Effects of Polyethylene Terephthalate Fibre Reinforcement on Mechanical Properties of Concrete

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Cracked concrete is a problem due to several factors such as poor maintenance, insufficient reinforcement, or steel corrosion leading to crack propagation. There is a need to increase the load-bearing capacity of concrete slabs and increase their life span. The use of waste polyethylene terephthalate fibres in concrete can dramatically alleviate the problem of crack propagation and failure sustainably. Furthermore, the utilization of waste plastic in this manner is environmentally friendly. This study presents the experimental investigation into the mechanical strength properties of concrete with respect to the effect of various mass fractions of polyethylene terephthalate fibre. The polyethylene terephthalate fibres were added at mass fraction of 0.5%, 1.0%, 1.5%, and 2.0%. An experimental investigation was carried out to explore the effect of varying fibre mass fractions on the slump value, rebound number, split tensile strength, flexural strength, and compressive strength. An increase in flexural strength, rebound number and compressive strength was noted with an increase in fibre mass fraction. However, a decrease in split tensile strength was noted. The addition of 0.5% fibre gave the highest compressive and flexural strength of 29.32 N/mm² and 28 N/mm², respectively. However, the addition of fibre lowered the split tensile strength beyond the control specimen at all fibre mass fractions. The experimental results of this study indicate that the addition of polyethylene terephthalate fibre enhances the mechanical strength of concrete at low fibre mass fraction percentages. The PET fibre reinforced concrete is suitable for use in paving and ceiling slabs at a fibre addition of 0.5% for optimum workability and mechanical strength.

1. Introduction

Concrete is an important material in the construction industry and is generally composed of fine and coarse aggregates, cement, and water. The importance of concrete is due to its high durability, low cost, workability, and strength [1–3]. However, concrete has a number of intrinsic flaws, which include micro-cracks within the material and at the interfaces. These defects can originate from strain and stress from external restraints, excess water, bleeding, plastic settlement, and thermal shrinkage. When the load is applied to unreinforced concrete, these micro-cracks tend to amalgamate and form macro-cracks [4]. On further loading, the macro-cracks can result in catastrophic concrete failure. The fracture from micro- and macro-cracks can be lessened by the use of reinforcement material in the form of fibres such as nylon, polypropylene, steel, acrylic, and aramid. These fibres assist by stopping the growth of cracks within the concrete [5–7]. There is a need to increase the load-bearing capacity of concrete slabs and increase their life span. The use of waste polyethylene terephthalate (PET) fibres and fly ash in a hybrid composite slab dramatically alleviates the problem of crack propagation and failure sustainably [8–10].

When plain concrete develops tensile stress that exceeds its tensile strength, cracking occurs due to bending or changes in temperature and shrinkage. Concrete has good compressive strength; however, it does not respond adequately under high tensile stresses [11]. Synthetic fibres in fibre reinforced cementitious composites (FRCCs) can prevent the effect of excessive tensile stresses by bridging and dispersing cracks and holding the concrete in place. Most synthetic fibres reduce the amount of plastic and post-hardening crack formation [12]. Synthetic fibres assist concrete in developing its optimum long-term integrity by
reducing plastic and drying shrinkage crack formation, increasing energy absorption, and improving resistance to impact forces.

Polyethylene terephthalate (PET) is a popular thermoplastic used mainly in textile fibres, beverages, and other liquid containers [13]. Most PET bottles are single use and are disposed of after use, by either burying or incineration. Plastic pollution has been on a steady increase with annual plastic production being approximately 368 million tonnes in the year 2019. Thereafter, there was a slight decrease due to the coronavirus pandemic [14]. Plastic wastes such as PET can find use in various applications such as load-bearing bricks, walls, components in asphalts, base, and subbase for road construction [15]. Recycling plastic material is an environmentally friendly method to reduce plastic pollution and also conserve the precious raw petrochemical resources [16, 17]. Various synthetic fibres such as polyethylene [18], polyvinyl alcohol (PVA) [19], polyethylene terephthalate (PET), and polyethylene (PP) [20] have been researched as reinforcements in concrete to improve their mechanical properties. Ataei et al. (2017) [21] studied the compressive strength effect of recycled PET particles in concrete. The research reported a decrease in compressive strength after adding PET particles. This occurrence was attributed to the weak cohesion between the particles and the cement resin. Rahmani et al. (2013) [22] gave a similar conclusion of a general decrease in compressive strength with PET particles to concrete. Rahmani et al. (2013) [22] reported that the compressive strength of PET particle reinforced concrete had an increase in compressive strength of 8.86% at a 5% particle mass fraction. However, at 10% PET particle mass fraction, the compressive strength was found to remain the same as that of unreinforced concrete [22]. The compressive strength decreases to 5.14% at a PET particle mass fraction of 15%. Studies that used PET fibre addition reported a marginal increase in compressive strength at 0.5% fibre addition [10]. Sayi et al. (2021) [12] studied the effect of varying PET fibre addition on water and sound permeability and concluded that permeability was reduced by fibre addition. However, research by Sayi et al. (2021) [12] did not consider the mechanical properties of the concrete.

Choi et al. (2005) [23] also studied the effects of increasing the mass fraction of PET particles on compressive strength. The author showed a decline in compressive strength with an increase in the mass fraction of PET particles. At 50% PET particle mass fraction, the loss in compressive strength was found to be 14.52%, while at 75% PET particle mass fraction, the compressive strength loss was 33.06% in reference to unreinforced concrete slabs [8]. The conclusion reached by the work of Choi et al. (2005) [23] was consistent with that of previous studies by Ataei et al. (2017) [21] and Rahmani et al. (2013) [22].

Mukhopadhyay et al (2015) [24] studied the use of hybrid PET and steel fibres to give superior toughness to concrete slabs. The study reported an increase in ultimate tensile strain capacity at peak with an increase in PET fibre loading. However, beyond a certain fibre loading, the ultimate tensile strain starts to decrease. Further, the author noted that an increase in PET fibre length improves strain hardening and multiple cracking behaviours. This improvement increases the ultimate strain capacity of the concrete slab. However, the study failed to account for the critical length phenomenon, whereby the strength of the concrete starts to reduce at certain fibre lengths.

Ismail et al. (2008) [25] studied the flexural strength properties of waste PET particle reinforced concrete. This study concluded that at 20% PET particle mass fraction, there was a decrease of 30.5% in flexural strength. This decrease in flexural strength was attributed to a reduction in adhesive strength due to the hydrophobic nature of PET. Furthermore, the reduction in flexural strength can also be attributed to the elastic aggregate’s elastic nature and non-brittle loading characteristics. Nonetheless, the flexural strength can be increased using PET fibres, which have a high aspect ratio as shown in study by Alani et al. (2020). Alani et al. (2020) reported an 18% increase in flexural strength when 1% PET fibres were added. This finding was in line with research by Borg et al. (2016) [26] and Pelisser et al. (2012) [27] who reported an increase of over 18% with PET fibre addition of less than 1%. However, more research needs to be conducted to establish PET fibre fractions that give optimal mechanical strength properties, which form the basis of this study.

The problem of single-use PET plastic is a problem for our environment. The use of waste PET fibres in concrete can alleviate the disposal problem of PET and serve as an efficient and economic reinforcement in concrete preventing crack propagation. Previous research has focused mainly on the use of PET particle and flakes as a replacement for aggregates and tape strips of waste PET. Moreover, limited research has been done on the use of recycled PET fibres, which have undergone the extrusion process commonly used in textile grade fibres. The purpose of this study was to study the use of varying mass fractions of PET fibre on concrete mechanical strength. Various test specimens were fabricated to access the flexural, compressive, and tensile strength and rebound number.

2. Materials and Methods

2.1. Materials. Clean tap water from municipality treatment facilities was used in this study. The properties of the cement, fine and coarse aggregate, and polyethylene terephthalate are outlined in the following subsections.

2.1.1. Cement. The Portland cement used in this study was the Suretech Portland Cement CEM I 52.5N manufactured by PPC. This cement is of strength class SANS 50197–1 [28]. The properties of the cement used are shown in Table 1.

2.1.2. Polyethylene Terephthalate Fibres. The PET fibres used in the fibre reinforced concrete were obtained from recycled PET material extruded into 12 mm fibres. The properties of the PET fibres used are shown in Table 2.
2.1.3. Fine Aggregates. The fine aggregate used consisted of river sand with the properties shown in Table 3.

2.1.4. Coarse Aggregates. The coarse aggregate used consisted of 13mm dolomite with the properties shown in Table 4.

2.2. Mix Design. The mix design used in this study is for M20 concrete as shown in Table 5. The PET fibre mass fraction was varied over five levels with varying percentages from 0 to 2.0%. The fibre mass fraction was varied in this range due to the strength gain reported by several authors to fall within this range for synthetic fibre reinforced concrete [30]. Furthermore, any further addition above 2.0% drastically compromised the workability of the concrete paste. The dependent variables measured included the slump value, rebound number, compressive strength, flexural strength, and split tensile strength.

2.3. Fresh Concrete Mixture. Concrete was mixed in accordance with SANS 5861-1 [31] using the hand mixing technique. The ambient temperature was recorded and maintained between 22°C and 25°C for storage of the materials. The concrete was hand mixed in a laboratory with the cement and fine aggregate mixed first in accordance with SANS 5861-1 [32]. Thereafter, the coarse aggregate and fibres were added and mixed thoroughly until the coarse aggregate was uniformly distributed in the mixture. The fibres were sprinkled over the mixture while mixing to avoid clumping of the fibres. Water was then added slowly until the batch appeared homogeneous and of uniform consistency. The concrete mix was then placed in a lubricated mould of dimensions consistent with the test to be carried out. The samples were covered with a damp hessian sack for 24hrs and then demoulded and put into temperature-controlled water tanks at 23 °C ±/-2°C for 28 days.

Table 1: Product specifications for Suretech Cement from PPC [28].

| Parameter                          | Physical properties                  | Result               |
|------------------------------------|--------------------------------------|----------------------|
| Setting time:                      | Initial (mins)                       | 125                  |
|                                    | Final (hours)                        | 2.5                  |
| Compressive strength (mortar prism EN 196–1) | Specific area (Blaine) (m²/kg)      | 400                  |
|                                    | At 2 days (MPa)                      | 28                   |
|                                    | At 28 days (MPa)                     | ±58                  |
| Soundness                          | Le Chatelier expansion (mm)          | 1                    |
|                                    | Relative density                     | ±3.14                |
| Densities                          | Bulk density, aerated (kg/m³)        | 1100–1300            |
|                                    | Bulk density, as packed (kg/m³)      | ±1500                |

Table 2: Physical properties of PET fibres [29].

| Property                               | Specification                               |
|----------------------------------------|---------------------------------------------|
| Appearance                             | White staple fibre                          |
| Chemical name                          | Polyethylene terephthalate                  |
| Description                            | Thermoplastic fibre, round, and uncrimped  |
| Fibre diameter                         | 18µm                                        |
| Fibre count per gram                   | 231.4 for 12 mm fibre                      |
| Specific density                       | 1.34–1.4                                    |
| Melting point                          | 254°C                                       |
| Autoignition temperature               | 515°C                                       |
| Physical state                         | Solid                                       |
| Moisture regain                        | 0.5%                                        |
| Solubility in water                    | Not soluble                                 |
| Solvents                               | None                                        |
| Tenacity at break                      | 45 cN/Tex (± 5)                             |
| Elongation at break                    | 40% (±)                                     |
| Fibre tenacity at 10% elongation       | >10 cN/Tex                                  |

Table 3: Properties of river sand.

| Characteristics | Specification |
|-----------------|---------------|
| Fineness modulus| 3.69          |
| Uniformity coefficient | 4.007       |
| Specific gravity | 2.15          |

Table 4: Properties of coarse aggregate.

| Characteristics | Specification |
|-----------------|---------------|
| Uniformity coefficient | 4.007       |
| Flakiness index | 74.82%        |
| Elongation index | 46.72%        |
| Water absorption | 0.80%        |
| Specific gravity | 2.608         |
| Apparent specific gravity | 2.663       |
| Bulk specific gravity | 10.5243     |
2.4. Experiments

2.4.1. Slump Test. A representative composite sample was obtained in line with SANS 5861–2 [31] from the freshly mixed concrete sample. The slump after demoulding was measured to the nearest 5 mm in accordance with the SANS standard.

2.4.2. Rebound Hammer Test. A rebound hammer test was carried out on the fabricated FRCC using a rebound hammer. The hardness test gave an indication of the quality and strength of concrete. This test ascertains the in-plane uniformity of concrete to delineate regions of poor quality. The test was done in accordance with ASTM C806-02 [33].

2.4.3. Compressive Strength Test. A compressive test was carried out on the FRCC to determine the yield stress and compressive strength. The standard used for the compressive tests on the concrete was SANS 5863 : 2006 [34]. A steel cube mould (150 mm × 150 mm × 150 mm) was used for casting cubes. The samples were cured for 28 days in the water tank and thereafter tested. The ultimate load at failure and stress were recorded, and the compressive strength was calculated.

2.4.4. Flexural Strength Test. The FRCC flexural strength and modulus were determined on a Versa tester beam press machine in accordance with ASTM C78 [35]. This test uses a simple beam with four-point loading. The mould used for this flexural test was of dimensions of 150 mm × 150 mm × 510 mm. The modulus of rupture was then calculated.

2.4.5. Split Tensile Strength Test. The split tensile test was carried out using the universal model number 1887B0001 ELE machine. The test was carried out in accordance with ASTM C496–10 [36]. The maximum load was divided by the geometric dimensions of the test specimen to calculate the splitting tensile strength. The rate of loading used was 690 kPa/min, and the splitting tensile strength was then calculated.

3. Results and Discussion

3.1. Effect of PET Fibre on Concrete Workability. The graph shown in Figure 1 shows the effect of PET fibre addition on the slump value of the fresh concrete.

| PET fibre mass fraction (%) | Cement Kg/m$^3$ | Fine aggregate Kg/m$^3$ | Coarse aggregate Kg/m$^3$ | Fibre Kg/m$^3$ | Water Kg/m$^3$ |
|----------------------------|-----------------|-------------------------|--------------------------|--------------|--------------|
| 0                          | 346.50          | 519.75                  | 1093.50                  | 0.00         | 207.90       |
| 0.5                        | 346.50          | 546.75                  | 1093.50                  | 9.93         | 207.90       |
| 1.0                        | 346.50          | 546.75                  | 1093.50                  | 19.87        | 207.90       |
| 1.5                        | 346.50          | 546.75                  | 1093.50                  | 29.80        | 207.90       |
| 2.0                        | 346.50          | 546.75                  | 1093.50                  | 39.74        | 207.90       |

The slump value dropped sharply from 50.30 mm for the control specimen without any reinforcement to 15.00 mm for the FRCC containing 0.5% PET fibre. As PET fibre content was increased to 1.0%, the slump value dropped from 15.00 mm to 0 mm. Any further increase in fibre content yielded a zero-slump value. Any additional increase in polypropylene fibre beyond 0.72% fibre content resulted in an insignificant slump value as observed in this study. Further, research is needed to improve the slump value of PET FRCC beyond 1.0% fibre addition.
3.2. Effect of PET Fibre on Rebound Number. The graph in Figure 2 shows the average rebound number with an increase in PET fibre addition.

The addition of PET fibres lowered the rebound number as the percentage of fibres increased. The addition of 0.5% PET fibre resulted in a reduction of 13.27% from the control specimen. Further addition of PET fibre to 1.0% resulted in a decrease in rebound number of 19.67% from that of 0.5% fibre content. However, the addition of 1.5% fibre content resulted in a slight increase in the rebound number. Further addition of 2.0% fibre resulted in a drop in rebound hammer number to 12.3.

The general decrease in rebound number with an increase in fibre loading is related to the compressive strength. There is a decrease in the interfacial bond between the PET fibres and the cement paste with an increase in fibre loading. This phenomenon results in a progressively decreasing rebound number with an increase in fibre content. A study conducted by Baboo et al. (2012) [39] reported a similar trend with the decrease in rebound number with incremental synthetic fibre content. The author concluded that the decrease in rebound number was due to the decrease in adhesive strength between the surface of the synthetic fibre and the cement paste. Figure 3 shows a comparison between the compressive strength obtained from the destructive cube test and the results of the rebound compressive test.

The nondestructive test results follow the same trend as that of the destructive tests, which indicated a decrease in compressive strength with an increase in PET fibre content. The trend observed was like that reported by Ede and Ige (2014) [40], who reported a decrease in the rebound number of concretes containing polypropylene fibre. However, the rebound number gave significantly lower calculated values of compressive strength compared with the destructive test. This phenomenon could be attributed to the random dispersion and orientation of the PET fibres within the concrete giving varied readings of the rebound hammer at different points of the concrete specimen.

3.3. Effect of PET Fibre on Composite Compressive Strength. The graph in Figure 4 shows the effect of fibre addition on the 28-day compressive strength of concrete.

Figure 4 shows that an increase in compression strength of concrete occurs up to 0.5% PET fibre addition. Thereafter, there is a 45% decline in compressive strength from 0.5% up to 1% fibre addition. The strength of FRCC is significantly less than the strength of unreinforced concrete at 1.0% fibre addition. Thereafter, there is a moderate decline in compressive strength with increased fibre content up to 2%. The maximum compressive strength recorded was at 0.5% fibre addition, which gave compressive strength of 29.32 N/mm², an increase of 23% in compressive strength over the control specimen. The stress on the FRCC followed a similar trend to the compressive strength, as shown in Figure 5.

The compressive stress was reduced with the addition of PET fibre in a gradual trend. The failure of the specimens under compressive test for the PET reinforced concrete cubes was not catastrophic as realized for the control specimen. It was a gradual failure. On the other hand, the failure of the control specimen of concrete without any fibre reinforcement was a sudden and explosive global failure. The addition of 0.5% PET fibres has a modest increase in the compressive strength between 0% and 0.5% and 0.5% can be attributed to an increase in the bonding that occurs between the concrete mixture contents due to the fibre addition. Similar results were observed by Mashrei et al. (2018) [41] and Umasabor et al. [42], who both reported a sharp increase in the compressive strength of concrete reinforced with polypropylene fibres and polyethylene.
terephthalate fibres from 0% to 0.2% and thereafter a moderate increase to 0.5%. Another research carried out by Nuruddin (2015) [43] indicated that PVA fibres have a small effect in increasing the compressive strength of FRCC. The author further reported that the optimum results for polyvinyl alcohol (PVA) fibre addition were at 0.5%, which is consistent with the results obtained in this study. Govindasami et al. (2018) [38] studied the effect of polypropylene fibre on the compressive strength of concrete and reported an initial increase in strength up to 1.0% fibre addition. Thereafter, there was a significant decrease in compressive strength. The study by Silva et al. (2019) reported an increase in compressive strength in PET fibre reinforced concrete up to 0.5% due to the reduced workability at higher fibre loading. Silva et al. (2019) [44] stated that reduced workability led to concrete not being compacted properly reducing its compressive strength.

There is a sharp decrease in compressive strength between 0.5% and 1.0% of fibre addition due to fibres having a negative effect on the hydration of cement. Furthermore, high fibre percentages tend to encourage fibre clumping during fabrication. Fibre clumping creates nucleus sites for crack formation under a compression load, leading to lower compressive strength. The use of a high percentage of fibre in FRCC > 0.5% significantly affects the workability of the concrete. The finish of the concrete is not smooth and may have some voids, which are the origin of the failure cracks of the concrete under compressional load. It was concluded that the best range of PET fibre addition is between 0.1% and 0.5% for optimal compressive strength of the FRCC.

3.4. Effect of PET Fibre on Composite Flexural Strength.
The graph in Figure 6 shows the effects of PET fibre addition on the flexural strength of the FRCC. The addition of 0.5% PET fibre increased the flexural strength of the FRCC significantly from the control specimen of 2.82 N/mm² to 3.59 N/mm². Adding a further quantity of PET fibre to 1% resulted in a drastic drop in the flexural strength to less than that observed for the control specimen giving a flexural strength of 1.80 N/mm². Further, the addition of fibre gave a steady increase in flexural strength. In addition, 1.5% PET fibre gave flexural strength of 2.25 N/mm². Further, the addition of PET fibre to 2.0% gave flexural strength of 2.87 N/mm². The highest flexural strength was obtained with 0.5% PET fibre addition.

The results are consistent with the results of Govindasami (2018) [38], who also reported a significant increase in flexural strength with the addition of polypropylene fibre up to 0.5% and after that a drastic reduction in flexural strength with the addition of 2.0% fibre. A study by Umasabor (2020) reported a steady decrease in flexural strength at the percentage of PET fibre above 0.5% fibre loading. This finding was consistent with the results observed in this study. The decrease in flexural strength at high fibre loading was attributed to a decrease in adhesive strength between the surface of the PET fibres and the concrete paste by Baboo et al. (2012) [39]. A study by Huang et al. (2021) reported a similar trend with an increase in concrete flexural strength at first at low fibre loading percentages and then a decrease in strength with further fibre loading.

3.5. Effect of PET Fibre on Composite Split Tensile Strength.
The graph in Figure 7 shows the effect of fibre addition on the split tensile strength of FRCC. The addition of fibre decreased the split tensile strength of the FRCC. Unreinforced concrete had a split tensile strength of 2.06 N/mm², which dropped marginally to 1.82 N/mm² with 0.5% PET fibre. However, the further addition of PET fibre resulted in a drastic drop in the split tensile strength. The addition of 1.0% PET fibre gave a split tensile strength of 1.16 N/mm². This was a drop of 44% from the split tensile strength of unreinforced concrete. After that,
there was a slight increase in the split tensile strength with a 1.5% addition of PET fibre, giving a strength of 1.21 N/mm². Further addition of PET fibre to 2.0% resulted in a reduction in split tensile strength to 0.92 N/mm². The splitting strength of the FRCC was negatively affected by the addition of fibres. However, the fibres helped delay the development and propagation of cracks during the testing.

The low splitting strength with an increase in fibre content could be attributed to the effect of high air voids due to fibre clumping. These results were consistent with the study carried out by Irwan et al. (2013) [45], who reported a decrease in split tensile strength with PET filaments. The author reported that the split tensile strength dropped from 3.65 N/mm², the control specimen, to 3.57 N/mm² with 0.5% PET filament reinforced concrete. Irwan et al. (2013) [45] reported a steady reduction in split tensile strength up to 1.5% PET fibre addition with various water-to-cement ratios, and the trend remained the same. In contrast, Govindasami et al. (2018) [38] reported a marginal 19% increase in split tensile strength of FRCC containing polypropylene fibre up to 1.0% fibre addition. The increase in strength, which contrasts with this study, can be attributed to significantly higher fibre tensile strength properties of polypropylene over PET.

3.6. Application of PET Fibre Reinforced Composites in Slabs. The fabricated PET fibre reinforced concrete is suitable for use in paving slabs and ceiling slabs. The concrete pavers can be used in numerous applications such as low volume roads, street roads, and other landscape pavement applications. Furthermore, the use of the PET reinforced paver slabs in these applications is economic in terms of cost of manufacture. These PET paver slabs will be able to resist crack propagation and will not easily buckle or break.

The use of PET reinforced concrete in ceiling slabs has several advantages such as durability, crack control system through the randomly oriented PET fibres, and increased ductility. The ductility introduced by the use of the polymeric PET fibres increases the toughness of the concrete. This study has shown that the use of the PET fibres in mass fraction of <0.5% gives the best mechanical properties.

4. Conclusion

The study investigated the effect of addition of varying mass fraction of PET fibre on the mechanical properties of concrete slabs. Based on the experimental results carried out in the study, the following conclusions can be drawn:

(i) The slump value was observed to decrease with incremental amounts of PET fibre. The use of lower amounts of fibres less than 0.5% gave acceptable workability of the FRCC. Therefore, it is recommended to maintain less than 0.5% fibre content to have acceptable concrete workability.

(ii) The addition of 0.5% PET fibre to the FRCC increased the compressive strength to 28 N/mm². However, further fibre addition exceeding this percentage resulted in a decrease in compressive strength.

(iii) The addition of PET fibre only decreased the split tensile strength of the FRCC. Unreinforced concrete had a split tensile strength of 2.06 N/mm², which dropped marginally to 1.82 N/mm² with the addition of 0.5% PET fibre. The addition of 1.0% PET fibre gave a split tensile strength of 1.16 N/mm². This was a drop of 44% from the split tensile strength of unreinforced concrete. Further addition of PET fibre to 2.0% resulted in a reduction in split tensile strength to 0.92 N/mm².

(iv) The addition of 0.5% PET fibre alone gave the highest flexural strength. However, further addition
above 0.5% gave a decreasing trend and unsatisfactory flexural strength.

(v) The addition of PET fibre to the FRCC gave a decreasing rebound number with an increase in fibre content. This was in line with the trend observed for the destructive test.

(vi) The developed PET fibre reinforced concrete is suited for use in ceiling slabs and paving slabs at a fibre addition of 0.5% for optimum strength.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this study.

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References

[1] L. S. Rasheed, A. M. Shaban, and A. T. Abdulrasool, "Mechanical and structural characteristics of PET fiber reinforced concrete plates," *Smart Science*, vol. 9, pp. 1–15, 2021.

[2] R. K. Rohman and S. Aji, "Effect of fly ash on compressive strength of concrete containing recycled coarse aggregate," *AIP Conference Proceedings*, vol. 2014, no. 1, Article ID 020097, 2018.

[3] A. Caporale, L. Feo, and R. Luciano, "Limit analysis of FRP strengthened masonry arches via nonlinear and linear programming," *Composites Part B: Engineering*, vol. 43, no. 2, pp. 439–446, 2012.

[4] N. Banthia, C. Zanotti, and M. Sappakittipakorn, "Sustainable fiber reinforced concrete for repair applications," *Construction and Building Materials*, vol. 67, pp. 405–412, 2014.

[5] N. Banthia and R. Gupta, "Influence of polypropylene fiber geometry on plastic shrinkage cracking in concrete," *Cement and Concrete Research*, vol. 36, no. 7, pp. 1263–1267, 2006.

[6] V. C. Li, "On engineered cementitious composites (ECC)," *Journal of Advanced Concrete Technology*, vol. 1, no. 3, pp. 215–230, 2003.

[7] X. Cui, G. Liu, C.-J. Wang, and Y. Qi, "Effects of PET fibers on pumppability, shootability, and mechanical properties of wet-mix shotcrete," *Advances in Civil Engineering*, vol. 2019, pp. 1–14, Article ID 2756489, 2019.

[8] W. Cheng, G. Liu, and L. Chen, "PET fiber reinforced wet-mix shotcrete with walnut shell as replaced aggregate," *Applied Sciences*, vol. 7, no. 4, pp. 14–23, 2017.

[9] R. K. Padhan and A. A. Gupta, "Preparation and evaluation of waste PET derived polyurethane polymer modified bitumen through in situ polymerization reaction," *Construction and Building Materials*, vol. 158, pp. 337–345, 2018.

[10] C. Marthong and D. K. Sarma, "Influence of PET fiber geometry on the mechanical properties of concrete: an experimental investigation," *European Journal of Environmental and Civil Engineering*, vol. 20, no. 7, pp. 771–784, 2016.

[11] P. A. Vaccaro, A. P. Galvin, J. Ayuso, A. Barbudo, and A. L. Uceda, "Mechanical performance of concrete made with the addition of recycled macro plastic fibers," *Applied Sciences*, vol. 11, no. 9862, pp. 1–13, 2021.

[12] O. C. Sayi and O. Eren, "Physical and durability properties of recycled polyethylene terephthalate (PET) fiber reinforced concrete," *European Journal of Environmental and Civil Engineering*, vol. 9, 2021.

[13] V. Patil and V. Shukla, "Use of PET fibre as constituent of concrete," *IJARIE*, vol. 3, no. 2, pp. 280–284, 2017.

[14] P. M. Europ, "Plastics - the facts 2020: an analysis of European plastics production, demand and waste data," *Plastics*, vol. 28, 2021.

[15] P. O. Awoyera, O. Olalusi, and C. O. Ekpe, "Plastic fiber-strengthened interlocking bricks for load bearing applications," *Innovative Infrastructure Solution*, vol. 6, no. 2, pp. 1–10, 2021.

[16] R. Sharma and P. P. Bansal, "Use of different forms of waste plastic in concrete - a review," *Journal of Cleaner Production*, vol. 112, pp. 473–482, 2016.

[17] A. Ghalfampour and T. Özbakkaloglu, *In New Trends Eco-Efficient and Recycled concrete*, pp. 59–85, Woodhead Publishing, Sawston, United Kingdom, 2019, https://www.plasticsandpolymersfacts.com/efficiencies/2020.

[18] Z. Wang, Z. Ma, and L. Li, "Flow-induced crystallization of polymers: molecular and thermodynamic considerations," *Macromolecules*, vol. 49, no. 5, pp. 1505–1517, 2016.

[19] M. Sahmaran and I. O. Yaman, "Hybrid fiber reinforced self-compacting concrete with a high-volume coarse fly ash," *Construction and Building Materials*, vol. 21, no. 1, pp. 150–156, 2007.

[20] D. Foti, "Use of recycled waste pet bottles fibers for the reinforcement of concrete," *Composite Structures*, vol. 96, pp. 396–404, 2013.

[21] H. Ataei, K. K. Anaraki, and R. Ma, "Mechanical properties of polyethylene terephthalate particle based concrete: a review," *Airfield and Highway*, vol. 1, pp. 57–68, 2017.

[22] E. Rahmani, M. Dehestani, M. H. A. Beygi, H. Allahyari, and I. M. Nikbin, "On the mechanical properties of concrete containing waste PET particles," *Construction and Building Materials*, vol. 47, pp. 1302–1308, 2013.

[23] Y.-W. Choi, D.-J. Moon, J.-S. Chung, and S.-K. Cho, "Effects of waste PET bottles aggregate on the properties of concrete," *Cement And Concrete Research*, vol. 35, no. 4, pp. 776–781, 2005.

[24] S. Mukhopadhyay and S. Khatana, "A review on the use of fibers in reinforced cementitious concrete," *Journal of Industrial Textiles*, vol. 45, no. 2, pp. 239–264, 2015.

[25] H. A. Ataei, K. K. Anaraki, and R. Ma, "Mechanical properties of polyethylene terephthalate particle based concrete: a review," *Airfield and Highway*, vol. 1, pp. 57–68, 2017.

[26] Z. Z. Ismail and E. A. Al-Hashmi, "Use of waste plastic in concrete mixture as aggregate replacement," *Waste Management*, vol. 28, no. 11, pp. 2041–2047, 2008.

[27] R. P. Borg, O. Baldacchino, and L. Ferrara, "Early age performance and mechanical characteristics of recycled PET fibre reinforced concrete," *Construction and Building Materials*, vol. 108, pp. 29–47, 2016.

[28] F. Pelisser, O. R. K. Montedo, P. J. P. Gleize, and H. R. Roman, "Mechanical properties of recycled PET fibers in concrete," *Materials Research*, vol. 15, no. 4, pp. 679–686, 2012.
[28] Ppc, Product Datasheet PPC Suretech 55,5N Cement, PPC, Johannesburg, Africa, 2018.
[29] E. Ace, Fibre Plast Con, Eco Ace, Johannesburg, Africa, 2020.
[30] A. Meza, P. Pujadas, L. M. Meza, F. Pardo-Bosch, and R. D. López-Carreño, “Mechanical optimization of concrete with recycled PET fibres based on a statistical-experimental study,” Materials, vol. 14, no. 2, p. 240, 2021.
[31] S 5863:2006, Sampling of Freshly Mixed Concrete, The South African Bureau of Standards, Pretoria, Africa, 2006.
[32] SANS5861-1, Mixing Fresh Concrete in the Laboratory, South African Bureau of Standards, Johannesburg, Africa, 2006.
[33] ASTM C806-02, Standard Test Method for Rebound Number of Hardened concrete, ASTM International, West Conshohocken, PA, USA, 2004.
[34] S5863:2006, Flexural Strength of Hardened concrete, The South African Bureau of Standards, Pretoria, Africa, 2006.
[35] ASTM C78, Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading), American Standard of Testing Materials International, West Conshohocken, PA, USA, 2010.
[36] ASTM C496, Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens, American Standard of Testing Materials International, West Conshohocken, PA, USA, 2010.
[37] A. Hasan, N. Maroof, and Y. Ibrahim, “Effects of polypropylene fiber content on strength and workability properties of concrete,” Polytechnic Journal, vol. 9, no. 1, pp. 7–12, 2019.
[38] S. Govindasami, P. Sakhivel, and R. Harish, “Strength assessment of polypropylene fibre reinforced concrete (PPFRC),” International Journal of Engineering & Technology, vol. 7, no. 3.34, pp. 436–438, 2018.
[39] R. Baboo, T. Rushad, K. Bhavesh, and K. Duggal, “Study of waste plastic mix concrete with plasticizer,” International Scholarly Research Notices, vol. 20, pp. 2–5, 2012.
[40] A. Nkem Ede and A. Oluwabambi Ige, “Optimal polypropylene fiber content for improved compressive and flexural strength of concrete,” IOSR Journal of Mechanical and Civil Engineering, vol. 11, no. 3, pp. 129–135, 2014.
[41] M. A. Mashrei, A. S. Ali, and A. M. Mahdi, “Effects of polypropylene fibers on compressive and flexural strength of concrete material,” International Journal of Civil Engineering & Technology, vol. 9, no. 11, pp. 2208–2217, 2018.
[42] I. U. Richie and S. C. Daniel, “The effect of using polyethylene terephthalate as an additive on the flexural and compressive strength of concrete,” Heliyon, vol. 6, 2020.
[43] M. F. Nuruddin, S. Ullah Khan, N. Shafiq, and T. Ayub, “Strength prediction models for PVA fiber-reinforced high-strength concrete,” Journal of Materials in Civil Engineering, vol. 27, no. 12, Article ID 04015034, 2015.
[44] S. Silva and T. Prasanthan, “Application of recycled PET fibers for concrete floors,” Engineer, vol. 52, no. 1, p. 27, 2019.
[45] J. M. Irwan, “Development of mix design nomograph for polyethylene terephthalate fiber concrete,” Applied Mechanics and Materials, vol. 253-255, pp. 408–416, 2013.