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A sustainable approach on the utilisation of COVID-19 plastic based isolation gowns in structural concrete

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ABSTRACT
Single-use isolation gowns have become an important practice across medical centres, testing sites, and emergency rooms since the onset of the Coronavirus pandemic; within the later months of 2019. Although reusable isolation gowns have proved beneficial, 80% of frontline centres opt for disposable isolation gowns, increasing the demand for plastic-based personal protective equipment (PPE) and the environmental strain from excess waste in landfills. This research aims to explore the practicability of using plastic-based isolation gowns in structural concrete to scale back the quantity of pandemic-generated waste ending up in landfills. The shredded isolation gowns were added to aggregates at 0.01%, 0.02%, and 0.03% of the volume of concrete. The effects of various concentrations of shredded isolation gowns on the mechanical properties of the concrete were investigated through a series of experiments alongside an SEM-EDS analysis. Results demonstrate an enhanced bridging effect between the cement matrix and shredded isolation gowns, allowing for the steady trend of improved mechanical properties of the concrete were investigated through a series of experiments alongside an SEM-EDS analysis. Results demonstrate an enhanced bridging effect between the cement matrix and shredded isolation gowns, allowing for the steady trend of improved mechanical properties of the concrete with increases of 15.5%, 20.6%, and 11.73% across compressive strength, flexural strength, and the modulus of elasticity, respectively.

1. Introduction

The Coronavirus pandemic has rapidly put the world on hold since its first emergence in late 2019, affecting economies, health systems and livelihoods on a global scale [1]. Personal protective equipment (PPE) is a crucial line of defence to reduce the spread of Coronavirus (COVID-19). Originally designed to protect frontline workers, PPE is now primarily consumed in response to the emergence of the global pandemic [2,3]. The global demand for isolation gowns, for instance, is expected to grow by 12.8% and is set to exceed $2.65 billion by 2025 [4]. PPE waste management through medical streams is generally contained through specialised waste
management systems; however, the overload of household PPE use due to the pandemic creates increased stress on current waste management solutions [2,5,6]. Pre pandemic, an estimated 2% of plastic-based waste was mismanaged via littering. However, recent research shows that COVID-19 triggered an astounding global use of 129 billion face masks and 65 billion gloves every month, causing a drastic increase of plastic production [7,8]. In Africa alone, the daily use of face masks exceeds 586 million [9]. In 2020, the United States produced an entire year’s worth of medical waste in 2 months [10].

Similarly, in Tehran, Iran, approximately 5.5 million PPEs were disposed of daily during the pandemic in 2020, with an increase in landfilling of waste PPE by around 30 tonnes per day after the outbreak of COVID-19 [11]. Additionally, plastics generated through COVID19 have been detected floating throughout the aquatic environment, ultimately adding a new source of micro-plastics to our oceans [12-16]. With millions of contaminated face masks, gloves, and other medical PPE waste involved in diagnosing, detecting, and treating COVID19 becoming infectious waste daily [17]. There has never been a greater need to ensure the materials are safely handled, stored, treated and reused [18]. It is estimated that hospitals alone are producing approximately six times more plastic-based medical waste than in pre-pandemic conditions [19], with solutions to the ever-growing piles of COVID19-generated waste needed urgently.

Thermoplastics such as polyethylene (PE) and polypropylene (PP) are typical examples of plastics that are utilised daily in numerous products globally [20]. Malek et al. [21] researched the utilisation of recycled polypropylene fibres as an addition to concrete. The experimental work incorporated polypropylene fibres at a rate of 0.5, 1.0 and 1.5 wt. by % of cement for two types of recycled PP fibres. They found that the highest values within the mechanical properties of concrete were obtained at 1.0% polypropylene fibres for both types included in concrete, with an increase of 69.7% and 39.4% for green and white PP fibres, respectively [21]. Yoo and Kim [22] studied the effect of PE fibres on high-energy absorbent ultra-high-performance concrete with steel fibres, where steel fibres were replaced with PE fibres at 0.5%, 1.0% and 1.5%. The study by Yoo and Kim [22] concluded that the compressive and tensile strengths decreased relative to the amount of PE fibres introduced into the concrete with the addition of PE fibres. However, strain capacity and energy absorption dramatically improved when the PE fibres were introduced, with increasing rates showing better results [22].

Similarly, Zéhil and Assaad [23] experimented with the feasibility of concrete containing cross-linked PE waste materials. The PE fibres were shredded to varying sizes and incorporated into the concrete up to 8% of cement mass, initially noting the cross-linked PE fibres resulted in superior water permeability; however, concrete strength and shrinkage results were minorly affected. Overall, compressive and splitting tensile strengths decreased relative to the content of PE fibres, with the drop in strength relating to the weaker mechanical properties of the cross-linked PE fibres [23].

Saberian et al. [8] analysed experimental data on repurposing single-use face masks generated through the pandemic for pavements base/subbase. Shredded face masks (SFM) made from a polypropylene blend were combined with dry recycled concrete aggregates (RCA) at 1%, 2% and 3% by weight. It was noted throughout the study that incorporating shredded face masks at 1–2% increased the strength and stiffness of RCA aggregates caused by the SFM playing a reinforcing role in binding the RCA. Similarly, Kilmartin-Lynch et al. [24] studied the effect of COVID19 single-use face masks on the compressive and tensile strengths of concrete. They noted that a 0.20% inclusion of shredded face masks by volume of concrete showed an overall increase in both the compressive and tensile strengths of 17% and 12%, respectively. In another study, Kilmartin-Lynch et al. [25] investigated the effect of shredded nitrile gloves (SNG) generated from COVID19 PPE medical waste on the mechanical properties of the blended concrete composites. The study concluded that the inclusion of SNG in concrete resulted in a ~20% increase in compressive strength.

To the best of the authors’ knowledge, based on the review of existing literature, no existing study appears available on the application of shredded isolation gowns in structural concrete. One of the largest in the world economy, the construction industry can play a significant role in transforming different wastes into a valuable resource [26,25,27-33]. Therefore, to address this research gap and look at transforming this medical waste into a valuable resource, experimental work was undertaken on structural concrete incorporating shredded isolation gowns at 0%, 0.01%, 0.02% and 0.03% by volume of concrete. Fundamental mechanical properties such as compressive strength, flexural strength and elastic modulus were undertaken in conjunction with the ultrasonic pulse velocity test to ascertain the integrity and quality of structural concrete. SEM analysis was conducted to identify the bond performance of the shredded isolation gowns with the cement matrix, which is crucial to utilise its high tensile strength effectively. Since SEM images are greyscale images, and it is sometimes difficult to identify and separate different features from the SEM images, it was coupled with the EDS analysis [34,35], an analytical method that permits the chemical characterization and elemental analysis of different features of the SEM image [36]. A material that has been activated by an energy source (such as the electron beam of an electron microscope) releases a core-shell electron that helps release part of the energy that has been absorbed. The difference in energy is subsequently released as an X-ray with a distinctive spectrum depending on its parent atom as a higher energy outer-shell electron moves in to take its place. As a result, it is possible to analyse the composition of a sample volume that has been excited by an energy source. The location of the peaks in the spectrum identifies the element, while the signal’s strength reflects the element’s concentration.

2. Experimental programme

2.1. Materials and methods

Four concrete mixes were utilised to investigate the mechanical properties of concrete mixed with personal protective equipment (PPE) isolation gowns. Shredded isolation gowns (SIG) (20 mm long and 5 mm wide) were mixed with concrete in proportions of 0%, 0.01%, 0.02%, and 0.03% by volume of concrete. The cement used throughout the experiment was general Portland cement containing at least 92% Portland cement clinker and a maximum of 8% mineral addition (limestone and gypsum), as per Australian Standard
AS3972 [37], having a specific gravity of 2.85. The fine aggregates in the concrete mixes were oven-dried at a temperature of 110 °C for 48 h, removing any additional moisture present in the material. Sika Plastiment 10 was the preferred choice of superplasticiser used throughout the experimental study. A ratio of 300 mL of superplasticiser was utilised per 100 kg of cement in the concrete mixes. The particle size distribution curve of the aggregates used throughout the concrete mixes is shown in Fig. 1. X-Ray fluorescence (XRF) testing and X-Ray powder diffraction (XRD) testing were also undertaken in this experiment, with the results outlined in Table 1 and Fig. 2, respectively. XRD testing utilised the Bruker AXS-D4-Endeavor equipped with lynxeye linear strip detector and X-ray source of Cu Kα radiation on oven-dried cement powder; the instrument ran at 40 kV and 40 mA current. The cement was tested between 5° and 70° 2-theta range with a step size of 0.01° and counting time of 1 s per step. Fig. 3 details the elongation curve of the plastic-based isolation gowns. The ultimate load is shown across three samples of isolation gowns detailing the highest load the material can bear before failure, thus allowing a better understanding of the material’s deformation capacity. From these results, it is possible to analyse the mean maximum tensile strength of the PE/PP blended isolation gowns, being 108.3 MPa.

XRF was carried out using Bruker AXS-S4-Pioneer to ascertain the elemental composition of Portland cement. Isolation gowns conforming to standards GB/T 20097 were the main form of PPE utilised throughout the experiment. The gowns containing 55% polypropylene and 45% polyethylene can be seen in Fig. 4. Before the isolation gowns could be utilised in the experiment, they were left in an airtight container untouched to quarantine for 96 h, washed, dried, and cut to a nominal size of 5 mm wide and 20 mm long. The isolation period is in line with the New England Journal of Medicine studies, which outlines the virus COVID-19 being noticed up to 72 h after exposure to stainless steel and plastics (Van [38]). The material dimensions align with previous studies [39,40].

2.2. Physical Properties of Isolation Gowns

Compromising a blend of PP/PE fibres, the melting point for the isolation gowns varied for the two separate layers. The PP layer experienced a melting point of 165 °C, whereas the PE layer had a melting point of 110 °C. The melting point test was conducted following ASTM D7138–16. The isolation gowns had a 24-hour water absorption of 1.97% when conducted under ASTM D570–98. The mean tensile strength of the isolation gowns tested as per ASTM D638–14 was 108.3 MPa. The tensile strength samples had a width of 10.2 mm and thickness of 0.025 mm, and a cross-sectional area of 0.255 mm².

2.3. Mix Proportions

Table 2 breaks down the mix proportions used in the casting process and the various percentages of isolation gowns incorporated into the concrete mix. CM0C implies the control mix (0% isolation gowns present), whereas CM02C and CM03C signify 0.02% and 0.03% isolation gowns (by volume of fine concrete), respectively, presented in the mix design.

2.4. Casting and Curing

Concrete samples were prepared for compression, elastic modulus, and flexural strength testings. The preparation of compression strength samples was following AS 1012.8.1 using moulds of 100 mm (D) x 200 mm (H). Casting for elastic modulus followed AS 1012.17, whereas flexural strength testing utilised moulds of 350 mm long x 100 mm high x 100 mm wide under AS 1012.8.2 and AS 1012.11. The dry materials were mixed for three minutes, and the superplasticiser was thoroughly mixed with the water during this period. After initially dry mixing for three minutes, the mixture of water and superplasticiser was slowly added to the cement mixer and further mixed for a supplementary period of three minutes. The isolation gowns were introduced to the concrete mix in small batches to avoid the material clumping together. The concrete mix was then transferred to pre-prepared moulds, placed on the
vibrating table, and vibrated for 20 s to remove any additional voids and air bubbles before being topped up and vibrated for a further 20 s. The mixing process was repeated for the additional two mix designs and allowed to cure at room temperature for 24 h. Our previous studies have used a similar procedure [25,36].

After 24 h, the concrete samples were removed from their respective moulds and placed in a curing tank with clean, fresh water at approximately 22°C for the remaining 28 days [41-43]. After 28 days, the concrete specimens were taken out of the curing tank and air-dried in preparation for testing. Cylindrical samples used throughout compressive strength and elastic modulus testing were smoothed off using a grinder to ensure a flat contact surface during mechanical testing.

2.5. Testing procedures

Ultrasonic Pulse Velocity (UPV) measures were performed under ASTM C597–16; this testing was applied to evaluate the quality of the concrete as well as relative density and uniformity, therefore, aiding in understanding crack development and voids that may not be evident on the surface of the concrete. The compressive strength of the concrete samples was carried out as per AS1012.9 using Materials Testing System (MTS) equipment with a loading rate of 157 kN/minute. Flexural samples were tested as per AS1012.11 under a standard loading rate of 1 MPa/minute utilising the same MTS equipment mentioned previously. Elastic modulus samples were tested following AS1012.8.1. Three replicates were prepared and tested for each mix design to reduce any margin of error.
2.6. SEM-EDS analysis of concrete samples containing shredded isolation gowns

The SEM-EDS testing focused on ascertaining the bond performance of the isolation gowns with the cement matrix. The testing was performed on concrete samples containing PPE isolation gowns utilising the FEI Quanta 200 SEM. Small samples of concrete containing isolation gowns were removed from the visible section of the flexural strength samples after being tested and fractured. Samples were then placed with carbon tape onto the steel stub and coated in gold to create higher conducive SEM imagery. SEM images of the isolation gown samples were captured at 500× and 2000× magnification. Since the SEM only provides greyscale imagery, an energy dispersive spectroscopy (EDS) analysis was taken to determine the elements present in the samples. Since the samples were gold coated to undertake SEM-EDS analysis, it was deconvoluted during the EDS analysis.

3. Results and discussion

3.1. SEM-EDS analysis for the bond performance of shredded isolation gowns with the cement matrix

Fig. 5 shows the SEM-EDS images of the bond performance between shredded isolation gowns and the cement matrix, detailing the interfacial transition zone (ITZ) between the cement matrix and isolation gowns at both 500x and 2000x magnifications. Fig. 5 also outlines the EDS analysis of the chemical composition of the shredded isolation gowns (spectrum 1) and the cement paste (spectrum 2). Spectrum 1 can be noted as a shredded isolation gown from the more significant percentage of carbon present (86.7 wt%), whereas spectrum two details greater levels of Calcium, Oxygen and Silicon. It is clearly shown in Fig. 5 that the shredded isolation gowns form an outstanding bond with the cement matrix. Fig. 5(c) and 5(d) show no gap present in the ITZ, clearly reflecting that the isolation gowns form an excellent bond with the cement matrix. The excellent bond between the shredded isolation gowns and the cement matrix is further demonstrated in Fig. 5(e) and 5(f) showing no gaps present in the ITZ, clearly reflecting that the isolation gowns form an excellent bond with the cement matrix.
Fig. 5. SEM-EDS analysis of the bond-performance of shredded isolation gowns with the cement matrix (a) EDS Spectrum 1 of shredded isolation gowns; (b) EDS Spectrum 2 of cement paste; (c-d) ITZ between cement matrix and shredded isolation gown at 500x and 2000x magnification levels.
matrix is vital for the crack bridging effect within the cement matrix. Therefore, supporting the reasoning behind the variation in the strength development outlined in Sections 3.2–3.5.

3.2. Ultrasonic Pulse Velocity (UPV)

Fig. 6 details the performance of the UPV test taken at 7-day and 28-day curing periods. The graph demonstrates that all mix designs from CM01C to CM03C improve from the initial control sample across both 7-day and 28-day results. UPV testing is undertaken frequently to understand the overall quality of the concrete and outline any voids or cracks that are not present on the concrete surface area. Generally, UPV results showing speeds greater than 4500 m/s are deemed excellent quality [44]. Fig. 6 also shows the quality of the concrete samples increased by higher inclusion of isolation gowns, creating an increasing trend respective to each other. This demonstrates that incorporating shredded isolation gowns helps in improving the overall quality of the blended concrete composites. This is most likely the result of the polypropylene/polyethylene isolation gowns aiding in the bond formation between the cement and aggregates, thereby limiting the microcracking in the blended concrete composites.

3.3. Compressive Strength

The results of the compressive strength tests at both 7 and 28-days, containing different concentrations of the SIG, are detailed in Fig. 7. A 7-day result of 42.11 MPa and a 28-day result of 50.34 MPa is shown in the control sample, with an increasing trend developing between samples CM01C to CM03C at both testing periods. The concrete mix denoted CM03C containing 0.03% isolation gowns by volume of concrete led to the highest result throughout the experimental study with a compressive strength of 43.98 and 58.15 MPa at 7-days and 28-days respectively. The presence of the SIG showed an increase in compressive strength of 15.5% at its highest point. The mix designs CM01C and CM02C increased at rates of 1.23% and 4.09% at 7 days and 5.3% and 15.4% at 28 days, respectively, compared to the control mix. It can be determined from the results that CM03C represents the optimum value to include the SIG. Fibre addition in the form of SIG positively affects the compressive strength of the concrete samples. The fibrous material contributes to the concrete by increasing the crack resistance within the mix design. As seen in previous studies [45], Fibre reinforcement has a confinement effect on a simple cement matrix, increasing the load-bearing capacity of the concrete. Therefore, these results imply that the inclusion of SIG helped in improving the compressive strength of the blended concrete composites, which increases with the increase in SIG content. This can be attributed to the crack bridging effect produced by the fibrous content of the SIG having an excellent bond formation with the cement matrix.

3.4. Flexural Strength

Flexural strength results at both 7-day and 28-day are demonstrated in Fig. 8. Results for the experiment were determined by following AS 1012.11 by obtaining a relationship between the load and deflection of the beam. As represented in the figure, an increasing trend can be seen developing between the concrete mixes CM0C to CM03C, showing an increase in flexural strength of 22% and 20.6% at 7-days and 28-days, respectively, at its highest point compared to the control mix. The steady trend in flexural strength development is strongly supported across the board alongside increases in compressive strength and UPV results. The flexural strength test results show that the concrete benefited from incorporating polypropylene (PP) and polyethylene (PE) isolation gowns; this is likely because of aiding in bond formation between the cement paste and shredded gowns, limiting the crack bridging effect under stress. Studies conducted by Liu et al. [46] demonstrate how polypropylene fibres can improve the crack resistance in concrete and, as a result, also improve the durability of concrete incorporated with PP fibres. It has also been noted in previous studies [45,47] that fibre reinforcement in concrete can limit the spread of microcracks and, as a result, increase the overall flexural strength of the concrete.

Fig. 6. 7 and 28-Days UPV results.
samples. Therefore, it can be noted that the use of the PP/PE isolation gowns in concrete has a positive effect on the samples.

3.5. Modulus of elasticity

Outlined in Fig. 9 are the results of the elastic modulus test. The control mix CM0C showed an elastic modulus of 29.24 GPa. The addition of 0.01%, 0.02%, and 0.03% of shredded isolation gowns showed a slight incremental increase in the elastic moduli of the blended concrete composites by 29.82, 32.17, and 32.67 GPa at 28-days, respectively. A similar trend can be seen developing across the 7-day results, whereas the control sample shows an elastic modulus of 24.92 GPa, 0.01% isolation gowns show a slight decrease before the continuing trend develops between 0.02% and 0.03% isolation gowns. The concrete mixes of CM01C, CM02C, and CM03C showed increases in the elastic modulus compared to the control mix at rates of 1.98%, 10.02%, and 11.73% at 28 days, respectively. The 28-day results for the elastic modulus test can be seen following the same increasing trend line in comparison to the UPV test, compressive strength, and flexural strength, further supporting the beneficial impact of the PP/PE isolation gowns. The excellent bond between cement paste and isolation gowns aiding in the crack bridging effect of the concrete composites allows the increase across the elastic modulus. Therefore, it can be stated that the fibrous content of the SIG aids in the bond formation between the material and cement paste which is evidently the main reason that the increase across all mechanical properties is occurring.

4. Conclusions, challenges and recommendations for future work

This study outlined the use of single-use isolation gowns in concrete applications through a series of experiments and material analysis. From the results of the experiments, it is conclusive that:

1. Based on the SEM-EDS analysis, the cement matrix and the shredded isolation gowns formed an excellent bond, with no gap observed at the interface between the shredded isolation gowns and the cement matrix. Therefore, the SEM-EDS analysis built a
solid basis for an enhanced bridging effect between the materials, thus, allowing for improved mechanical properties displayed across all experiments.

2. The inclusion of the shredded isolation gowns allowed for an overall increase across the UPV results compared to the control sample, allowing the overall quality of the concrete to improve. This can be reasoned by the shredded isolation gowns creating a more substantial bond with the cement matrix, thus limiting microcracks and increasing concrete quality.

3. The inclusion of the shredded isolation gowns increased the compressive strength of concrete with all mix designs; the addition of 0.03% isolation gowns by volume of concrete led to an increase of 15.5% compared to that of the control samples. The increasing trend development of compressive strength is closely linked to the increasing quality of concrete, as displayed in the UPV results.

4. Overall, flexural strength properties showed small incremental increases; however, they greatly benefitted from the shredded isolation gowns. This is likely caused by the isolation gowns aiding in the crack bridging effect under stress.

5. The modulus of elasticity was seen following the same increasing trend as all experimental studies previously mentioned; therefore, it can be noted that the inclusion of the shredded isolation gowns could provide excellent beneficial properties when included in concrete applications.

6. Overall, this study demonstrates that PPE medical waste like isolation gowns has a great potential to be used as a secondary reinforcement material in structural concrete.

1. The key challenges for the sustainable adoption of shredded isolation gowns in concrete construction applications would be a steady supply of this waste material and a suitable process to safely decontaminate this waste from harmful bacteria and viruses before handling for construction applications.

1. Detailed long-term mechanical and durability studies incorporating shredded isolation gowns need to be undertaken before it can be accepted by the construction industry.

2. The effect of different sizes of the shredded isolation gowns on the mechanical properties of concrete needs to be investigated.

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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