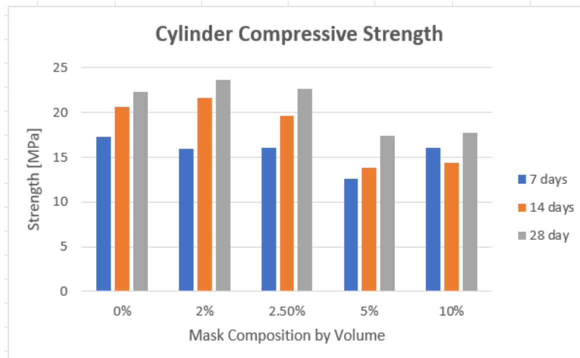

Figure 2. Compressive Strength Development of Cylinder Specimens

With the addition of 5% mask by volume to the concrete mix, the average strength of cylinder specimens was 12.6 MPa at seven days, around 13.85 MPa at 14 days, and reached 17.4 MPa after 28 days. The strength of the concrete mix with a 5% mask was significantly lower than previous mixes in both cylinder and cube samples, which suggests that adding a 5% mask exceeds the optimal quantity, negatively impacting concrete strength. In the final experiment, the mix with 10% mask resulted in cylinder samples with an average strength of 16 MPa at seven days and reached 21.2 MPa after 28 days. Surprisingly, similar to the cube's strength, the cylinder specimens had higher strength than the mix with a 5% mask at 28 days.

4.2.3. Strength Comparison at 28 Days

The compressive strength of the conventional concrete met the initial set design characteristic strength. The assumed characteristic strength for a fully hardened cube was 30 MPa, and the mean strength calculated in the mix design was 38.2 MPa.

The average compressive strength of the cube specimens was found to be 36.76 MPa, and impressively, all individual results were above 30 MPa. This outcome is noteworthy as it indicates that the design mix was appropriately formulated, and the measurements and procedures were carefully executed. Although not directly related to the research 's main goals, it is a positive indicator of the research 's early progress. Regarding the cylinder, the compressive strength was determined to be 22.26 MPa.

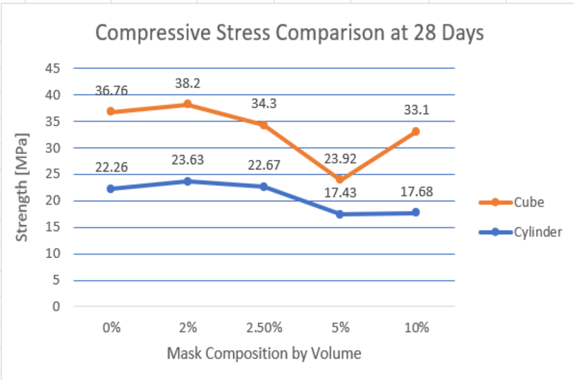

Figure 3. 28 Day Compressive strength of the Concrete Mixes.

The experiment results reveal intriguing insights about the impact of adding masks to concrete. Adding 2% masks to the concrete mix from the cube specimens resulted in an approximately 4% increase in strength at 28 days, as determined by the average of three samples taken for each test. These results are promising and suggest that it is possible to incorporate used masks into concrete with minimal impact on the overall strength. However, the strength of the concrete decreased by nearly 6% for the cube when 2.5% shredded masks were added. The result can still be considered within the normal range, as some samples in the standard concrete exhibited similar strength levels.

Nonetheless, the overall results of both the 2% and 2.5% mask concrete experiments were optimistic, indicating that the used masks could be used effectively in concrete. The addition of masks beyond 2.5% showed an extensive decrease in the strength of concrete. The compressive strength of cube specimens with 5%, 23.92 MPa, showed a 35% decrease from the standard. While adding more masks was expected to reduce strength, the sudden decline was concerning. The addition of 10% has also decreased the strength, as anticipated.

For the cylinder samples, the compressive strength of a cylinder was found to be 23.63 MPa at 28 days of curing, which is higher than the standard concrete, roughly by 1 MPa – representing a 6% increase when 2% mask by volume was added to the concrete. For the concrete mix with a 2.5 % mask, the average compressive strength of the cylinder was 22.67 MPa, still greater than the cylinder compressive strength of standard concrete by approximately two percent; this shows that 2.5 % of the mask has minimal impact on the concrete strength properties. However, when the mask content was increased to 5%, the compressive strength of the concrete dropped to approximately 17.43 MPa, reflecting a reduction of around 20% compared to the standard concrete mix. The final experiment involving the addition of 10% shredded masks resulted in a similar compressive strength to that obtained with a 5% mask content.

5. CONCLUSION

Several studies have been conducted on the possibility of reusing various types of waste in concrete structures to harness their positive impact on the engineering properties of concrete, aiming to provide a sustainable solution to the growing waste issue by reducing the amount of waste sent to landfills and minimizing the overall negative impacts on the environment. The utilization of face masks, which has significantly increased due to the COVID-19 pandemic, has further contributed to waste generation and landfill demands. In some areas where proper waste management practices are lacking, discarded face masks can be found on streets in cities and beaches and which eventually break into tiny particles, micro-plastics, that contaminate waterways, freshwater, marine life, and coastal areas, posing potential environmental hazards.

During the peak of the Covid-19 pandemic in 2021, the UAE stood out among countries with the highest per capita consumption of masks. This surge in mask usage led to a significant increase in waste generation and subsequently raised the demand for landfill disposal. Unfortunately, no sustainable measures have been implemented to address the issue of face mask waste. This research 's primary purpose was to explore the possibility of reusing face mask waste in concrete structures and assess the safe quantity of masks that can be incorporated into the concrete without compromising its mechanical properties or potentially enhancing them. The experiment involved developing mixes with varying mask content and casting cube and cylinder samples for each mix to investigate their strength properties. These properties were then compared to conventional concrete (with zero mask content) with the same design mix to determine the optimal mix design yielding the best characteristic strength. The following conclusions have been drawn from the findings of this investigation:

- When cut into small pieces, the face masks possess a lightweight nature. When these small pieces of masks are piled up, they tend to suspend over each other and create voids. This situation presents difficulties in accurately determining the actual volume of the masks. Finding a suitable approach for calculating the number of masks was carefully considered in order to overcome this difficulty. It was determined that using a graduated mould and thoroughly compacting the mask material minimizes voids and enables accurate measurement of the mask volume.
- The reference concrete mix was successfully prepared, meeting the required characteristics for the design, which allowed for the success of the investigation of concrete mixes with different mask compositions. Each result was thoroughly examined throughout the experiment, from assessing the fresh concrete properties to testing the compressive strength of hardened concrete. The results were then compared to the properties of the reference concrete mix.
- As the mask content increased in the concrete mix, it caused the concrete to become stiffer due to the absorption of water by the masks. This affected the workability of the concrete, resulting in a significant decrease in slump. Additionally, the compaction factor decreased as more masks were added to the mix. Therefore, if maintaining the desired slump is necessary, the mix would require additional water.

Interestingly, the concrete mix with 2% mask content yielded better results than the control concrete, suggesting that incorporating shredded masks in concrete could enhance its strength. Based on the overall experiment results, adding 2% to 2.5% of mask quantity by volume to the concrete mix can improve its strength or, at the very least, not harm its performance. However, adding mask content beyond 2.5% by volume significantly decreased the concrete's properties.

In general, utilizing used masks in concrete structures reduces waste disposal and the demand for landfill space. Most importantly, it provides a sustainable solution that positively impacts the environment and promotes green concrete technology and circular economy principles. On a larger scale, implementing this approach will play a significant role in environmental protection, contribute to resource conservation, and promote the adoption of more sustainable practices in the construction industry.

Overall, the experimental results are quite promising and indicate that it is feasible to incorporate used face masks into concrete with minimal impact on its overall engineering properties. As a further recommendation, the authors suggest the establishment of a more comprehensive framework that evaluates not only the workability and strength of the concrete but also the modes of failure, stress development, and rate of absorption, which would solidify the acceptance of the proposal on a commercial scale in the UAE. This research can serve as a guide and an initiative for those interested in further exploring this promising area of research and application, keeping in mind that the world could face another pandemic.

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