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Advances on concrete strength properties after adding polypropylene fibers from health personal protective equipment (PPE) of COVID-19: Implication on waste management and sustainable environment

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ABSTRACT

Using Health personal protective equipment (PPE) such as face masks, safety foot shoes and protective suits has expanded dramatically due to COVID-19 pandemic leading to a widespread distribution of the PPE, particularly the face masks, in the environments including streets, dump sites, seashores and other risky locations. The environmental degradation of polypropylene, the essential plastic component in single-use face masks (SUM), takes between 20 and 30 years and thus it is essential to develop experimental approaches to recycle the polypropylene or to reuse it in different ways. This paper explores the integration of SUM into concrete structures to improve its mechanical properties. We first to cut the inner nose wire and ear loops, then distribute the PPE material among five different mixed styles. The PPE were applied by volume at 0%, 1%, 1.5%, 2.0%, and 2.5%, with tests focusing on UCS, STS, FS, and PV to determine the concrete’s overall consistency and assess the improvement in its mechanical properties. The results showed that adding PPE improves the strength properties and general performance of the concrete specimens. The pattern of rising intensity started to fade after 2%. The findings demonstrated that adding PPE fibers enhanced the UCS by 9.4% at the optimum 2% PPE. The PPE fibers, on the other side, are crucial in calculating the STS and FS of the reinforcement concrete.

1. Introduction

The massive global production of plastics with more than 350 million tons in 2019 (Plastics Europe, 2020) and the relatively high disposal rates of these products limit the capabilities of solid waste management systems to contain these products and thus necessitate the development of novel methods to either physically or chemically degrade these products (De-la-Torre et al., 2022) or to integrate these products into materials with relatively long lifetime through secondary recycling (Merrington, 2017). The COVID-19 pandemic, especially between 2019 and 2021, introduced extremely high numbers of wasted face masks and other health personal protection equipment (PPE) to the environment over a very short period of time as the most efficient tools to reduce the spreading level of the deadly virus (Selvaranjan et al., 2021).

Consequently, a lot of attention is currently paid to develop sustainable plastic economy (Eben and Lacovidou, 2021) to cope with the challenges of increased plastic waste and the introduction of a plastic pandemic (Parashar and Hait, 2021).

Saudi Arabia, however it is characterized by arid conditions (Othman et al., 2021), it witnesses a rapidly growing economy and population rates (Amirat and Zaidi, 2020) leading to several environmental problems such as land subsidence (Aljammaz et al., 2021), urban heat islands (Mohamed et al., 2021), deterioration of air quality, degraded visibility and groundwater drawdown (Othman and Abotalib, 2019). The rapid urban sprawl at the expense of baren lands over a short time period in major cities in Saudi Arabia (e.g., Riyadh and Jeddah), resulted in the development of uncontrolled dump sites in random areas (Aljammaz et al., 2021). Left unmanaged, these uncontrolled dump sites, especially those containing medical waste can trigger several environmental

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problems such as groundwater contamination and leachate leakage to the surroundings (e.g., Patras, Greece [Papadopoulou et al., 2007], and in Delhi city [Jhamnani and Singh, 2009]) or cause transmission and intensification of disease [Patwary et al., 2011]. Among the best protection measures is to reduce the input of medical waste into the dump sites through secondary recycling.

Following the COVID-19 outbreak in 2019, several methods have been suggested to benefit from the PPE through either applying it to health care services or through their integration into other lifetime products such as in road construction (Abdullah and Abd El Aal, 2021; Saberian et al., 2021), soil reinforcement (Xu et al., 2022), sound porous absorber (Maderuelo-Sanz et al., 2021) and in concrete industry (Kilmartin-Lynch et al., 2021).

Fibers generally are applied to the concrete mix to improve its mechanical properties and avoid brittle failure. Polypropylene (PPE) is a cement-based composite material with scattered reinforcement in the form of fibers, such as steel, glass, polymer, gas, and other cementing materials (Blazy and Blazy, 2021). Steel bar resistance to corrosion and sulfate attack as well as to ions water penetration through cracks and concrete pores are related to reinforced concrete durability. Early plastic shrinkage, on the other hand, is among the most common reasons for cracks in concrete. Thus, integrating fibers for concrete reinforcement instead of traditional methods appears to be a successful strategy for lengthy improvement (Blazy and Blazy, 2021).

Moreover, polypropylene is particularly used in concrete manufacturing because of its mechanical qualities (Yin et al., 2015; Kazemi et al., 2020a & b), such as TS and Young’s modulus, as well as its ease of manufacture and good alkaline tolerance. Sadqiul Islam and Gupta (2016) examined the efficiency of adding polypropylene to produce fiber-reinforced concrete through adding 0.30 percent PP by concrete volume. The experiment decreased UCS marginally during the testing period and the most significant decrease was met at 10% by volume. The findings also elaborated that at 0.1 percent PP by volume, STS increased by 39 percent while UCS decreased. Similarly, Xu et al. (2020) performed comparative tests on PP reinforced concrete and found that once fiber of cellulose mater (CTF) was utilized in an amount of 1.5 kg/m³, the UCS of the concrete improved by up to 12%, but when (PP) was used in the amount of around 4.0 kg/m³, the UCS of the concrete decreased by 35%. Moreover, the STS of CTF decreased by 23% when the amount was 2.0 kg/m³, while the STS of PP decreased by 55%. The STS of polyolefin fiber was also reduced. Pesic et al. (2016) investigated the mechanical aspects of concrete in structural concrete using high-density recycled polyethylene (HPDE) fibers. Two diameters of fibers were investigated with HDPE at 0.40%, 0.75%, and 1.25 percent. As HPDE fibers were applied to the concrete mix at 0.40 percent and 1.25 percent, UCS and Young’s modulus remained unchanged, but FS and STS’s strength increased by about 3% and 14%, correspondingly. Al-Hadithi and Hilal (2016) looked at how waste plastic fibers from soda bottles affected the action of self-compacting concrete (SCC). The fibers extracted from waste plastic were applied to a reference mix in various volumetric ratios ranging from 0% to 2%. FS and UCS measurements were performed for up to 28 days throughout the test. According to Al-Hadithi and Hilal (2016), UCS improved through all mixes with the addition of PP relative to the reference mix, with UCS of 46 and 56 MPa, 51–68 MPa, and 53–77 MPa, correspondingly, at 7, 14, and 28 days.

Yu et al. (2021), Study the impact of adding short fibers and crumb rubber to the epoxy polymer core of composite railway sleepers to enhance mechanical performance. According to the experimental findings, which also included information on the microstructure of the polymer mixtures, short fibers improved the flexural and shear performance whereas crumb rubber increased the flexibility of polymer mixtures.

Abousnina et al. (2021), study the impact of macro polyfibers on the mood of filler which was modified from longitudinal splitting to shear failure. Additionally, compared to plain concrete, the addition of 4 kg/m³ and 6 kg/m³ fiber dosages increased compressive strength by 9.6% and 19.4%, respectively. Also, he studied the influence of macro polyfibers splitting tensile strength, the resolute showing that, STS increased by 28.7% and 41.9%, respectively, by adding fiber dosages of 4 kg/m³ and 6 kg/m³, respectively. This caused by the evenly distributed fibers’ resistance to internal tensile stresses, which also prevent crack initiation and reinforce existing fissures from spreading.

Although there are several advantages to using PPE in concrete mixtures, there haven’t been many studies done on how to improve the material’s technical properties and durability for use in construction. Recently, Kilmartin-Lynch et al. (2021) introduced a novel approach to incorporate single use-face masks in the concrete manufacturing. The approach used cement and other aggregates commonly found in Australia in addition to water reducer and applied uncommon lower concentrations of PPE (i.e., 0.10%, 0.15%, 0.20% and 0.25%) to examine the influence of adding PPE to improving the mechanical properties of concrete. Their results pointed out to increasing the concrete strength with the PPE addition until the concentration of 0.20%, where the strength started to decline beyond this concentration. Given the significant impact of PPE on the behaviour of concrete, different laboratory samples containing more commonly used concentrations of PPE (0%, 1%, 1.5%, 2.0%, and 2.5%) were examined in the present study using a typical mix of concrete that are commonly used in the construction purposes. The study herein integrates the experience obtained from previous studies (e.g., Haque et al., 2022; Shalaby et al., 2020; Qadri and Malik, 2021; Qadri et al., 2017; Abd El Aal, 2017) to provide a motivation for the present study, using integrated strategies to understand whether PPE could be reused and repurposed to reduce the pandemic-related waste and potential environmental threats that will probably end up in landfills or improper waste disposal on the roads throughout this crisis. The study also examines, for the first time, the impact of adding PPE on the internal structure of the concrete using integrated X-ray diffraction and scanning electron microscope at different PPE concentrations and finally assesses the environmental hazards of the PPE and recommends the best methods for decontamination of the PPE.

2. Materials and methodology
2.1. Materials
2.1.1. Type of cement
Najran cement of type I, which represents the ordinary Portland cement (OPC) was utilized in this research. The cement has a specific gravity of 3.15 and a Blaine Fineness of 410 kg/m³. As per the producer, the cement’s Bogue phases were 59 percent C3S, 12.1 percent C2S, 10.6 percent C3A, and 10.4 percent C4AF. Table 1 lists the oxides and chemical composition of cement.
2.1.2. Aggregates

For molding the concrete specimens to meet the ASTM C33/C33M-18 protocol, the used fine aggregate was coarse sand with a grain size of up to 4.75 mm, while the coarser aggregate was mainly composed of crushed stone with grain size of up to 20 mm. Table 2 shows the physical characteristics of the used aggregates that meet the ASTM C33 protocol.

2.1.3. Water

Drinkable water tap water is utilized in the blending and conditioning of concrete. The water’s properties satisfied the ASTM C1602/C1602M standard.

2.1.4. PPE polypropylene fibers

The polypropylene fibers (PPE) utilized in this work are commercially available in face masks, protective suits and safety foot shoes, which were cut into small pieces with each is 1 cm in both length and width, as illustrated in Fig. 1. Polypropylene fibers make up 2.5 percent of the total volume of concrete.

2.1.5. The overall number of FM annually used in Saudi Arabia

Because FM was the most often used item during the coronavirus epidemic, it was used to evaluate regular mask use. The mask use rate in Saudi Arabia is calculated using the total population (P), the proportion of the urban population (c), the acceptance rate (d) for the use of masks, and the average personal use (b) per day. The total daily mask usage (DMU) is computed as follows: DMU = P c d b, according to Nzediegwu and Chang (2020). The formula AMU = DMU 365 is used to compute the annual mask consumption (AMU). For varied acceptance rates, this study looked at several values of d and b, such as d = 0.5, 0.6, 0.7, 0.8, and 0.9, and b = 1, 2, 3, and 4. The AMU is determined for each conjunction of d and b.

Saudi Arabia is expected to hold one of the world’s most significant quantities of FM and PPE (5336–38426 million) as well as polypropylene/(micro-plastic materials (32.69–235.36 thousand tons; Table 3). FM are commonly reported in Saudi Arabia’s terrestrial and aquatic environments that contain a large amount of microplastics. These microplastics may act as a probable transporter of hazardous pathogens such as viruses, bacteria, and fungi (Patwary et al., 2011).

2.2. Methodology

The concrete specimens were mixed with cut-up PPE and then were analyzed using six concrete mix combinations in proportions of 0 percent (control mix), 0.5, 1, 1.5, 2, and 2.5 percent by volume of concrete. The utilize coarse and fine aggregates were oven-dried to remove excess moisture for 48 h at 110 °C. The studies employed Najran as detailed in section 2.1.1. To eliminate extra moisture, coarse aggregate with a nominal maximum size of 20 mm and fine aggregate with a specific gravity of 2.63 were oven-dried for 48 h at 110 °C. However, due to limitations imposed by the coronavirus “COVID-19,” we did not use disinfected PPE, particularly the face masks described in this study. Instead, unused PPEs were employed to avoid transmission and infection of Coronavirus. The PPE were cut into small pieces 1 cm long and 1 cm wide (Fig. 1). The use of scanning electron microscope (SEM) with energy dispersive analytical x-ray (EDX) is detailed in Abd El Aal et al. (2020). The microstructural properties and elemental content of the examined concrete samples were characterized by SEM analysis. The X-ray diffraction was also utilized to identify the samples after their crushing (Revenko 2002).

2.2.1. Concrete mix proportions

Table 4 shows the mixing patterns utilized to cast the specimens and the varying amounts of PPE. CM0 denotes a baseline mix containing no surgical masks, whereas CM25 denotes concrete with a 0.25 percent by volume content.

Concrete samples were designed by following the ASTM C192M standards with a w/c ratio of 0.50 in a regular mixer. This analysis did not use any additional materials or chemical admixtures. The PPE fibers were used as an additional percent in the amounts of 0.5%, 1%, 1.5%, 2%, and 2.5%. The concrete mix proportions are described in Table 4. Concrete samples were then mixed and placed into various moulds (cylinders, cubes, and prisms) for 24 h before being demolished and cured in clean drinkable tap water. The specimens were left to cure for 28 days at the room temperature (Fig. 1).

The dry materials were gently added and stirred for three minutes following a 3 min of mixing with water. During this time, the PPE pieces were gently added to the mix to assure uniform dispersion and minimize clogging. The mixture was put into the cylindrical moulds after being withdrawn from the mixer. The internal surfaces of the installed mould should be lightly coated with oil to prevent concrete adherence. The cylindrical moulds were filled with the mixed concrete and then were put on a vibrating table for 20 s to allow the concrete mix to settle. During the first 20 s, the moulds were filled with concrete and then vibrated for another 20 s to verify there were no voids. A smooth steel trowel was then used to finish the new concrete surface. Following casting, the samples were covered with a damp bag and left at room temperature for 24 h. After 24 h, the samples were extracted and placed in water to cure for a period of 28 days before they are tested for strength. For each concrete mix, this technique was performed. Identical casting processes were employed in previous studies such as in Al-Hadithi and Hilal, 2016; Sadiqu Islam and Gupta (2016) and Al-Hadithi et al., 2019.

The concrete specimens were extracted from the cylinder moulds after 24 h and placed in a curing container full of clean water, in which they were cured for the next 28 days at around 22 °C. The concrete specimens were removed from the conditioning container and left to dry for a period of 28 days and finally were grounded back on the top to give a smooth contact surface with the compression and testing machinery, as specified by ASTM C31/C31M-21. The loading rates varied between 0.14 and 0.34 MPa/s (ASTM C39).

2.2.2. Experimentation protocols

ASTM C39/C39M, ASTM C496/C496M, and ASTM C78/C78M were used to conduct compressive, split tensile, and flexural strength testing, accordingly. The compressive strength test was performed on 100 × 100 × 100mm3 cube samples. In contrast, the split test was performed on 100 mm diameter, 200 mm height, flexural strength of 100 mm diameter, 200 mm height, and Flexural strength of 100 mm diameter, 200 mm height, prism specimens. The average of three samples for each mix

| Table 1 | Chemical composition of cement. |
|-----------------|---------------------------|
| Items SiO2 Al2O3 Fe2O3 CaO SO2 MgO K2O Insoluble LOI | wt.% 19.73 6.2 3.44 63.78 2.23 0.96 1.02 0.93 1.51 |

| Table 2 | Lists the physical aspects of the material used in the study. |
|-----------------|---------------------------|
| Material | Fineness Modulus | Specific Gravity | Absorption (%) | Dry rodded unit weight (kg/m3) |
| Coarse Aggregate | – | 2.81 | 0.46 | 1555 |
| Fine Aggregate | 2.43 | 2.63 | 1.65 | 1596 |
| (PPE) | – | – | 8.8 | – |
Fig. 1. Experimentation protocols, casting and curing of the concrete with PPE.

### Table 3
The annual use of masks (in millions) and the volume of polypropylene (in thousands of tons) in Saudi Arabia. Updated after Akber Abbasi et al. (2020).

| Number of Masks (millions) in acceptance rate (d) | Number of Masks (millions) Polypropylene/(micro-) plastic (Thousands of tons) in acceptance rate (d) |
|-----------------------------------------------|-------------------------------------------------------------------------------------------------|
| 0.5                                           | 0.6 0.7 0.8 0.9                                                                                |
| 0.5                                           | 32.69 39.23 45.76 52.30 58.84                                                                |
| 0.5                                           | 65.38 78.45 91.53 104.60 117.68                                                               |
| 0.5                                           | 98.07 117.68 137.29 156.91 176.52                                                              |
| 0.5                                           | 130.76 156.91 183.06 209.21 235.36                                                             |
after 28 days of curing age was recorded. The testing compression machine has a capacity of 2000 kN. Before being subjected to a 157 kN/min load, three specimens of each mix arrangement were inspected for errors. In order to assess the structural integrity of the manufactured PPE concrete mix, non-destructive wave pulse velocity (PV) was performed on cube samples according to ASTM C597-16 (2016). PV also can be used to determine the relative consistency and uniformity of the concrete samples, as well as voids and cracks that can not be examined on the surface.

3. Results

Polypropylene (PPE) was used as a crack-resistant improvement material in concrete. The PPE, according to the producers, is constructed of synthetic polypropylene fibers with great chemical strength and stability. Fiber content ranged from 0.5 percent to 2.5 percent by volume. PPE is divided into little pieces, each measuring 1 cm in length and width. Table 5 shows the physical characteristics of the examined PPE.

3.1. X-ray diffraction patterns of PPE

Fig. 2a shows the combined X-ray diffraction patterns of the fibers. Fig. 2a shows the diffraction patterns of the fibers, which were located between 10 and 30°. Peaks at 14 o, 17 o, 18.6 o, 21–22 o, and 28 o are similar to those in polypropylene (JCPDS 00-050-2397–1970). SEM was used to look for any microstructural changes in PPE. The PPE layer (PP) was cut into a scale of 10 mm × 20 mm and examined using a scanning electron microscope (SEM) (Hitachi, TM3000). Melting, distortion, entanglement, and cracking are structural changes in PP fibers seen in Fig. 2b.

3.2. Slump

The slump measurements for concrete mixes, including the different ratios of PPE as addition, are shown in Fig. 2. As the percentage of PPE put to concrete increases, the slump values are supposed to decrease linearly. Compared with the reference sample’s reference slump, the slump has reduced by about 5%, 13%, 20%, 30%, and 43%, respectively. The reduced slump might be ascribed to the heterogeneity and roughness of the PPE particles, which could reduce the fluidity of the mixes and PPE’s high absorption (8.8%), as seen in Table 6. Because of the PPE’s high porosity with an average of 8.8% as well as the high stability between the PPE and the concrete matrix (Das et al., 2018), adding more PPE led to a decline in slump values (Fig. 3). It is also worth noting that employing fibers for concrete reinforcement imposes certain mix composition constraints, necessitating a change (Markovic, 2006; Singh and Rai, 2018; Mohajerani et al., 2019). The workability of concrete is influenced by the fibers’ number, shape, slenderness, and mix composition (Markovic, 2006, Karahan and Atis, 2011; Blazy and Blazy, 2021; Zych and Krasodomski, 2016; Wan Ibrahim et al., 2017).

When fiber dose surpasses this limit, fiber clamping or balling is more likely, resulting in uneven fiber distribution and a more apparent loss in workability (Ranjbar and Zhang, 2020).

3.3. Uniaxial compressive strength (UCS)

The UCS of the specimens is depicted in Fig. 4. The experiment’s control mix had a 28-day UCS of roughly 448 kg/Cm². However, the UCS came from a 2% volume addition of shredded PPE (Fig. 4). Compared to the control mix analysis, 1% and 2% volumes indicated a considerable rise in UCS before reducing to 2.5 percent. Compared to the reference specimen, volume increments of 0.5, 1, 1.5, and 2% resulted in sample increases of 8.82, 11.05, 13.68, and 9.40 percent, correspondingly (Table 6, Figs. 4 and 5). As a consequence, the findings suggest that including PPE in concrete has a significant impact on the UCS. Xu et al. (2020) showed similar results of UCS; with different plastic fibers, UCS increased to the point where it began to fall. The rise in UCS with the inclusion of PP fibers may be due to the impact of the fiber’s fracture limitation, as demonstrated in earlier investigations (Nili and Afroughsabet, 2010). The declining trend at 2.5 percent, according to Mohammadosseini et al. (2017), can be related to the existence of voids at a high percentage of PPE. Furthermore, a high concentration of PPE (greater than 2.5%) can result in worsening interface bonding between the cut-up PPE and the cement.

On the other hand, adding PPE to the mixtures changed the concrete’s failure mode from brittle to ductile. Due to the bridging action of the PPE fibers, the specimens did not crush and remained intact until the test was completed. PPE-containing mixes had a lower UCS at a young age, but a greater UCS after a longer duration of curing. This shows that fiber’s bridging effects can improve the concrete’s UCS over time.

3.4. Non-destructive wave velocity (PV)

PV testing is a non-destructive method to determine the consistency and efficiency of concrete samples. Concrete pores and cracks are called PV (Ahmed et al., 2016) and the effects of the PV test are depicted in Fig. 6. PV increased as the PPE grew to 2%, then decreased slightly to 2.5 percent, as shown in the results. Adding a PPE to a volume of 2% yields the optimum performance and serves as a UCS indication. Concrete with a PV result of higher than 4500 m/s is regarded very good to exceptional concrete (Simsek et al., 2019; Khatib et al., 2019). Compared to the reference sample, the concrete quality declined by 2.5 percent; however, it should be noted that the concrete quality enhanced in all mix designs, implying favorable attributes. As per Yap et al. (2013), there are no substantial voids or cracks in high-quality concrete between the above ranges. As a result, the usage of chopped PPE can reduce the number of concrete microcracks (Wan Ibrahim et al., 2017), hence enhancing the quality of concrete. As previously stated, concrete within the limit ensures that no bulky cavities or cracks compromise structural integrity. Due of increased void content and porosity with improved fiber composition, PV values tend to decrease above 2.5 percent. Per the BIS, the PV readings vary between 3.8 and 4.04 km/s, demonstrating that the concrete quality is adequate (IS 13311–1 1992). Adding PPE to the equation raised the UPV values to a certain volume fraction. On the other hand, increasing carpet fiber content led to a decline in UPV values, as anticipated. The presence of voids and microcracks in the concrete samples is assumed to have affected homogeneity at more significant fiber volume fractions, resulting in a reduction in velocity variation.

| Table 4 | Shows the concrete proportions. |
|---------|-------------------------------|
| Percentage % | 0 | 0.5 | 1 | 1.5 | 2.0 | 2.5 |
| Water | 217 | 217 | 217 | 217 | 217 | 217 |
| Cement | 400 | 400 | 400 | 400 | 400 | 400 |
| Coarse Agg. | 1054 | 1054 | 1054 | 1054 | 1054 | 1054 |
| Fine Agg. | 666 | 666 | 666 | 666 | 666 | 666 |
| PPE | 0 | 11.68 | 23.36 | 35.04 | 46.72 | 58.4 |

| Table 5 | Physical properties of examined (PPE) Saberian et al., 2021. |
|---------|-------------------------------------------------|
| Physical properties | SHM | Standard |
| Specific gravity | 0.91 | ASTM D792-20 (2020) |
| Melting point (°C) | 160 | ASTM D7138-16 (2016) |
| Water absorption 24 h (%) | 8.8 | ASTM D570-98 (2018) |
| Tensile strength (MPa) | 3.65 | ASTM D638-14 (2014) |
| Tensile strength at break (MPa) | 3.97 | ASTM D638-14 (2014) |
| Elongation at break (%) | 118.9 | ASTM D638-14 (2014) |
| Rupture force (N) | 19.46 | ASTM D638-14 (2014) |
| Aspect ratio | 24 | – |
Table 6
Summarizing the results of strength properties of concrete mixed with PPE.

| PPE % | UCS (kg/cm²) | IR % in USC | Flexural strength MPa | IR % in FS | Tensile strength MPa | IR % in TS | PV (m/s) | IR % in PV | slump | DR in slump |
|-------|--------------|-------------|-----------------------|-----------|----------------------|-----------|----------|-----------|-------|-------------|
| 0%    | 448          | –           | 4.407                 | –         | 3.237                | –         | 4249     | –         | 90    | –           |
| 0.5%  | 491          | 8.82        | 5.363                 | 17.8      | 3.343                | 3.190     | 4653     | 8.19      | 85    | 5           |
| 1%    | 503          | 11.05       | 5.803                 | 24.0      | 3.463                | 3.465     | 4740     | 9.61      | 77    | 13          |
| 1.5%  | 519          | 13.68       | 6.080                 | 27.5      | 3.560                | 2.715     | 4866     | 12.49     | 70    | 20          |
| 2%    | 542          | 9.40        | 6.617                 | 33.4      | 3.730                | 4.558     | 4922     | 14.03     | 60    | 30          |
| 2.5%  | 412          | –           | 4.480                 | 1.63      | 3.527                | 8.696     | 4631     | 3.67      | 50    | 40          |

Fig. 2. XRD and SEM image of PPE fibers, b appearance of PPE layers under a scanning electron microscope at 1000 ×.

Fig. 3. Slump of different percentages of PPE.

Fig. 4. Compressive strength results after 28-day enhanced by the adding of PPE.

Fig. 5. Strength rate of addition of PPE at different doses.

Fig. 6. P-wave velocity results after 28-day enhanced by the addition of PPE.
3.5. Splitting tensile strength

According to the findings, the PPE fibers effectively raised the splitting tensile strength values. As demonstrated in Fig. 7, the STS of concrete specimens containing PPE were much more significant than those of reference concrete that did not include any PPE. When the splitting occurred, the PPE bridges the split sections of the samples worked over the load transferring from the matrix to the PPE and maintained it, eventually supporting the maximum tensile stress. The transmitted stress improved the tensile strength of the fibrous mixes over their non-fibrous counterparts by increasing the tensile strain power of the concrete matrix (Mohammadhosseini et al., 2017).

The control mix had an indirect tensile strength of 3.236 MPa, as shown in Fig. 7, with the highest results (3.730 MPa) obtained at 2% of PPE, similar to the UCS and PV results (see Figs. 4–6). Overall, the volume of the samples increased from 1% to 1.5 and 2%, with a marginal decrease in indirect tensile strength at 2.5%; however, the 2.5%; percent volume of the PPE sample has a higher indirect tensile strength than the reference mix by 8.22%. Overall, the 1% and 2% samples increased STS by 1.72%–7.14%, whereas the 2.5% PPE sample increased by 8.22%. As previously mentioned, with the improvement in the consistency of the concrete (as shown by the PV results), STS will rise in similar ranges. UCS and STS increase as FM fibers become more closely spaced, according to Al-Hadithi and Hilal (2016). The increased STS of fibrous PP mixes was demonstrated in research by Mohammadhosseini et al. (2017), who found that the transferred stress of fibrous PP mixes increased the concrete mix’s STS. Fig. 7 shows that the STS values increase with the addition of PPE up to 2%, after which the STS values begin to decline at 2.5 percent. Fig. 7 also depicts the relationship between PPE fiber content and corresponding STS of concrete intensity compared to control concrete. It has been discovered that adding PPE fibers to a concrete mixture improves the STS of the concrete. However, the finding that STS increases with increasing fiber dosage may not always be factual due to workability deterioration, unfavorable fiber distribution, or other factors (Behfarnia and Behravan, 2014; Widodo, 2012; Yap et al., 2014; Das et al., 2018).

3.6. Flexural strength

The FS follows the same pattern as the UCS and PV, rising up to 2% PPE fiber before declining as the number of fibers increases. Fig. 8 depicts the reported FS of prismatic beams. The results in this graph reveal that, like STS, concrete FS improved as PPE content increased. For example, increasing the FS of specimens by 17.8%, 24 percent, 27.5 percent, 33.4 percent, and 1.6 percent by adding 0.5 percent, 1 percent, 1.5 percent, 2 percent, and 2.5 percent PPE to plain concrete. Furthermore, PPE was crucial in improving FS after a longer curing process. As seen by a 33.4 percent increase in FS in concrete with 2.0 percent PPE, the cumulative influence of PPE appears to be focused on increasing strength. Because voids in the matrix increase as the number of PPE fibers increases, the FS values decrease as the fiber content increases.

The sample’s FS was improved significantly when PPE was applied to sustainable concrete. As a result, integrating PPE with an optimized shape to generate stronger concrete bond strength can result in greater FS gains. Due to advancements in recycled PPE processing, structurally enhanced fibers with enhanced bond strength can yield durable structural concrete capable of building more significant residual capacities. A bridging mechanism could result from the enhanced flexural performance of the concrete containing PPE. The increase in flexural strength was generated by the fibers crossing the cracks in the tension region of the prism samples. PPE fibers bend to keep the crack face apart, allowing for more energy absorption and stress relaxation in the microcracked area at the crack tip (Fig. 8). In contrast, increased PPE fiber content (2.5 percent) led to lower flexural strength. The lower workability of the concrete at increasing volume fractions in the combinations could be the cause of this problem. Fig. 9c depicts the measured flexural strengths of prismatic beams.

3.7. Efficiency fibers in the enhancement of strength properties

3.7.1. Microstructure analysis

Concrete also can be subject to cracking almost immediately after pouring and even before it is fully set. These cracks are a major cause of concrete weaknesses, especially in large-scale worksites, where these cracks can cause a lack of overall durability of concrete and lead to its failure (Sivakumar and Santhanam, 2007a). Conventional reinforcing and the usage of a sufficient quantity of certain fibers can help mitigate tension weakness to some extent (Ahmed et al., 2006). The microstructure of PPE-added concrete sample with a 2% volume fraction was examined by SEM. The microstructure of a concrete specimen after cracking at 0.5 percent, 1 percent, and 1.5 percent PPE surface and hydrated cement matrix is shown in Fig. 9a, b, c, d. The surface of the PPE is covered with a heavily hydrated cement matrix, as seen in Fig. 9a, b, c, d. As a result of this occurrence, PPE and the hydrated cement matrix have formed a strong link.

The PPE and cement matrix exhibit a strong interface connection (Fig. 9e). Because of the bonding, the size and number of cracks were reduced, resulting in a 2% increase in PPE strength. The better flexural efficiency of concrete containing PPE could be explained by the bridging mechanism of fibers that partly transmitted the stress across the fracture. Nili and Afroughsabet (2010) found that introducing polypropylene to concrete greatly enhanced the flexural strength of the concrete.

At 2 percent PPE fibers, the highest UCS was attained. The alterations, however, are negligible in nature. The highest UCS increases are 13.6 percent and 9.40 percent, correspondingly, for 1.5 percent and 2 percent PPE. As a result, fibers are likely to impact UCS values significantly. According to the findings, as contrasted to standard concrete,
Fig. 9. SEM images of concrete with PPE fibers. (a) Cubes with different percentage of PPE, (b, c, d, e, f) 0.5%, 1%, 1.5%, 2% and 2.5% of PPE fibers.
PPE fibers substantially impact UCS values. This behaviour of fiber-reinforced concrete could be explained by the great fineness and varied length of fibers in staple PPE fibers, which create a pattern that functions as a bridge and stops the microfracture from propagating. However, because of poor workability and mixing, when the PPE fiber level is larger (2.5%), the fiber is dispersed irregularly in concrete. The accumulation of these fiber bundles resulted in weaker places.

The fibers act as a bridging feature in comparison to the standard mix, essentially moving load from the matrix to the fibers and absorbing the increased load, resulting in better split tensile and flexure strength values. The form and size of the PP fibers affect the STS of concrete. Due to the decreased w/c ratio, the STS and FS values are relatively high, increasing by 15.24 and 33.4 percent at 2 percent PPE, correspondingly, when compared to reference samples. In a dispersed fiber cement matrix, stress concentrations are not consistent along the length of the fiber.

Although stresses are greatest at the ends and in discontinuous short-length fibers, there are more critical places with high stresses and a larger probability of failure. This discusses why values of the split tensile decrease as fiber contents increases (Das et al., 2018).

Fig. 10 depicts PPE’s critical role in the concrete structure. As indicated, plastic shrinkage stresses exceed concrete’s strength in the early hours of its life when both UCS and STS are strong. Shrinkage cracks arise as a result, and the phenomenon can be delayed by a large number of uniformly distributed PPE, which reduces their breadth by two orders of magnitude (Yang et al., 2020). PPE functions as a three-dimensional reinforcement, bridging cracks and preventing them from spreading (Yang et al., 2020). It is vital to remember that fractures that do not reach a specific size are not hazardous to the structure or serviceability. Because the Young’s modulus of concrete exceeds the Young’s modulus of the PPE when it changes from a plastic to a solid state, micro PPE is no

![Fig. 10. Schematic representation of the mechanism of bridging formed by PPE fibers.](image-url)
longer regarded to serve an important impact. Moreover, the fracturing area in concrete with 0.5 percent PPE was reduced by 99% (Sivakumar and Santhanam, 2007b). PPE inhibits cracks from emerging during both plastic and drying shrinkage (Sivakumar and Santhanam, 2007b; Zych and Krasodomski, 2016). PPE fibers also have a bridging effect, resulting in higher STS and FS.

The PPE material heavily influences the STS values of the samples. Adding PPE fibers causes cracks to be bridged, improving the FS and STS values. However, as shown in Fig. 10, voids appear to form between the cement paste and the PPE fiber in some cases, supporting the results obtained for UCS and STS as fiber content increases. Furthermore, failure can occur due to PPE fiber rupture in some cases.

3.7.2. Environmental hazard of PPE

Millions of polluted PPE will be discarded, creating serious environmental and health dangers (Fig. 11 a-h), given that coronavirus can persist for up to 9 days on material surfaces such as metals, glass, and plastics (Kampf et al., 2020). Such hazards can be reduced in developing countries that implement sustainable and green waste treatment procedures that can handle viruses and conversely threats will be significantly worsen in developing countries with insufficient waste management policies. Even though many developing nation governments are taking aggressive measures to restrict and limit the spreading of COVID-19, there are no procedures to deal with solid waste, such as worn personal protective equipment, during and after the epidemic. The governments should follow the lead of the Lagos State Rubbish Management Authority in restricting waste pickers’ access to landfills. Special trash collect buckets for disposable PPE could be given in buildings (residential, government, and hospital) and public spaces. These waste disposal buckets must be emptied at least once a day by trained personnel, who will disinfect or dispose the PPE per the WHO guidelines (World Health Organization, WHO, 2020). Before being repurposed to package local beverages and herbal medicines, discarded plastic bottles should be decontaminated with a 70% alcohol solution, according to NCDC recommendations.

Inappropriate handling of used PPE could further promote COVID-19 transmission through additional mechanisms. Therefore, we encourage the academic society to communicate its concern to governments at all

![Fig. 11. Waste of HHM related to the Covid-19 pandemic: (a, b) disposable medical facemasks found on roads and parking, (b, c) Masks found in public gardens, and (d, e) disposable medical face masks on highroad and besides building.](image-url)
levels regarding the importance of implementing adequate solid waste management systems to avoid the spread of the new Coronavirus.

4. Common strategies to reduce the danger associated with the PPE

In the current situation, various effective techniques for disinfecting the collected PPEs in order to persuade the construction sector to use masks and other PPE wastes without the risk of disease transmission. These techniques include:

1. Hydrogen peroxide in vapor (VH₂O₂), either alone or in combination with ozone for high-throughput decontamination of PPE has been certified by the FDA in the United States under an emergency use authorization (EUA) to alleviate supply shortages caused by the COVID-19 pandemic.

2. Ultraviolet (UV) light methods, particularly those utilising the UVC wavelength, can also be used as a possible PPE decontamination method. Additionally, several UV technologies are used to avoid process harmonization.

3. Because it provides scalability and high-throughput processing, moist heating at 60 °C–70 °C for 60 min combined with high humidity is a potential decontaminating technique for PPE. Microwave-generated steam would be ineffective for PPE decontamination.

4. Physical irradiation techniques, including gamma, electron beam, and ethylene oxide, are ineffective for PPE reprocessing.

5. Conclusions

This research introduces a new waste management method for integrating pandemic-related waste into long lifetime materials such as the concrete. The results of adding shredded PPE into the strength aspects of concrete were investigated for the first time using integrated experimental, x-ray diffraction and SEM analyses. Several ratios of PPE (0, 0.5, 1%, 1.5%, 2.0%, and 2.5%) were used in manufactured concrete and the slump, UCS, FS, STS, and PV tests were examined. Our findings indicated that: (1) PPE can improve the mechanical characteristics of the concrete when used in limited quantities of less than 2%, (2) the UCS and STS tests both revealed a clear trend indicating that a 2% volume of PPE in the concrete is the ideal amount to use, (3) PPE utilization improved the concrete quality compared to the reference mix, as the fibers became more closely dispersed, resulting in an improvement in PV, UCS, FS and STS, (4) regardless of the volume content of PPE, all concrete mixes are held to the same high standard of excellent quality, high strong concrete, and structural strength., (5) decontaminated PPE can be used as a building material to manufacture sustainable concrete and contribute to a clean and healthy environment, (6) tensile tests indicated that the polypropylene layer of the PPE contributed most of the tensile power. Furthermore, the PPE fibers used in this study were categorized as short or discontinuous, resulting in improved strength and stiffness, and (7) PPE fibers (up to 2%) have a substantial role in crack bridging, as demonstrated in SEM images, while at volume percentage of more than 2.5% of PPE voids form within the cement paste and result in lowering the overall strength of the concrete. The findings contribute into the development of eco-friendly solid waste managemnt and sustainable plastic recycling through providing new insights into the PPE integration into concrete manufacturing. The study also alarms the necessity to improve the public perception of environmental conservation and how to deal with PPE through governmental and community programs. To promote sustainable development and reduce adverse environmental effects of health-related wastes, especially in wealthy Gulf countries, more attention should be paid to waste management systems and implementing policies that make the region more prosperous, responsible, and ecologically friendly and increase environmental care and awareness to be better prepared for any future pandemics.

Author statement

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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