Reutilizing Single-Use Surgical Face Masks to Improve the Mechanical Properties of Concrete: A Feasibility Study

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ABSTRACT

The coronavirus outbreak (COVID-19) has caused a sharp increase in the use of Single-Use Surgical Face Masks (SUSFMs) as personal protective equipment. These eventually end up in waste disposal facilities causing environmental pollution. Those that end up in the water bodies fragment into microplastics that affect marine life. Since the SUSFM materials are made from polypropylene, a thermoplastic polymer material that takes a long time to degrade, it is important to develop sustainable mitigation measures to remove them from the environment. This study investigated the feasibility of reutilizing SUSFMs in concrete. SUSFMs were shredded and added to C30/37 grade concrete in various percentages, 0%, 0.5%, 1.0%, 1.5%, 2.0%, 2.5%, and 3.0%, by mass of cement content. The specimens were cured for 28 days before being tested for compressive strength, splitting tensile strength, and ultrasonic pulse velocity. The compressive strength decreased with an increase in the length and dosage content. The least decrease of 10.4% was observed at 0.5% content of 30mm length of SUSFM material. The results showed that concrete improved regarding splitting tensile strength, with the highest increase of 15.2% at 0.5% content of 30mm SUSFM. In addition, the overall quality of concrete remains at UPV values of more than 4000m/s registering good quality concrete. The results underscore the use SUSFM material in concrete in order to improve its quality while at the same time reducing waste.

Keywords-covid-19; polypropylene; surgical face masks; personal protective equipment

I. INTRODUCTION

With the outbreak of coronavirus disease (covid-19), a sharp increase in the use of Single-Use Surgical Face Masks (SUSFMs) occurred globally [1]. The daily use of SUSFMs in Africa and Asia is currently over 700 million pieces and 2.2 billion pieces, respectively [2]. In June 2020, it was estimated that the SUSFMs that were discharged into the environment every month were 129 billion pieces [1]. With the use of the model developed in [2], 6.9 billion pieces, or 0.2 million tons of SUSFMs are generated globally per day. These eventually end up in waste facilities or water bodies and landfills. The SUSFMs are mainly made from polypropylene, a thermoplastic polymer, which remains in the environment for a long time (over 25 years) [1]. Those that end up in water bodies fragment into microplastics causing problems to marine life [3] and probably end up in the food chain. Authors in [4] deduced that the effects of this environmental pollution will continue to have an impact on human life long after the Covid-19 pandemic.

In Kenya, the Government made mandatory wearing face masks in public. So, there has been a massive use of SUSFMs leading to a massive generation of waste. Despite the Government putting in place systems, especially in health facilities, to ensure the safe disposal of SUSFMs, hand gloves, and other pieces of Personal Protective Equipment (PPE), some are finding themselves in the environment. At the household level, there is a haphazard disposal of SUSFMs. They are disposed of along with normal household disposables, hence they end up in landfills or are dumped directly into open fields, roadsides, and walkways and are eventually washed away into water bodies. In addition, they are often flushed through toilets into the sewer lines, blocking the sewer reticulation systems and causing overflows.

To mitigate this global problem, several studies have been undertaken to examine the re-utilization of SUSFMs in the construction of infrastructure to not only reduce pollution, but also offer green solutions [5]. Concrete is strong when subjected to compressive forces and weak to tensional forces. Authors in [6] deduced that adding uniformly dispersed, small, and closely spaced fibers to concrete would not only control dry shrinkage cracking, but also enhance tensile strength, fatigue resistance, and ductility. Studies are active in areas of reutilizing waste materials to generate green concrete [7]. Authors in [8] used SUSFMs with Recycled Concrete Aggregates (RCA) to produce a blend material that can be used as a base and/or subbase for road construction. 1% of SUSFM material content mixed with RCA gave the best values of unconfined compressive strength and resilient modulus. Authors in [9] used shredded plastic fibers from beverage bottles in concrete. The results showed that there was an increase in compressive strength by 43.4% at 1.5% fiber content. Further, there was a notable increase of 82.2% in the flexural strength at a fiber content of 1.75% and improved Ultrasonic Pulse Velocity (UPV) of concrete by 44.4% at 0.25% fiber dosage. Authors in [10], while evaluating permeability and plastic shrinkage of polypropylene fiber reinforced concrete, concluded that increasing the polypropylene fiber content in concrete decreases compressive strength. The highest decrease in compressive strength of 10% was recorded at 0.3% fiber content while the least decrease of 2% was recorded at 0.1% fiber content. There was a noticeable increment in the tensile strength with the highest increase of 39% at 0.1% polypropylene fiber content. It was also concluded that plastic fibers reduce shrinkage cracking by more than half.

Authors in [11] used green and white recycled polypropylene fibers in concrete. It was found that with 1% green polypropylene fiber content, there was an increase of 69.7% in compression strength, 276.0% in flexural strength, and 269.4% in split tensile strength. At the same content of 1% white polypropylene fibers, an increase of 39.4% compressive strength, 162.4% flexural strength, and 254.2% split tensile strength was reported. Authors in [12] used industrial waste plastic fibers in concrete. It was deduced that the highest compressive strength was registered at fiber content at 0.5% of 50mm fibers while the highest flexural strength was recorded at 1.0% fiber content of 50mm length. They concluded that the optimum dosage of 50mm waste plastic fibers was 0.75%. Authors in [13] studied the influence of the length of polypropylene fibers on compression and flexural strength. It was observed that an increase in the length of polypropylene fibers increased flexural strength but decreased the compressive strength of concrete.

Much research has been conducted on the effect of waste plastic materials on concrete. However, there are no conclusive studies on the use of waste SUSFM material in new concrete. Therefore, this study aims to evaluate the possibility of the use of SUSFM material in concrete production. The objective was to evaluate the effect of the addition of SUSFM material on concrete's compressive strength, UPV, and splitting tensile strength. The results can guide the concrete consumers on how to incorporate SUSFMs in order to enhance the quality of concrete and at the same time break the landfill lifecycle of SUSFMs.

II. MATERIALS AND METHODS

Ordinary Portland Cement (OPC) of strength class CEM1/42.5N confirming to Kenyan standard (KS EAS 18-1:2001) was used in the mixes. The coarse aggregates were obtained from Nzoia Quarry Ltd. The used coarse aggregates had granular sizes ranging from 10mm to 20mm with flakiness index of 16.5 and water absorption of 1.9%. The fine aggregates were river sand sourced from river Malakisi. They had maximum size of 5mm, specific gravity of 2.7, finess modulus of 2.8, and a bulky density of 1510kg/m^3. The particle size gradation obtained through sieve analysis showed that fine aggregate particle distribution was within the grading limits.

Fig. 1. A single-use surgical face mask.

For commercial consumption of the recycled SUSFMs, there must be an elaborate disinfection process to avoid cross-infection of the covid-19 virus. Several methods of cleaning surgical face masks have been proposed, such as ultraviolet germicidal irradiation [14]. It was also reported that the covid-19 virus can be destroyed in SUSFMs by heating at 70^{o}C for 60 minutes [15]. However, with the current covid-19 restrictions, the use of recycled SUSFM materials in the study was not allowed, hence unused SUSFMs were utilized. Promo-Kings 3-ply surgical face masks (Figure 1) were sourced from a local chemist in Bungoma town with the properties shown in Table I. The SUSFM fibers were produced by cutting off the nose strip and ear loops before cutting up into rectangular fibers of 5mm width and varied lengths of 20mm, 30mm, and 40mm (Figure 2). Sika plastiment 40 KE with a density of 1.05kg/m^3 was used as a plasticizer to achieve the desired workability in all concrete mixes where 1kg SUSFM fibers for every 100kg of cement dosage was adopted as per manufacturer's specifications. Ordinary drinking tap water supplied by the local water service provider was used in all mixes and specimen curing. The mix design adopted the Department of Environment (DOE)'s concrete design to produce C30/37 concrete. The mix material proportions are shown in Table II.

Fig. 2. Shredded single-use surgical face masks.

The fine and coarse aggregates were batched in saturated dry conditions by weight. Fine aggregates, coarse aggregates, and cement were weighed and mixed on a dry metallic non-absorbent pan manually by using a spade until the mix was uniform. Half of the mixing water was added and mixing continued until the mix was uniform. The remaining half of the mixing water was mixed with sika plastiment 40KE plasticizer before adding it to the concrete mixture to avoid the cement paste from reacting directly with the plasticizer. The mixing continued until a uniform mix was achieved. The shredded SUSFMs were added slowly while mixing to allow even distribution and avoid clamping (Figure 3). Testing specimens from a total of 7 concrete mixes were used with cut-up SUSFM material in proportions of 0% as the control mix, 0.5%, 1.0%, 1.5%, 2.0%, 2.5% and, 3.0% by weight of cement in concrete for of 20mm, 30mm, and 40mm length of SUSFM fibers. This range is consistent with [11]. Despite the increase in the scope of the study, this aggregate range enabled the determination of both optimum volume and size of the SUSFM fibers in concrete in agreement with [12]. Using one set of aggregates (fiber) would not have yielded meaningful results for analysis.

TABLE I. PROPERTIES OF SUSFMs

Physical properties	
Size of SUSFMs	172.5mm by 97.0mm
Width of SUSFM fibers	5mm
Length of SUSFM fibers	20mm, 30mm, 40mm
Thickness	0.35mm
Aspect ratio	20m – 29; 30mm – 43; 40mm – 58
Density	0.166kg/m^3
Weight	3.5g
Shape	Rectangular

TABLE II. DESIGN MIX PROPORTION OF CONCRETE CONSTITUENTS PER m^3 OF CONCRETE

Batch No.	00	05	10	15	20	25	30
Cement (kg)	404	404	404	404	404	404	404
Water (kg)	210	210	210	210	210	210	210
Fine aggregates (kg)	679	679	679	679	679	679	679
Coarse aggregates (kg)	1107	1107	1107	1107	1107	1107	1107
SUSFM content (% of cement weight) %	0	0.5	1.0	1.5	2.0	2.5	3.0
SUSFM content (kg)	0	2.02	4.04	6.06	8.08	10.1	12.12

To prepare specimens for casting, the concrete molds were cleaned, dried, and lubricated with a thin coat of mold oil to aid in the removal of specimens. For the preparation of compressive strength and UPV test specimens, 150mm cubes were adopted, while for splitting tensile strength tests, specimens were cast in 100mm diameter and 200mm height cylinders. The prepared concrete was poured into molds in 3 layers while compacting with a poker vibrator for 20s to allow the concrete to settle and fill up all the voids. The concrete in the mold was levelled with a trowel and left undisturbed for 24 hours at room temperature under shade. The specimens were then de-molded by pressure from a compressor and were then submerged in the curing tank for 28 days (Figure 4). The test specimens of hardened concrete were removed from the curing tank and then were allowed to air dry before being tested. The same process was repeated for all the mixes.

A. *Compressive Strength Testing*

Compressive strength testing was conducted on a Universal Testing Machine, Basic wizard type with digital readout unit model no. 00701/A in accordance with EN 12390-3:2019. The specimens were placed on the bearing surfaces of the testing machine between the platens central to the loading axle. A uniform rate of loading was applied until the tested specimen failed. The maximum load to the nearest 0.1N/mm^2 and the compressive strength were recorded. Three specimens were tested for each concrete regime and the average was considered as the compressive strength of the batch with the respective SUSFM material dosage.

B. *Split Tensile Strength Testing*

Split tensile strength testing was conducted on the same Universal Testing Machine in accordance with EN 12390-6:2009. The cylindrical test specimens were placed horizontally between the loading surface of the test machine and the load was gradually applied until the cylinder failed along the vertical diameter, as shown in Figure 5. The split tensile strength of the concrete cylinder specimen was recorded. Three specimens were tested for each concrete regime and the average was considered as the split tensile strength of the concrete batch with the SUSFM material.

Fig. 3. Mixing of concrete with added SUSFM fibers.

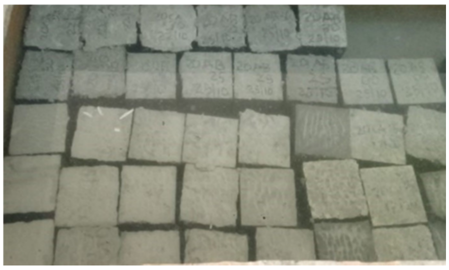

Fig. 4. Curing of concrete specimens.

Fig. 5. Concrete split tensile strength testing.

C. *Ultrasonic Pulse Velocity Testing*

UPV was conducted on the samples using MATEST UPV testing machine model no. C372M in accordance with EN 12504-4:2004 (Figure 6). The ultrasonic pulse was generated by a pulse generator transmitted to the concrete surface. The time taken for the pulse to travel through the concrete and be received by the transducer on the opposite side of the concrete specimen was measured. To ensure good contact, a thin film of solid jelly was applied between the interface of the concrete specimen surface and the transducer. UPV was determined to evaluate the relative quality of the concrete specimens with SUSFM material. Three specimens were tested for each concrete regime and the average was considered as the UPV of the concrete batch.

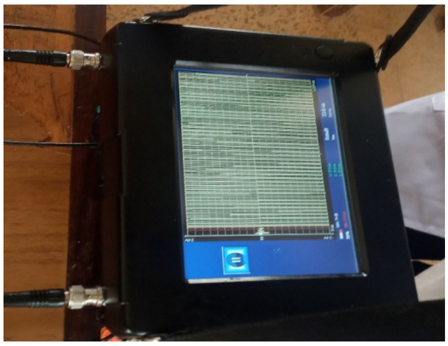

Fig. 6. UPV testing equipment.

III. RESULTS AND DISCUSSION

The compressive strength results are shown in Figure 7. The results indicated that the re-utilization of SUSFM materials in the manufacture of concrete leads to a systematic decrease in compressive strength. The compressive strength of the control specimen was 50.1N/mm^2. The lowest decrease in compressive strength was 10.4% at 0.5% of 30mm length of SUSFM fibers, 11.6% at 0.5% of 20mm length, and 20.8% at 0.5% of 40mm length. The optimum dosage to yield the least negative impact on compressive strength was 0.5% content of 30mm length fibers. These results are in agreement with [10] in which it was concluded that increasing polypropylene fiber content in concrete decreases compressive strength. Similarly, a decrease in compressive strength was recorded in [16] when expanded polystyrene beads were added to the concrete. The reduction in compressive strength can be attributed to the low specific gravity of SUSFMs induced in concrete [12] and the presence of weak interfacial bonds between the binder material and SUSFM materials [4].

A total of 57 test cylindrical specimens were used in split tensile strength tests. The results, as represented in Figure 8, have shown that at 20mm length, split tensile strength decreases progressively from 9.1% at 0.5% dosage to the highest of 24.2% at 2.0% dosage. This shows a gradual decrease in split tensile strength with an increase in SUSFM material content in the concrete matrix. For 30mm length, the split tensile strength increased, compared to the control specimen, by 15.2% at 0.5% dosage and 3.0% at 1.0% dosage before dropping off and starts decreasing gradually at 1.5% dosage to the lowest decrease of 27.3% at 3.0% dosage. For 40mm length, split tensile strength registered an equal value to the control specimen of 3.3N/mm^2 at 0.5% SUSFM material dosage before decreasing gradually from 3.0% at 1.0% dosage to the lowest of 21.2% at 3.0% dosage.

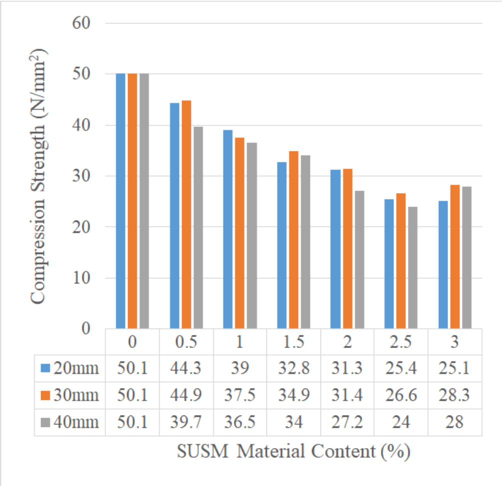

Fig. 7. Compressive strength of concrete with different contents and lengths of SUSFM fibers.

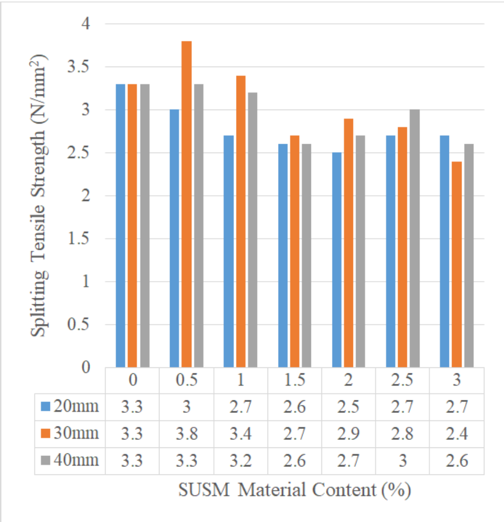

Fig. 8. Split tensile strength of concrete with different contents and lengths of SUSFM fibers.

The specimens with SUSFM material of 30mm length at 0.5% and 1.0% dosage and with 40mm length at 0.5%, registered increased split tensile strength in comparison with the control specimen. These results showed that the best mix with regard to the highest split tensile strength was 0.5% dosage of 30mm length SUSFM fibers. The results obtained were in agreement with [10], where the split tensile strength was found to be more than the control specimen's when polypropylene fibers were added to normal concrete mix in percentages up to 0.25%. Above this dosage, the split tensile strength decreased in comparison with the control specimen. This also affirms to the results obtained in [17]. The increase in split tensile strength may be a result of filling of the micro-cracks developed in the concrete matrix by the fibers, hence preventing their propagation. They may have caused the cracks to meander and hence demand more energy to propagate and therefore increasing the ultimate tensile load [17]. The reduced split tensile strength could be a result of insufficient binder matrix around the fibers for transfer of stresses from concrete fibers through bonding.

The results of the UPV test are shown in Figure 9. The UPV value for the control specimen was 4436m/s. For 20mm length of SUSFM material, UPV values increased by 1.4% at 1.0% dosage, after which the values dropped off at 1.5% dosage and progressively decreased to the lowest 4011m/s at 3.0% dosage representing a 9.6% decrease. For 30mm length of SUSFM material, UPV values increased at 0.5%, 1.0%, and 1.5% dosages by 1.2%, 2.0%, and 0.3% respectively before gradually decreasing. For 40mm length, the UPV values increased by 1.7% at 0.5% dosage before starting to reduce progressively to the lowest of 4026m/s. Concrete with 30mm length SUSFM material had higher values of UPV compared to the same dosages of 20mm and 40mm lengths. The optimum dosage was 1.0% of 30mm length of SUSFM material. The UPV values for 20mm length SUSFM material ranged between 4320 and 4011. For the 30mm length, the UPV values ranged from 4487 to 4152 while for 40mm the values ranged from 4509 to 4026. All values were more than 4000m/s indicating that the quality of concrete is very good [9], whereas concrete that has UPV values greater than 4500m/s is considered of excellent quality [18]. High UPV indicates concrete with no voids and cracks as a result of fibers limiting the micro-cracks in the concrete matrix [19]. Other dosages registered reduced UPV values, decreasing with an increase in the SUSFM material content. This may be attributed to the reduced bonding of SUSFM materials and concrete [9].

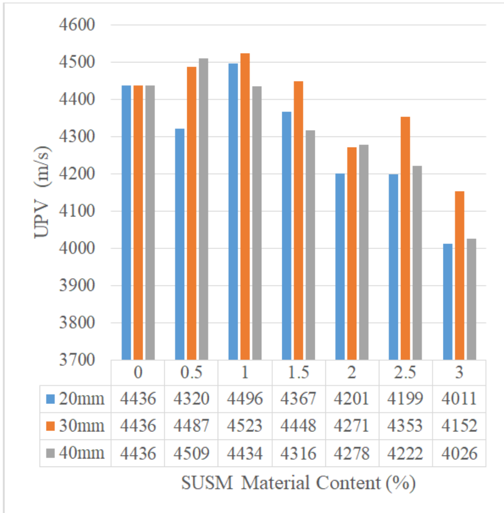

Fig. 9. UPV of concrete with different contents and lengths of SUSFM fibers.

IV. CONCLUSION

Compressive strength results indicated that the re-utilization of SUSFM fibers in the production of concrete leads to a systematic decrease in compressive strength. Among all the concrete-SUSFM mixes, the concrete incorporating 0.5% dosage of 30mm SUSFM fiber length gave the lowest reduction in compressive strength. The compressive strength of more than 40N/mm^2 can be produced with additional SUSFM material at a content of 0.5% by mass of cement material of 20mm or 30mm lengths.

The split tensile strength of concrete with 30mm and 40mm length SUSFM materials at 0.5% and 30mm length at 1.0% dosage was registered higher than that of the control concrete mix, indicating the benefits of SUSFM fibers. The optimum observed dosage was 0.5% of 30mm length of SUSFM fibers.

Concrete mixes with 20mm SUSFM fibers at 1.0%, 30mm at 0.5%, 1.0%, 1.5%, and 40mm at 0.5% registered higher UPV values than the control concrete mix. The optimum dosage observed was at 1.0% of 30mm SUSFM fibers. Therefore, the addition of SUSFM material in concrete has positive benefits regarding the UPV.

Summarizing, the reutilization of waste SUSFMs creates green concrete with improved quality and at the same time sustainably removes this waste from the environment.

REFERENCES

[1] J. C. Prata, A. L. P. Silvia, T. R. Walker, A. C. Duarte, and T. Rocha Santos, "Covid-19 pandemic repercussions on the use and management of plastics," *Environmental Science & Technology,* vol. 54, no. 13, pp. 7760-7765, Jun. 2020, https://doi.org/10.1021/acs.est.0c02178.

[2] C. Nzediegwu, and S. X. Chang, "Improper solid waste management increases potential for COVID-19 spread in developing countries," *Resources, Conservation & Recycling*, vol. 161, Oct. 2020, Art. no. 104947, https://doi.org/10.1016%2Fj.resconrec.2020.104947.

[3] O. O. Fadare, and E. D. Okoffo, "Covid-19 Face Masks: A Potential source of micro plastic fibers in the environment," *Science of Total Environment*, vol. 737, Oct. 2020, Art. no. 140279, https://doi.org/10.1016%2Fj.scitotenv.2020.140279.

[4] S. Kilmartin-Lynch, M. Saberian, J. Li, R. Roychand, and G. Zhang, "Preliminary evaluation of the feasibility of using polypropylene fibres from COVID-19 single use face masks to improve mechanical properties of concrete," *Journal of Cleaner Production*, vol. 296, May. 2021, Art. no. 126460, https://doi.org/10.1016/j.jclepro.2021.126460.

[5] N. Bheel, P. Awoyera, O. Aluko, S. Mahro, A. Viloria, and C.A.S. Sierra, "Sustainable composite development: Novel use of human hair as fibre in concrete," *Case Studies in Construction Materials*, vol. 13, Dec. 2020, Art. no. e00412, https://doi.org/10.1016/j.cscm.2020.e00412.

[6] F. A. Al-Hadithi, A. I. Al-Hadithi, and J. A. Al-Asafi, "The Mechanical properties of ferrocement mortar with waste plastic fibres at elevated temperatures," *Engineering, Technology & Applied Science Research,* vol. 12, no. 5, pp. 9347-9350, Oct. 2022, https://doi.org/10.48084/etasr.5209.

[7] M. F. Qasim, Z. K. Abbas, and S. K. Abed, " Producing green concrete with plastic waste and nano silica sand," *Engineering, Technology & Applied Science Research*, vol. 11, no. 6, pp. 7932-7937, Dec. 2021, https://doi.org/10.48084/etasr.4593.

[8] M. Saberian, J. Li, S. Kilmartin-Lynch, and M. Boroujeni, "Repurposing of covid-19 single use face masks for pavement base/subbase," *Science of Total Environment*, vol. 769, May. 2021, Art. no. 145527, https://doi.org/10.1016/j.scitotenv.2021.145527.

[9] A. I. Al-Hadithi, and N. N. Hilal, "The possibility of enhancing some properties of self- compacting concrete by adding waste plastic fibers," *Journal of Building Engineering*, vol. 8, pp. 20-28, Dec. 2016, https://doi.org/10.1016/j.jobe.2016.06.011.

[10] G. M. S. Islam, and S. D. Gupta, "Evaluating plastic shrinkage and permeability of polypropylene fiber reinforced concrete" *International Journal of Sustainable Built Environment,* vol. 5, no. 2, pp. 345-354, Dec. 2016, https://doi.org/10.1016/j.ijsbe.2016.05.007.

[11] M. Małek, M. Jackowski, W. Łasica, and M. Kadela, "Characteristics of Recycled Polypropylene Fibers as an Addition to Concrete Fabrication Based on Portland Cement," *Materials*, vol. 13, no. 8, Jan. 2020, Art. no. 1827, https://doi.org/10.3390/ma13081827.

[12] M. S. Meddah, and M. Bencheikh, "Properties of concrete reinforced with different kinds of industrial waste fiber materials," *Construction and Building Materials*, vol. 23, no. 10, pp. 3196-3205, Oct. 2009, https://doi.org/10.1016/j.conbuildmat.2009.06.017.

[13] I. A. Memom, A. A. Jhatial, S. Sohu, M. T. Lakhiar, and Z. Hussain, "Influence of fibre length on behavior of polypropylene fibre reinforced cement concrete," *Civil Engineering Journal*, vol. 4, no. 9, pp. 2124-2131, Sept. 2018, https://doi.org/10.28991/cej-03091144.

[14] I. H. Hamzavi, A. B. Lyons, I. Kohli, J. M. Gelfand, H. W. Lim, and D. M. Ozog, "Ultraviolet germicidal irradiation: Possible method for respirator disinfection to facilitate reuse during COVID-19 pandemic," *Journal of American Academy of Dermatology*, vol. 82, no. 6, pp. 1511-1512, Jun. 2020, https://doi.org/10.1016/j.jaad.2020.03.085.

[15] Y. Xiang, Q. Song, and W. Gu, "Decontamination of surgical face masks and N95 respirators by dry heat pasteurization for one hour at 70°C," *American Journal of Infection Control*, vol. 48, no. 8, pp. 880-882, Aug. 2020, https://doi.org/10.1016/j.ajic.2020.05.026.

[16] A. S. Salahaldeen, and A. I. Al-Hadithi, "The effect of adding Expanded Polystyrene Beads [EPS] on hardened properties of concrete," *Engineering, Technology & Applied Science Research,* vol. 12, no. 6, pp. 9692-9696, Sept. 2022, https://doi.org/10.48084/etasr.5278.

[17] N. Hidaya, R. N. Mutuku, and J. N. Mwero, "Physical and mechanical experimental investigation of concrete incorporated with polyethylene terephthalate (PET) fibres," *European International Journal of Science and Technology*, vol. 6, no. 8, pp. 31-41, Nov. 2017.

[18] B. Şimşek, T. Uygunoğlu, H. Korucu, and M. M. Kocakerim, "11 - Performance of dioctyl terephthalate concrete," in *Use of Recycled Plastics in Eco-efficient Concrete*, F. Pacheco-Torgal, J. Khatib, F. Colangelo, and R. Tuladhar, Eds. Woodhead Publishing, 2019, pp. 249–267, https://doi.org/10.1016/B978-0-08-102676-2.00011-6.

[19] S. P. Yap, U. T. Alengaram, and M. Z. Jumaat, "Enhancement of mechanical properties of polypropylene and nylon fiber reinforced oil palm shell concrete", *Materials & Design*, vol. 49, pp. 1034-1041, Aug. 2013, https://doi.org/10.1016/j.matdes.2013.02.070.