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Using plastic waste in construction: Recycled medical equipment to improve concrete

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***Abstract*— Urbanization and the evolution of people's lifestyles have a significant impact on the quantity of waste that is generated and dumped each year. In addition, due to the emergence of the COVID-19 pandemic, the use of masks has increased significantly, and the amount of plastic waste generation worldwide has doubled. The main component of Protective Suits (PS) and Disposable medical face masks (DMFM) is polypropylene plastic, which will end up contaminating the natural environment given the poor management of this kind of waste and will not decompose for hundreds of years. Faced with both increasing amounts of generated plastic waste and the growing interest in sustainability, the construction sectors can take advantage of this situation using recycled plastic waste to improve concrete properties such as compressive and splitting tensile strength to reduce the negative impact of the generated plastic waste, while meeting future infrastructure demands. The purpose of this paper is to address the massive plastic waste that increased during the pandemic by analysing an alternative material for infrastructure buildings that incorporates this kind of waste.**

Keywords: Plastic Waste, Construction, Construction Material, Recycling, Safety, Sustainability, Environment

I. Introduction

Due to the ongoing pandemic, plastic-based personal protective equipment (PPE) for frontline health workers, as well as face masks for the general public, have been used to combat the spread of COVID-19 [1]. Face shields, surgical masks, protective suits, N95 respirators, and surgical gloves are examples of standard PPE [2]. During such an outbreak, a significant amount of PPE was produced. Every month, it is estimated that 129 billion masks and 65 billion gloves were used over the world [3].

Although protective items have been key to the recovery efforts, the widespread use of PPE will bring serious environmental consequences. Disposable personal protective suits (PS) and face masks (DMFM) are a crucial part of PPE. However, such materials are not easily biodegradable because they have a higher volume and quality than general PPE, and may persist in the air, soil, or sea, posing significant risks to human and animal health [4]. As a result, the global pandemic has had a significant impact on the environment that will continue to disrupt our daily lives even after the pandemic is over [5]. However, this situation can be balanced by the high recycling value of these materials in a field that bears little connection with the medical one: the construction industry.

Concrete is the most common construction material used in the building industry. On average, approximately 1 ton of concrete is produced each year for every human being in the world. The production of 1 m³ (2.4 ton) of concrete requires 2,775 MJ of energy. This energy comes mostly from oil burning, which generates CO2. 2.775 MJ of energy is produced by 0.37 barrels of oil. [6].

The inclusion of recycled plastic in concrete reduces the dead loads of structures and the cost of its manufacturing [7]. Assuming that incorporating these aggregates to the concrete mix will reduce the amounts of cement required, the energy consumed will also decrease.

As this issue impacts on global scale, addressing it would help achieve two of the objectives of Sustainable Development Goals (SDG) 2030 Agenda: 11. Sustainable cities and communities, and also, 12 Responsible consumption and production since the installation and construction of buildings demands large amounts of concrete.

The aim of this paper is to introduce an alternative material for infrastructure building that incorporate plastic waste. To achieve this in the present work a comparison of two papers in which concrete was tested with the addition of medical equipment will be carried out. The first one was developed at the City University of Hong Kong [8], and the second at the School of Civil Engineering and Architecture, Anhui University of Science and Technology, China [9].

The discussion begins by presenting global statistics about the environmental impact of DMFM and PS. In the second place, the processes to obtain the polypropylene fibres which will bond inherently with the cement will be compared. Then, a comparison of the mix designs and the amounts of materials used in both of them is carried out. Finally, the main tests and an analysis of the results will be developed.

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II. Current Statistics and Environmental Impact of DMFM and PS

In order to magnify the quantities of PPE consumed and discarded in the last years, the following statistics are presented below.

A. DMFM and PS Consumption in Major Regions

As illustrated in [10, Fig 1a] the environmental footprints of PPEs for three main countries in 2019 and 2020 are presented. For disposable gowns, the quantity of imports has soared for the United States (606%), France (6209%) and the United Kingdom (606%). Similarly, for surgical masks, the import quantity increased dramatically for the USA (415%), France (1207%), and Germany (838%),[10, Fig 1b].

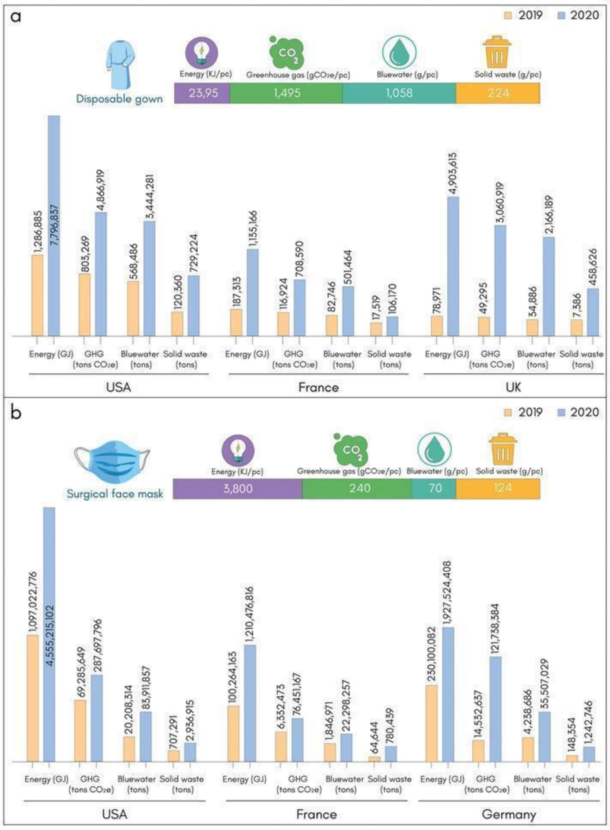

Fig. 1. Environmental impacts of personal protective clothing. Environmental impacts are calculated and compared based on import data for three major countries in 2019 (Pre-COVID-19) versInus 2020 (during COVID-19). [10]

B. *Statistics of Masks Waste*

To determine current DMFM waste statistics and the associated environmental challenges, the number of daily discarded face masks for world regions including Asia, Africa, Europe, Latin America, the Caribbean, North America and Oceania is estimated. Based on the latest population statistics reported by Worldometer [11], [12] and [13], the total daily number of discarded facemasks was calculated using the following equation [12, eq. (1)].

$$Daily\ waste = 1x10^{-4}x\ (P_{Total}x\ P_{Urban}x\ A\ x\ B)$$

Equation. 1. Daily number of discarded facemasks [14]

where PTotal, PUrban, A, and B, represent the total population of each region, the urban population of each region, the facemask wearing acceptance rate, and daily per person usage of facemasks, respectively.

Data for PTotal and PUrban were obtained from Worldometer [7], the facemask wearing acceptance rate (A) and daily per person usage of facemasks (B) were chosen as 80% and 1, respectively [10], [11]. According to the statistics shown in [11, Fig 2] the current daily estimated number of DMFMs is approximately 3503.7 million worldwide. Asia is currently the largest source of global waste DMFMs (1889.8 million daily), followed by Africa (469.7 million), Europe (445.6 million), Latin America and the Caribbean (431.6 million), North America (243.7 million), and Oceania (23.1 million) as shown in [11, Fig 2].

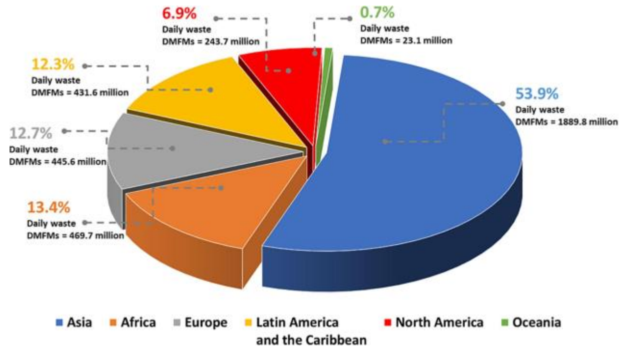

Fig. 2. Current estimated daily DMFM waste in different regions of the world, based on latest Worldometer data [9].

III. Application of Plastic Waste in Concrete

The opportunity to make use of these large amounts of plastic waste is presented by the application of these residues in concrete. In order to use them, they must go through a process in which the polypropylene fibres (PF) are obtained so they can adhere to the other materials of the mix, creating a cohesive mass. This will lead to better properties of the concrete such as strength and homogeneity.

A. *Processes to Obtain the Polypropylene Fibres*

To point out the differences between the processes of the two experiments, the main variation is that, in the first one [8], the polypropylene fibres are obtained from DMFMs, while in the second one [9] they are obtained from PS. In both cases, they were new and uncontaminated in order to reduce the risk of virus leakage. Zippers, elastics, metal nose wire frame and two ear-straps were removed to ensure homogeneity of the fiber material.

The geometrical shape of the samples are similar in the two experiments, in [8] the size of the fiber was 20x5mm [8, fig 3a] while in [9] the dimensions were 20x4mm [9, fig 4]

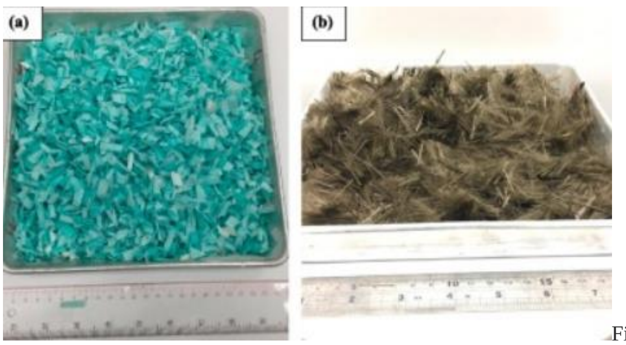

Fig. 3.Sample of fiber material used in this study. DMFM fiber. [8]

Fig. 4.Sample of fiber material used in this study. PSF stacking morphology. [9]

The material shown in [8, fig 3b] is the basalt fiber (BF) which is compositionally similar to glass fibers and is produced from naturally occurring basalt rocks [15] which makes it an environmentally friendly and sustainable fiber material requiring less energy resources and no additives during production [16]. These fibers were added in [8] experiment only and this may lead to differences between the testing results.

B. *Mix Design, Casting Procedures and Specimen-Making*

The mixtures made in the analysed tests present differences that are essential to highlight as they will cause differing results. The constituent materials of the experiment [9] are Ordinary Portland cement (OPC), two minerals admixtures used as binders, river sand from Hong Kong as natural fine aggregate, crushed stone and recycled concrete aggregate as the natural coarse aggregate; and a small dosage of superplasticizer was added to compensate for the low workability. The ratio of water to binder was maintained at 0.42 for all formulations.

To assess the combined effect of DMFM fiber and BF in fiber-reinforced recycled concrete (FRAC), ten concrete mix formulations were considered in this research study. The mix formulation designated as M0 was the control formulation, consisting of only concrete constituent materials and no fibers. The M0 mix was used as a reference for modified formulations M1–M9. All other mix formulations are specified in [9, tab. 1].

Mix ID	Fiber dosage (%)		Binder (kg/m^3)		
	DMFM fiber	Basalt fiber	OPC	FA	GGBFS
M0	0.00	0.00	489	–	–
M1	0.00	0.00	391	33	65
M2	0.10	0.00	391	33	65
M3	0.20	0.00	391	33	65
M4	0.00	0.25	391	33	65
M5	0.10	0.25	391	33	65
M6	0.20	0.25	391	33	65
M7	0.00	0.50	391	33	65
M8	0.10	0.50	391	33	65
M9	0.20	0.50	391	33	65

Tab. 1.Details of concrete mix formulations used in this study; 'OPC' represents ordinary Portland cement, 'FA' represents fly ash, 'GGBFS' represents ground granulated blast furnace slag. [9]

In the second experiment [9] the materials used are P·C 42.5 composite Portland cement, ordinary river sand as a fine aggregate and the coarse aggregate is crushed limestone with continuous particle gradation. The water-reducing admixture employs a high-performance water-reducing liquid with an effectiveness of 30% to assure the fluidity and water retention of concrete. The designed concrete water–cement ratio is 0.4 and the designed compressive strength is 40 MPa.

According to the different amounts of PSF content, six different mixes were designed, and the volume replacement rates of PF in concrete were 0, 0.2%, 0.4%, 0.6%, 0.8%, and 1.0% as it is shown in [10, tab. 2].

Group Number	PSF (% by Volume)
PS0	0
PS2	0.2
PS4	0.4
PS6	0.6
PS8	0.8
PS10	1.0

Tab. 2. Mixing proportions of the experiment (kg/m3). [9]

C. *Testing and Results*

To evaluate the effect of the fibers on the physical and mechanical properties of the FRAC, a series of laboratory experiments were conducted. Because of its importance in the Civil Engineering applications, emphasis will be put on the compressive strength tests.

The evaluated samples in [8] were concrete cylindrical specimens with height and diameter of 200 mm and 100 mm, respectively, and were tested according to standard ASTM C39 [18] procedure as it is shown in [8, Fig. 5].

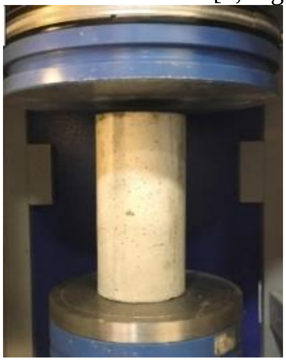

Fig. 5. Compressive loading strength test [8].

The compressive strength of the samples is presented in [8, Fig. 6]. It is evident that the strength of recycled concrete gradually increases with the use of fiber materials and mineral admixtures. Of all samples, M8 has the highest strength value (51.1 MPa), representing a 12.1% increase compared to the reference sample. However, M9 shows a slight reduction in overall improvement, possibly due to improper concrete mixing resulting from the high fiber dosage [18]. Nevertheless, it is still higher than the reference sample.

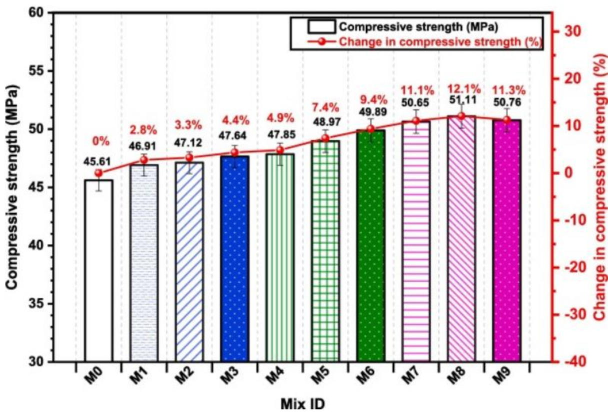

Fig. 6. The bar chart shows the compressive strength (MPa) of concrete samples (left axis); the line graph shows the change in compressive strength (%) of concrete samples (right axis).[9]

As regards the second experiment [9], the shape of the samples were cubic and their dimensions were 100x100x100 mm as illustrated in [9, fig 7], and three specimens were evaluated for each mix design to remove the probable experimental error.

Figure. 7. Compressive loading strength test [10]

[9, Fig. 8] summarizes the results from the concrete compression test. As it is represented, when PF were just added, due to few amounts, they may be unevenly distributed in the concrete, and the strength decreased to a certain extent. Then, with the gradual increase in the volume content of PF, the positive effect of fibers on the compressive strength of concrete began to appear. However, when a certain critical value is reached, continuing to increase the content will result in a decrease in strength.

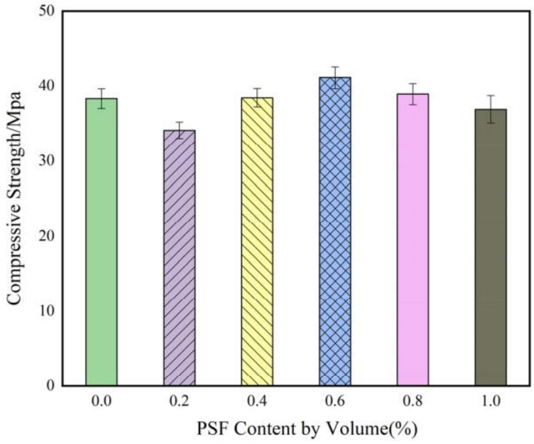

Figure. 8. Concrete compressive strength with different PF content [9].

IV. Analysis of the Research

This study provides a new possibility to solve the medical waste generated by COVID-19. From the results obtained in this study, it can be concluded that:

- The inclusion of PF improved the compressive strength of concrete. The mechanical properties of concrete containing fibers have been significantly enhanced because of the influence of fibers in transferring stress, absorbing energy, and confining behavior on cracks.
- Applying COVID-19 protective suits and masks to the production of high-quality concrete has the potential to show great environmental and economic benefits. The findings of this paper may help in the management of COVID-19 medical waste.
- Despite using new masks and protective suits in the mentioned experiments, the improvements in the concrete properties will be the same if the equipment were recycled. The only requirement is that the materials have to be cleaned and sanitized before starting the process.
- As a comparison between the experiments, we can conclude that adding PF to the concrete leads to a slight improvement in the compressive strength. Nevertheless, its performance can be increased by adding minerals and basalt fibers as it was proven in [9].

V. Conclusion

This article presented a comparison between two papers in which the application of recycled plastic in concrete was evaluated. The improvement of concrete properties was tested and verified. The amount of discarded an unrecycled DMFM and PS that can be used in concrete were mentioned.

This study did not take into consideration the disinfection process required for recycled equipment nor was tested on in-service structure that could lead to more complexities.

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