Journal of Cleaner Production 296 (2021) 126460

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Technical note

Preliminary evaluation of the feasibility of using polypropylene fibres from COVID-19 single-use face masks to improve the mechanical properties of concrete

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ARTICLE INFO

Article history:
Received 21 November 2020
Received in revised form
6 February 2021
Accepted 18 February 2021
Available online 1 March 2021

Handling editor: Prof. Jiri Jaromir Klemeš

Keywords:
COVID-19
Waste management
Face masks
Polypropylene plastic
Polypropylene concrete

ABSTRACT

With the ongoing global pandemic due to Coronavirus (COVID-19), the use of personal protective equipment (PPE), specifically single-use surgical masks, have been on a sharp incline. Currently, many countries are experiencing second and third waves of COVID-19 and as such have resorted to making face masks a mandatory requirement. The repercussions of this have resulted in millions of single-use face masks being discharged into the environment, washing up on beaches, floating beneath oceans and ending up in vulnerable places. The global pandemic has not only affected the economy and health of the world's population but now is seriously threatening the natural environment. The main plastic in single-use face masks is polypropylene which in landfill can take more than 25 years to break down. This paper explores an innovative way to use pandemic waste in concrete construction with the main focus on single-use face masks. Single-use masks have been cut-up by first removing the ear loops and inner nose wire to size and spread throughout five different mix designs to explore the possible benefits and uses within concrete. The masks were introduced by volume at 0% (control), 0.10%, 0.15%, 0.20% and 0.25% with testing focusing on compressive strength, indirect tensile strength, modulus of elasticity and ultrasonic pulse velocity to test the overall quality of the concrete. The introduction of the single-use face masks led to an increase in the strength properties of the concrete samples, as well as an increase in the overall quality of the concrete. However, beyond 0.20%, the trend of increasing strength began to decrease.

1. Introduction

With the ongoing global pandemic due to COVID-19 continuing through the majority of 2020, conservationists have warned that it may cause a spark in the already ongoing issues of environmental pollution (Boroujeni et al., 2021). Currently, divers have been finding vast quantities of pandemic type waste such as rubber gloves, single-use face masks and hand sanitiser bottles floating beneath the surface of the ocean (Roberts et al., 2020). With the World Health Organisation (WHO) introducing certain guidelines during the pandemic including the use of personal protective equipment (PPE) such as face coverings, the environmental impacts are only set to worsen as the majority of the masks are ending up in the streets or landfill (Saberian et al., 2021; Sangkham, 2020). The most popular single-use face mask being currently used are made from plastic polypropylene (Henneberry, 2020) with dozens washing up onshore across the globe long before the WHO set the guidelines (Roberts et al., 2020). Currently face coverings are being recommended on a global scale with them being mandatory in more than half of the world's countries (Royo-Bordonada et al., 2020). Although there have been some short-term positive environmental effects due to the outbreak of COVID-19 such as lower carbon emissions in China (Bao and Zhang, 2020) and the decrease in air pollution throughout New York (Hiscott et al., 2020), there are still severe environmental impacts being caused as a result of the COVID-19 pandemic. It is estimated that currently, Africa is consuming seven hundred million single-use face masks daily whilst in Asia that number is pushing 2.2 billion daily with an

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https://doi.org/10.1016/j.jclepro.2021.126460
0959-6526/

approximate of 468 tons of COVID-19 related waste being generated daily in China (Nzediegwu et al., 2020; Rowan and Laffey, 2020; Sangkham, 2020; Peng et al., 2020). Polypropylene, the main type of plastic used in single-use surgical masks is a thermoplastic polymer that takes more than 25 years to breakdown in landfill (Thomas, 2012); however, when the single-use masks end up in our waterways they are turned into microplastics that then enter our delicate ecosystems and potentially end up in our food sources (Mavrokefalidis, 2020). Thus, the effects of the global pandemic are not only severely impacting our economy but will continue to impact day to day lives long after the pandemic has ended.

Use of plastic fibres in concrete has attracted attention from the construction industry and academia for some time as plastic fibres hold many sustainability benefits when compared to steel reinforcement. Polypropylene fibres (PP) are widely used throughout the concrete industry due to their mechanical properties such as tensile strength and Young's modulus as well as their ease of production and high alkaline resistance (Yin et al., 2015; Kazemi et al., 2020a & b). Islam and Gupta (2016) undertook an experiment to analyse polypropylene fibre reinforced concrete. Varying volumes of polypropylene were included into the concrete mix between 0% and 0.3% (by volume of concrete) with compressive strength showing a slight decrease over the testing period with the most being a 10% decrease with the addition of 0.30% polypropylene fibres by volume. Although compressive strength showed a decrease, splitting tensile strength had a remarkable improvement when incorporated with polypropylene fibres showing a 39% increase with the inclusion of 0.1% fibres by volume. Xu et al. (2020) conducted similar studies on fibre reinforced concrete and found that the compressive strength of concrete increased by up to 12% when cellulose fibre (CTF) was used in dosages of 1.5 kg/m^3, however when compared to polyvinyl alcohol fibre (PF) the compressive strength shows a decrease by 35% when the dosage was around 4.0 kg/m^3. The splitting tensile strength of CTF at the same dosage shows a decrease of 23% where PF had visible decreases of 55% splitting tensile strength and polyolefin fiber showing signs of decreasing splitting tensile strength when the dosage was 2.0 kg/m^3. Pesic et al. (2016) conducted research to investigate the potential benefits of the use of recycled high-density polyethylene (HPDE) fibres in structural concrete; the research evaluated the mechanical properties of concrete through a series of different specimens. Apart from a control mix, two fibre diameters were tested with HDPE included by volumes at 0.40%, 0.75% and 1.25% for each diameter of the fibre. They noted that the compressive strength and Young's modulus were unaffected; however, flexural and tensile strength increased about 3% and 14% when HPDE fibres were included into the concrete mix at 0.40% and 1.25%, respectively. Al-Hadithi and Hilal (2016) also studied the impact behaviour of self-compacting concrete (SCC) by adding waste plastic fibres that had been generated from beverage bottles. Waste plastic fibres were introduced into a control mix in different volumetric percentages between 0% and 2%. Tests on flexural and compressive strengths were conducted at 7, 14 and 28 days during the experiment. Al-Hadithi and Hilal (2016) states that the compressive strength increased across all mixes with the inclusion of WPF when compared to the control mix with compressive strengths at 7, 14 and 28 days being between 46 and 56 MPa, 51–68 MPa, and 53–77 MPa, respectively. It should also be noted that the flexural strength improved across all mix designs and benefited from the inclusion of waste plastic fibres.

Although waste plastics have been already considered for concrete constructions, to the best knowledge of the authors, this is the first attempt to use polypropylene-based face masks in concrete. The main aim of this study is to investigate the feasibility of recycling and reusing of single-use face masks in a bid to limit the amount of pandemic-generated waste ending up in landfill or littering the streets during this ongoing crisis. The effects of polypropylene fibres from COVID-19 single-use masks on the mechanical properties of concrete were evaluated through a series of experiments.

2. Materials and methods

2.1. Materials

A total of five concrete mixes were used for testing the samples incorporated with cut-up surgical masks in proportions of 0% (control mix), 0.1%, 0.15%, 0.2% and 0.25% by volume of concrete. This range is consistent with previous studies of Al-Hadithi and Hilal (2016), Xu et al. (2020) and Sadiqul Islam and Gupta (2016). GP Eureka cement conforming to AS 3972 (2010) with a specific gravity of 2.8–3.2 and a bulk density of 1200–1600 kg/m^3 was utilised throughout the experiments as well as coarse aggregate with a nominal size of 9.5 mm and fine aggregate with a specific gravity of 2.65 that had been oven-dried at 110° Celsius for a period of 48 h to remove excess moisture, together with a superplasticiser. Sika Plastiment 10 was the preferred water reducer for the experiment with 300 mL being added per 100 kg of cementitious materials. Fig. 1 shows the particle size distribution curves of coarse and fine aggregates, whilst Table 1 outlines the properties of the cement used. The X-ray fluorescence (XRF) and X-ray powder diffraction (XRD) results of the cement are provided in Table 2 and Fig. 2, respectively. It is worth mentioning that the XRF test was conducted using Bruker AXS S4 Pioneer X-ray fluorescence instrument. Besides, XRD was conducted on the oven-dried powder of cement using Bruker AXS D4 Endeavour equipped with a lynxeye linear strip detector and Cu-Kα radiation, operated at 40-kV voltage and 40-mA current. The cement was tested between 5° and 70° 2-theta (2θ) with a step size of 0.01° and counting time of 1 s per step.

A few disinfectants and sterilisation methods have been recommended for cleaning the used face masks. For example, Hamzavi et al. (2020) suggested using ultraviolet germicidal irradiation (UVGI) for the inactivation of SARS-CoV-2 from the used masks. Lowe et al. (2020) demonstrated that UVGI could inactivate a large number of human pathogens, including coronaviruses, on N95 masks. Xiang et al. (2020) recommended the dry heat method for disinfecting and sterilising the face masks by heating the masks at 70 °C for 1 h. Doan (2020) reported that the microwave method which used 0.9% physiological saline to spray the used masks and then heated the masks in an 800 W microwave for about 1 min could destroy 99.9% of viruses. However, under the current stage of COVID-19 restrictions, we are not allowed to adopt the used face masks in this study. To limit community transmission and risk of infection from COVID-19, new, unused surgical masks were utilised in this study. Masks were cut-up into small pieces with the length and width of 2 cm and 0.5 cm, respectively. Table 3 outlines the physical properties of the single-use surgical masks.

2.2. Mix proportions

Table 4 outlines the mix design utilised to cast the samples and the varying percentages of surgical masks used. CM0 denotes the control mix containing 0% surgical masks similarly to CM25 denoting concrete containing 0.25% content by volume.

2.3. Casting and curing

To prepare the samples for casting, the concrete moulds were lubricated with mechanical fluid to aid in removal from the

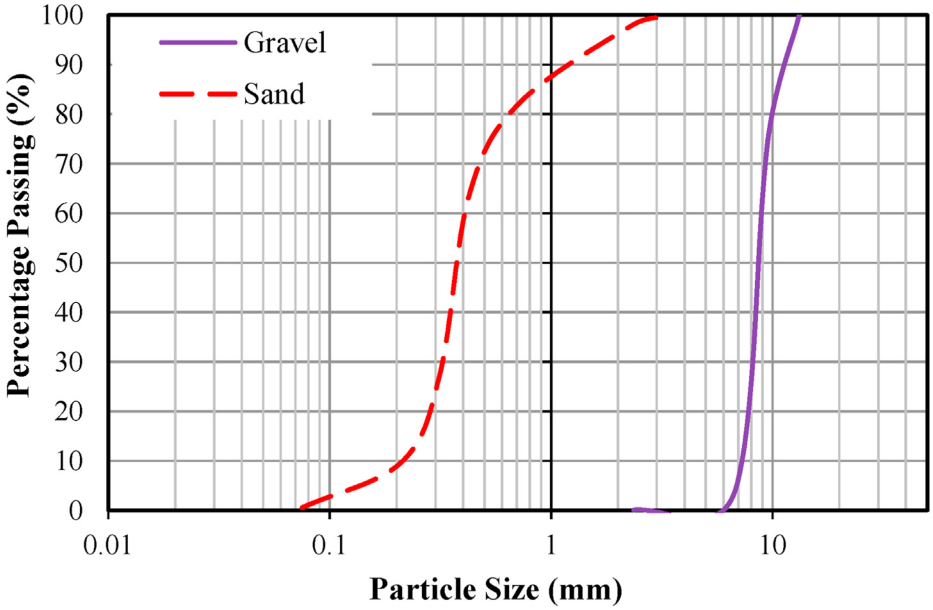

Fig. 1. Particle size distribution curves of fine and coarse aggregates.

Table 1
Eureka GP cement properties.

Ingredient	Formula	Proportion
Portland cement clinker	Not available	>92%
Limestone	$CaCO_3$	0–7.5%
Gypsum	$CaSO_4.2H_20$	3–8%
Clinker Kiln dust	Not available	0–2.5%
Chromium (VI) hexavalent	Cr^{6+}	Trace amounts

Table 2
XRF results of GP Eureka cement.

Oxides	Cement
CaO	69.5%
SiO_2	17.4%
Al_2O_3	3.9%
Fe_2O_3	3.3%
SO_3	2.9%
MgO	1.4%
P_2O_5	0.5%
K_2O	0.5%
TiO_2	0.3%
Na_2O	0.2%
MnO	0.1%
ZnO	0.1%

cylinders. To make the samples for Young's modulus and compressive strength tests, 100 mm (D) x 200 mm (H) cylinders were used as per AS 1012.17 (1997) and AS 1012.8.1 (2014), respectively. For the indirect tensile strength test, 150 mm (D) × 300 mm (H) cylinders were used as per AS 1012.10 (2000).

Initially, all the dry material was weighed up and placed into the concrete mixer and allowed to mix for a period of 3 min. After 3 min, the superplasticiser was mixed with the water then slowly added to the dry materials and allowed to mix for a further 3 min. During this time, the pieces of the shredded face mask were added into the mix slowly and in small amounts to allow for even distribution and to avoid clumping together. The concrete was then extracted from the concrete mixer and transferred into the cylindrical moulds. The cylindrical moulds were topped up with concrete and placed on the vibrating table for a period of 20 s to allow the concrete to settle. After the initial 20 s, the moulds were then topped up with the concrete again and allowed to vibrate for a further 20 s to ensure the moulds were filled up with no voids. This process was repeated for all concrete mixes. Similar procedures for casting were utilised in previous studies (Al-Hadithi et al., 2019; Al-Hadithi and Hilal, 2016; Sadiqul Islam and Gupta, 2016).

After curing for a period of 24 h, the concrete samples were removed from the cylindrical moulds and placed in a curing tank with clean, fresh water and allowed to cure for the remainder of the 28 days at an approximate temperature of 22 °C. Similar methods were utilised in previous studies (Sadiqul Islam and Gupta, 2016; Al-Hadithi et al., 2019). After 28 days of curing, the concrete samples were removed from the curing tank and allowed to dry. After samples were allowed to air dry, the top of the cylindrical samples was ground back to allow for a smooth contact surface with the machines utilised for compression and Young's modulus testing in accordance with AS 1012.0 (2014).

2.4. Testing procedures

Compressive testing was conducted in accordance with AS 1012.9 (2014), with a force of 157 kN/min applied to the samples. The capacity of the compression testing machine is capped at 1000 kN. Three samples per mix design were tested to reduce any error. Young's modulus was conducted in accordance with AS 1012.8.1 (2014), with a mean value set at 40% of the average compressive strength. Three samples per mix design were tested to reduce any error. Testing was recorded as per AS 1012.8.1 (2014) with the machine utilised for testing having a maximum capacity of 3000 kN.

Indirect tensile testing was conducted following AS 1012.10 (2000) with a rate applied at 1.5 ± 0.1 MPa per minute in the same machine as compression testing had taken place with a capacity of 1000 kN. Three samples per mix design were tested to reduce any error. Ultrasonic Pulse Velocity (UPV) testing was conducted on compression samples in accordance with ASTM C597-16 (2016). The test is applicable to assess the relative quality and uniformity of concrete samples, assisting with the determination of

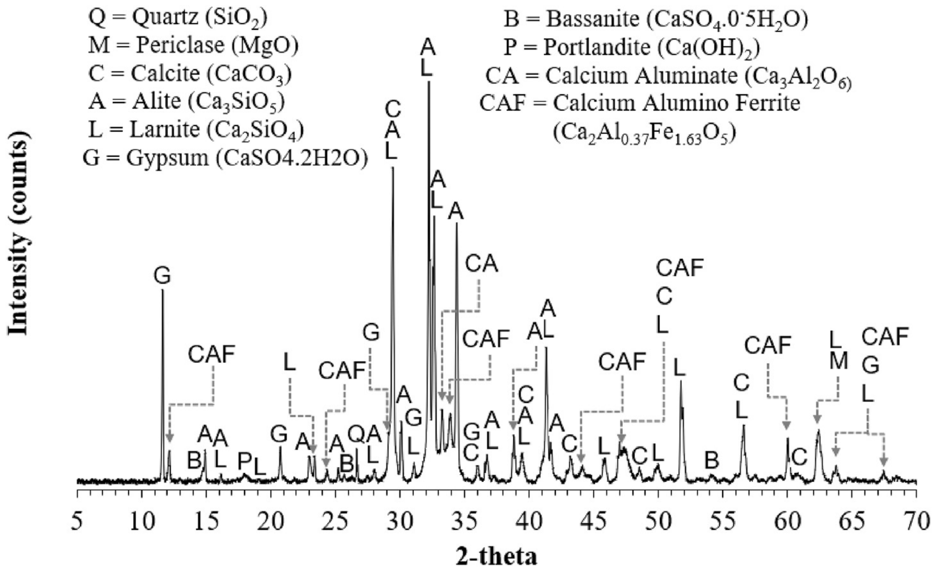

Fig. 2. XRD of GP Eureka cement.

Table 3
Physical properties of single-use surgical masks.

Physical properties	SHM	Standard
Specific gravity	0.91	ASTM D792-20 (2020)
Melting point (°C)	160	ASTM D7138-16 (2016)
Water absorption 24 h (%)	8.9	ASTM D570-98 (2018)
Tensile strength (MPa)	4.25	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 4
Concrete proportions and mix design.

Materials (kg/m^3)	CM0	CM10	CM15	CM20	CM25
Water	210	210	210	210	210
Cement	420	420	420	420	420
Coarse Agg.	1260	1260	1260	1260	1260
Fine Agg.	630	630	630	630	630
Superplasticiser (mL/m^3)	1260	1260	1260	1260	1260
Surgical Masks	0	3.70	5.55	7.41	9.26

cracks and voids that may not be visible to the surface.

3. Results and discussion

3.1. Compressive strength

Fig. 3 shows the compressive strength results of the samples. The control mix for the experiment showed a 28-day compressive strength of 54.4 MPa; however, as seen in Fig. 3, the best result was prevalent with a 0.2% addition of the shredded face masks by volume. Volumes between 0.10% and 0.20% demonstrated a steady increase in compressive strength before dropping off slightly at 0.25% when compared to the control mix sample. Samples showed an increase between 3.81% and 17.06% from volume additions of 0.10%–0.20% with the 0.25% sample showing an increase of 16.43% compared to the control sample. Therefore, the results outlined above confirm that the inclusion of shredded face masks in concrete had an evident influence on the compressive strength of the concrete mix. Similar results in compressive strength are shown by (Xu et al., 2020) where the inclusion of various plastic fibres showed an increase in compressive strength up to a certain point where the compressive strength then began to decline. As seen in previous studies by (Nili and Afroughsabet, 2010), the increase in compressive strength with the addition of polypropylene fibres can be attributed to the crack restriction effect of the fibre. Similarly, the decreasing trend at 0.25% volume of fibres can be due to the presence of voids at 0.25% volume replacement and the existence of weakening interfacial bonds between the cut-up masks and the cement as seen in the study of Mohammadhosseini et al. (2017).

3.2. Ultrasonic pulse velocity (UPV)

Fig. 4 outlines the results from the UPV test. As seen from the results, UPV steadily increased as the mask content by volume increased until the volume passes 0.20% there was a slight decrease after that at 0.25% volume. Like compressive strength results, the 0.20% volume of mask content is seen to show the best results. According to Şimşek et al. (2019) and Khatib et al. (2019), concrete with a UPV result greater than 4500 m/s is considered to be very good to excellent concrete, with a high-quality grade. Once again, the quality of the concrete dropped down at the 0.25% volume rate; however, it is due noted that the quality of the concrete showed an increase across all mix designs when compared to the control specimen for the experiment, therefore, showing beneficial properties. It was stated by Yap et al. (2013) that a good quality concrete in between the above ranges implies that the concrete specimen does not have any large voids or cracks; therefore, it can be hypothesised that the inclusion of the shredded face masks limited the amount of microcracks in the concrete as demonstrated in studies by Shen et al. (2020); thus improving the overall quality of the concrete.

3.3. Indirect tensile strength

As can be seen in Fig. 5, the control mix showed a 3.27 MPa for indirect tensile strength with the best results (3.67 MPa) observed at 0.20% mask content by volume similar to that of compressive strength and UPV results. Overall the samples showed an increase between volumes from 0.10% to 0.20% with a slight drop off in

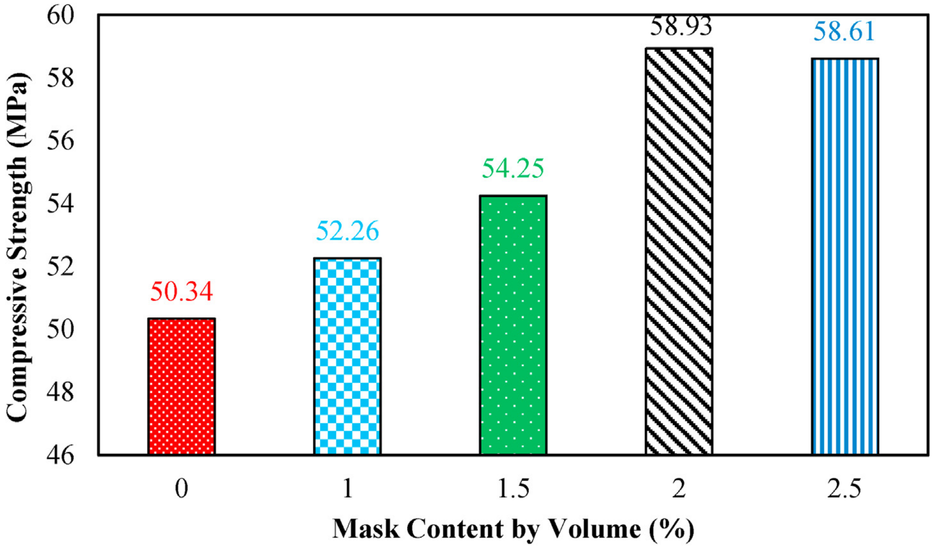

Fig. 3. 28-day compressive strength results.

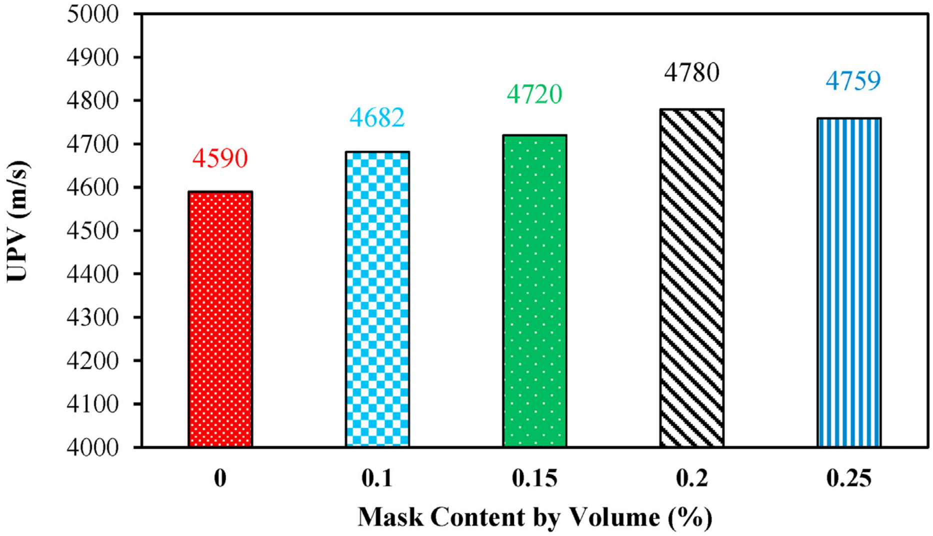

Fig. 4. UPV results.

indirect tensile strength at 0.25%; however, it should be noted that the 0.25% volume of shredded face masks still shows a higher indirect tensile strength when compared to the control mix. Overall, the range between 0.10% and 0.20% showed an increase in indirect tensile strength between 1.53% and 12.23% respectively, while the 0.25% sample provided an increase of 7.65%. As previously mentioned, the increasing quality of the concrete outlined in the UPV results could allow the indirect tensile strength to show increases in similar ranges. The results of the indirect tensile strength show that the concrete clearly benefited from the inclusion of the single-use face masks showing a steady increase in strength. Similar to Al-Hadithi and Hilal (2016), with the increase in single-use face mask fibres, the fibres become more densely spaced which therefore would allow and result in an increase to both compressive and indirect tensile strengths. The increase in indirect tensile strength can also be attributed to the fibrous content of the masks supporting the full tensile stress as seen in studies by Mohammadhosseini et al. (2017), where the transferred stress of the fibrous polypropylene mixes enhanced the tensile capacity of the concrete mix.

3.4. *Young's modulus*

Young's modulus results are provided in Fig. 6. The control mix for Young's modulus test was tested to be 29.24 GPa with a relatively unaffected Young's modulus throughout other samples as outline in Fig. 6. The range across all samples was between the values of 28.65 and 30.95 GPa with a sway from the control mix of −1.9%–5.86%, which can be determined as a negligible change as there is no significant variation to the modulus of elasticity. However, the test on Young's modulus is not on the same trend as other mechanical properties. This could be due to the low volume of single-use surgical masks used within testing. Although the results are not on the same trend as compressive strength and indirect tensile strength, the modulus of elasticity is still within the range of what should be expected for concrete. Similar to the results reported by Xu et al. (2020), the elastic modulus is similar to that of plain concrete demonstrating as a linear elastic material, naturally

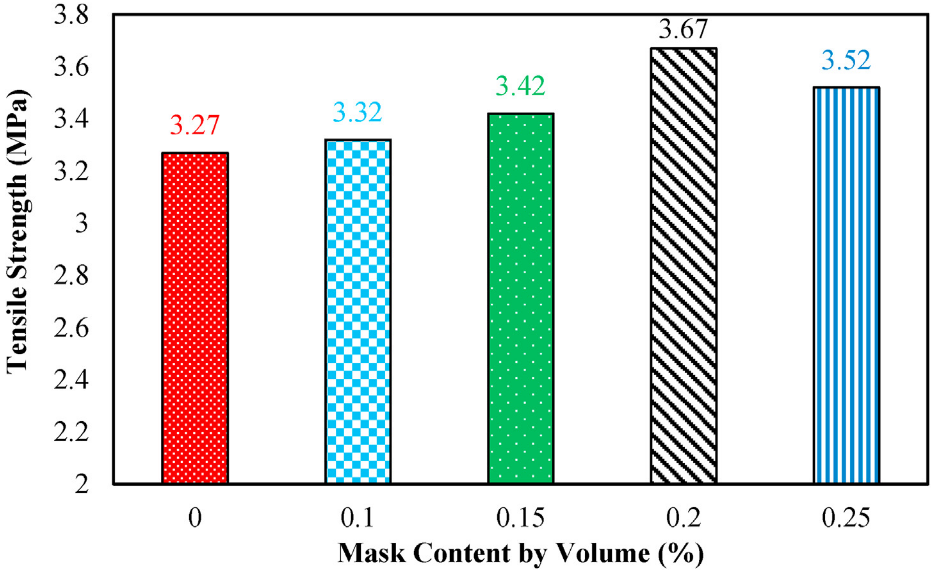

Fig. 5. 28-day tensile strength results.

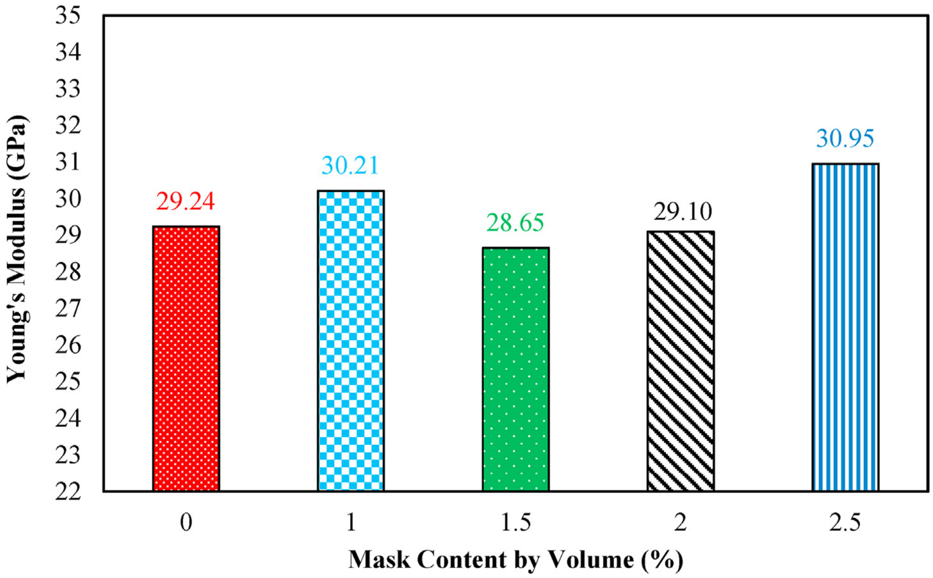

Fig. 6. 28-day Young's modulus results.

returning to an undeformed state post-testing. Thus, with such small increments regarding the elastic modulus, it can be confirmed that the single-use face mask fibres have no apparent influence on the modulus of elasticity. Similar results were reported in a study conducted by Pesic et al. (2016), where the plastic fibres utilised in the study had no significant effect on the modulus of elasticity.

4. Conclusion

In this study, a new and low carbon strategy is proposed to reduce pandemic-generated waste. For the first time, a series of experiments were conducted to study the effects of incorporating the shredded face masks on the mechanical properties of concrete. From the results obtained in this study, it can be concluded that:

- The use of single-use face masks at small percentages has the capability to increase some of the mechanical properties of concrete.
- A steady trend was seen across compressive and indirect tensile strengths showing that 0.20% volume of single-use surgical masks was the ideal percentage to incorporate into the concrete. The increase can be noted by the fibres becoming more densely spaced, which therefore resulted in an increase to both compressive and indirect tensile strengths.
- The use of single-use face masks improved the overall quality of the concrete when compared to the control mix under UPV results. The fibres of the cut-up face masks limited the number of micro-cracks in the concrete, therefore improving the overall quality of the concrete.
- The modulus of elasticity could be deemed unaffected when incorporating the shredded face masks into the concrete mix.

- Regardless of the volume content of cut-up face masks, all concrete mixes fall under the banner of high quality, good concrete, and maintaining strengths to a structural standard.
- Incorporating of the single-use face masks in concrete production has the potential to show great environmental benefits by removing them from the landfill lifecycle.

CRediT authorship contribution statement

Shannon Kilmartin-Lynch: Methodology, Validation, Investigation, Writing – original draft, Data curation, Formal analysis, Visualization. **Mohammad Saberian:** Methodology, Validation, Investigation, Writing – review & editing, Data curation, Formal analysis, Visualization. **Jie Li:** Conceptualization, Writing – review & editing, Resources, Validation, Supervision, Project administration, Visualization. **Rajeev Roychand:** Writing – review & editing, Visualization, Validation, Data curation. **Guomin Zhang:** Writing – review & editing, Validation, Visualization.

Declaration of competing interest

We declare that we have no direct/indirect competing financial, general, institutional, or personal interests that might have influenced the performance or presentation of the work described in this manuscript.

Acknowledgements

The authors gratefully acknowledge the RMIT X-Ray Facility for providing training and excess to the X-ray facilities. The authors would also like to acknowledge the generous support of the Lowitja Institute, Australia's national institute for Aboriginal and Torres Strait Islander health research.

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