ASPS Conference Proceedings 1: 499-506 (2022)

Proceedings of

12th Structural Engineering Convention - An International Event (SEC 2022)

Available at https://asps-journals.com/index.php/acp

Chronology of Recycled Plastic Mathematical Models, Mechanical & Thermal Characterisation

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Paper ID - 040531

Abstract

Recycled plastic fibers restrict the characteristics of hardened concrete. They offer no considerable ductility after the initial fracture. Their capacity to prevent bleed and separation helps preserve the original water-cemetery ratio of the surface mortar, thereby enhancing the abrasion resistance. Recycled plastic fibers can be efficient in dispersing stresses and improving frost resistance. The spilling of concrete into the fire has also proven to reduce. Recycled plastic fibers enhance initial characteristics in sprayed concrete and decrease the shedding and rebound. The tiny recycled plastic fibers, which should have similar structural advantages to steel fibers, must be distinguished from giant synthetic fibers. PP is fully resistant to acid and alkaline circumstances and is not affected by acid/alkaline environments, including marine conditions. Chemically PP is non-absorbent, i.e., no moisture absorption and associated characteristic changes.

Keywords:Mathematical model, Non-linear analysis, Thermal effect, Recycled plastic

1. Introduction

Recycled plastic fibers restrict the characteristics of hardened concrete. They offer no considerable ductility after the initial fracture. Their capacity to prevent bleed and separation helps preserve the original water-cemetery ratio of the surface mortar, thereby enhancing the abrasion resistance. Recycled plastic fibers can be efficient in dispersing stresses and improving frost resistance. The spilling of concrete into the fire has also proven to reduce. Recycled plastic fibers enhance initial characteristics in sprayed concrete and decrease the shedding and rebound. The tiny recycled plastic fibers, which should have similar structural advantages to steel fibers, must be distinguished from giant synthetic fibers. PP is fully resistant to acid and alkaline circumstances and is not affected by acid/alkaline environments, including marine conditions. Chemically PP is non-absorbent, i.e., no moisture absorption and associated characteristic changes. The recycled plastic market is expected to be worth USD 160.72 billion by 2028, with a growth rate of 3.70% from 2021 to 2028. The recycled plastic market research examines the present expansion, driven by the rising demand for electric cars. Recycled plastic is a thermoplastic substance used to produce molded objects or fibers. Recycled plastic fibers are made up of 85% propylene. The materials have enormous promise in many applications, especially in construction. The fast rise of the recycled plastic fiber market in recent years may be ascribed to the material's several advantages, including heat-insulating qualities, lightweight, durability, strong resistance to organic solvents, acids, alkalis, and others. According to this study, the amount of recycled plastic plastic waste created in India (CPCB, 2019) was 3,360,043 metric tonnes per year (roughly 9,200 metric tonnes per day). Given that total municipal solid trash output is 55-65 million metric tonnes, plastic pollution accounts for around 5-6% of solid waste in the country. Waste fiber fabric accumulates, accounting for nearly 30% of overall waste. Some organizations have implemented the usage of used clothing storage containers to limit the amount of life waste fiber fabric entering landfills. However, the impact of such collection remains modest due to the significant volume of this type of waste. As a result, researchers are interested in recycling and developing methods to minimize the issues created by its build-up.

2. Recycled plastic :literature review

The utilization of recycled plastic fibers is an assortment; thus, experimental investigations are carried out to characterize fiberbehavior in concrete and interface for numerous strength assets.

Grdic(Grdic et al., 2012) and Krishna Rao (Rao et al., 2016) examined recycled plastic fiber concrete. According to the authors, aggregate size, mix percentage, concrete strength, cementitious materials, fibers, and pores on the surface are all variables that impact the abrasion resistance of concrete.

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Published online: December 19, 2022
doi:10.38208/acp.v1.540

The fiber impacts on concrete mechanical characteristics are relatively modest at small volume fractions. A rigorous statistical analysis of a sufficient series of experiments would be necessary to discriminate between the natural fiber effects and random fluctuations in experimental findings. Recycled plastic fibers are consumed in reinforced concrete structures to augment cracking strength (Abid et al., 2018a), impact strength (J. Wang et al., 2019), and spalling resistance (Zhang et al., 2014).

The research also illustrates concrete matrix behavior using recycled plastic material in the periphery. The use of recycled plastic fibers varies; consequently, experimental studies characterize fiberbehavior in concrete and interface for various strength assets. The fibers help increase the strength and ductility of concrete under multiple types of stress (A.M. Alhozaimy et al., 1996). Fibers tend to increase the strain and absorb energy post ultimate load conditions (Mohammadhosseini et al., 2020). The outcomes of present experimental investigations bring to opted values that could estimate feasible fiber utilization in concrete. When constructing floors or pavements, abrasion resistance is a factor that affects the durability of concrete (Czarnecki, 2017; Li et al., 2006). The factors that influence abrasion resistance of concrete such as aggregate size (Rao et al., 2016), mix proportion, the strength of concrete, addition of cementitious ingredients, and fiber apertures on the surface (Grdic et al., 2012). The fiber consequences and concrete mechanical possessions depict small portions that exist infrequently. Recycled plastic fiber best-opted material in reinforced concrete structures to augment cracking strength (Abid et al., 2018a), impact strength (J. Wang et al., 2019), and spalling resistance (Mohammadhosseini et al., 2020).

Recently, Askari (Askari et al., 2020) demonstrated that employing a significant amount of Recycled plastic enhances loading capacity and flexibility. The mechanical properties of fiber concrete proposals have been improved. The primary goal of this composition is to provide information on the physical and mechanical characteristics of fiber cementation material. An investigation was carried out to demonstrate the crack zones of the material interface for various potencies. The recycled plastic concrete properties were investigated to determine the interface intensities and break region. Mechanical and microstructural methods have been used to characterize fiber concrete at various temperatures. The fiber influence adhesion with the fiber concrete matrix was examined by considering mass loss and mechanical interconnecting processes. The use of fiber is an essential component in green building and is classified as ecologically friendly. Green concrete is long-lasting concrete with a low environmental impact by replacing cement with natural aggregates made from recycled/waste materials or industrial by-products (Imran et al., 2018).

Malek (Małek et al., 2021) studied the impact of recycled plastic fiber addition on the mechanical characteristics of the concrete. The supplement of 0.3, 0.6, 0.9, 1.2, and 1.5 kg/m^3 of fibers utilized and compressive strengths obtained correspond to 0.062%, 0.12%, 0.19%, 0.25%, and 0.31% of cement mass, respectively, flexural strength increased by 4.1%, 8.2%, 14.3%, 20.4%, and 26.5%, respectively, while split tensile strength increased by 4.1%, 8.2%, 14.3%, 20.4%, and 26.5%. Furthermore, when fibers were added, the slump was reduced by 25.9%, 39.7%, 48.3%, 56.9%, and 65.5%, respectively, related to conventional concrete. Recycled plastic fibers have high flexural and splitting strength ratings.

3. Results and Discussion

Table 1. Physical characteristics of recycled plastic fiber

Particulars	Observations
Length	12 mm
Specific gravity	0.91 (g/cm^3)
Tensile strength	4.60 MPa
Melting point	175℃
Ignition point	590℃
Modulus of elasticity (GPa)	8.48

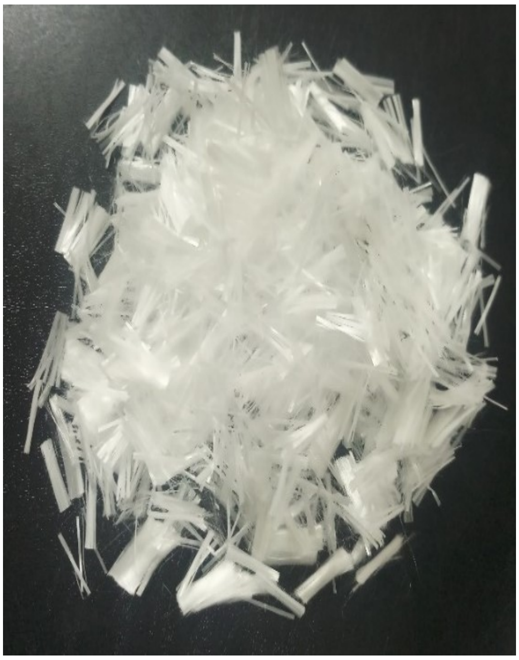

Fig. 1. Fibrillated mesh type recycled plastic fiber

Table 2. Concrete mix proportions in kg/m^3 for w/c ratio (0.4).

Recycled plastic (%)	**Cement**	**Fine Aggregate**	**Coarse Aggregate**	**Recycled plastic**	**Admixture (%)**
0	380	862.78	1137	0	1.20
0.25	380	862.78	1137	2.15	1.45
0.30	380	862.78	1137	2.59	1.65
0.35	380	862.78	1137	3.01	1.80
0.40	380	862.78	1137	3.45	2.20
0.45	380	862.78	1137	3.88	2.40
0.50	380	862.78	1137	4.31	2.45

Six concrete mixes with recycled plastic fibers were cast at a single water/cement ratio of 0.40. The supplement of PP was made in proportions of 0% (P0.0), 0.25% (P25), 0.3% (P30), 0.35% (P35), 0.4% (P40), 0.45% (P45), and 0.5% (P50) in order to prove the exact optimum substitution level. Supplement with PP was made on a volume basis. The superplasticizer dosage was varied from 1.2% to 2.41% to achieve a compaction factor of 0.9, as shown in Table 2.

The morphology of recycled plastic fiber utilized in this work is depicted in FIGURE 6 using FESEM, which exhibits a smooth texture on the surface. The elemental analysis of PP was determined by Energy Diffraction X-ray Analysis (EDAX), as illustrated in FIGURE 2. The elemental constitution of PP as determined by EDAX is shown in Table 3.

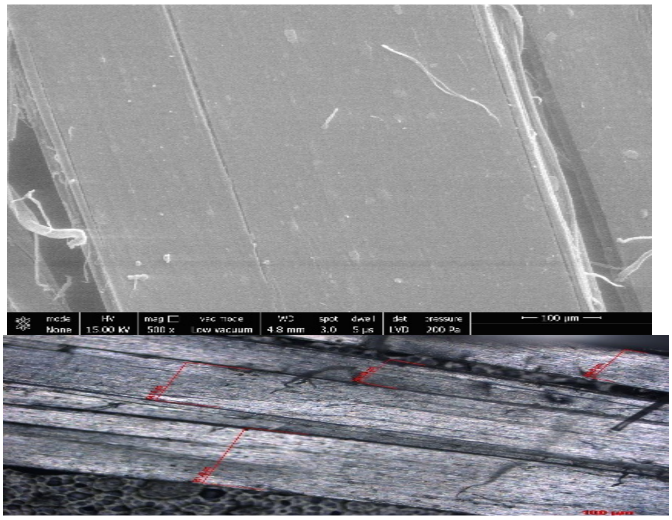

Fig. 2. FESEM and OM of recycled plastic fiber

Table 3. Element elements of recycled plastic fiber

Element Composition	Symbol	Percentage
Carbon	C	89.79
Oxygen	O	8.23
Silicon	Si	1.25
Manganese	Mg	0.73

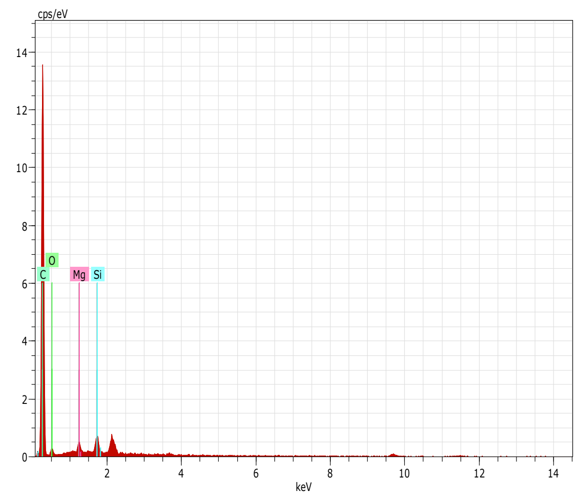

Fig. 3.Edax of recycled plastic fiberrecycled plastic : mechanical properties.

Table 4. Workability of fresh Recycled plastic fiber concrete

Mix Designation	Admixture (%)	Compaction Factor
P00	1.20	0.9
P25	1.45	0.91
P30	1.65	0.9
P35	1.80	0.91
P40	2.20	0.92
P45	2.40	0.91
P50	2.41	0.9

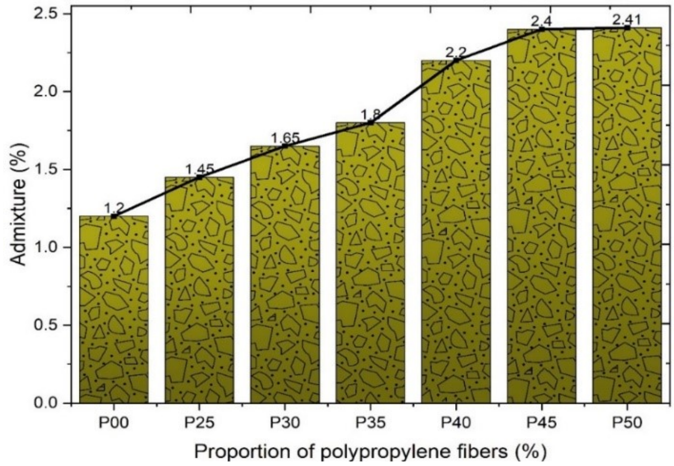

Fig. 4. Admixture quantity for recycled plastic concrete mixes

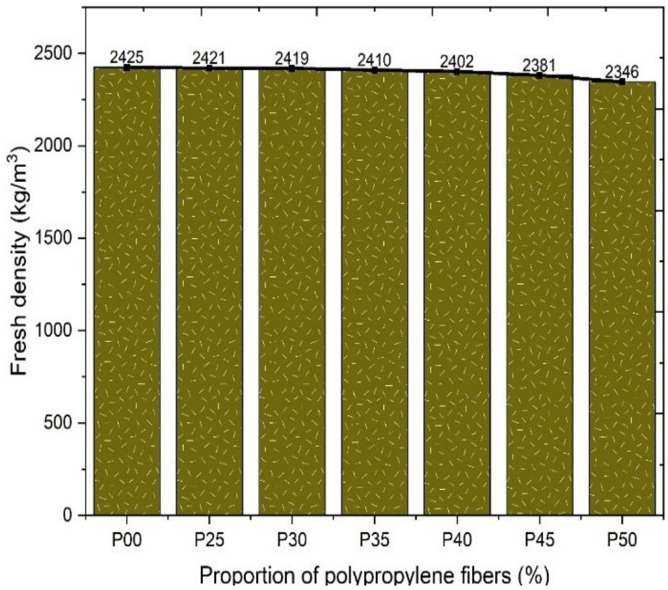

Fig. 5. Bulk density of fresh concrete

Table 5.Physical characteristics of recycled plastic fiber

Particulars	Observations
Length	12 mm
Specific gravity	0.91 (g/cm^3)
Tensile strength	4.60 MPa
Melting point	175℃
Ignition point	590℃
Modulus of elasticity (GPa)	8.48

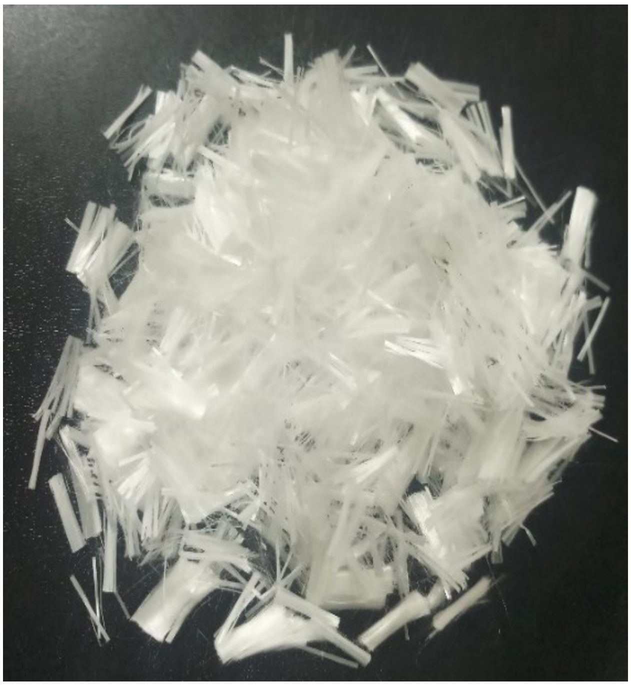

Fig.6. Fibrillated mesh type recycled plastic fiber

Table6. Concrete mix proportions in kg/m^3 for w/c ratio (0.4)

Recycl ed plastic (%)	**Ceme nt**	**Fine Aggreg ate**	**Coarse Aggreg ate**	**Recycl ed plastic**	**Admixt ure (%)**
0	380	862.78	1137	0	1.20
0.25	380	862.78	1137	2.15	1.45
0.30	380	862.78	1137	2.59	1.65
0.35	380	862.78	1137	3.01	1.80
0.40	380	862.78	1137	3.45	2.20
0.45	380	862.78	1137	3.88	2.40
0.50	380	862.78	1137	4.31	2.45

Six concrete mixes with recycled plastic fibers were cast at a single water/cement ratio of 0.40. The supplement of PP was made in proportions of 0% (P0.0), 0.25% (P25), 0.3% (P30), 0.35% (P35), 0.4% (P40), 0.45% (P45), and 0.5% (P50) in order to prove the exact optimum substitution level. Supplement with PP was made on a volume basis. The superplasticizer dosage was varied from 1.2% to 2.41% to achieve a compaction factor of 0.9, as shown in Table 2.
The morphology of recycled plastic fiber utilized in this work is depicted in FIGURE 6 using FESEM, which exhibits a smooth texture on the surface. The elemental analysis of PP was determined by Energy Diffraction X-ray Analysis (EDAX), as illustrated in FIGURE 7. The elemental constitution of PP as determined by EDAX is shown in Table 3.

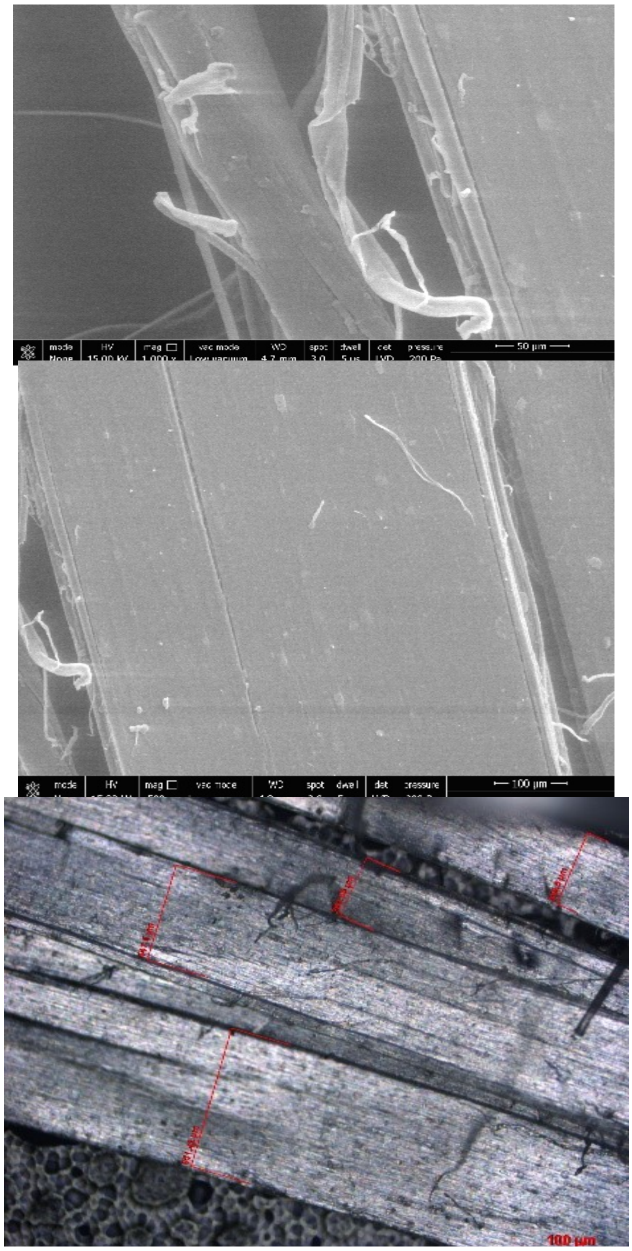

Fig.7. FESEM and OM of recycled plastic fiber

Table 7. Element elements of recycled plastic fiber

Element Composition	Symbol	Percentage
Carbon	C	89.79
Oxygen	O	8.23
Silicon	Si	1.25
Manganese	Mg	0.73

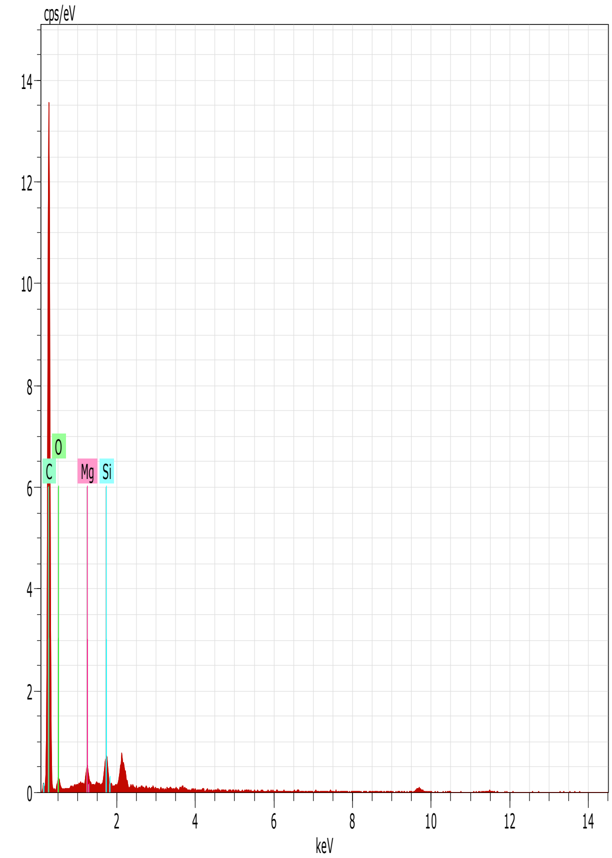

Fig. 8. EDAX of Recycled plastic fiber

Table 8.Workability of fresh Recycled plastic fiber concrete

Mix Designation	Admixture (%)	Compaction Factor
P00	1.20	0.9
P25	1.45	0.91
P30	1.65	0.9
P35	1.80	0.91
P40	2.20	0.92
P45	2.40	0.91
P50	2.41	0.9

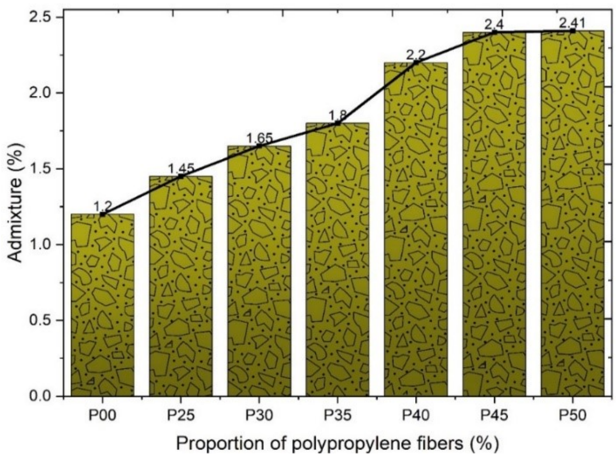

Fig.9. Admixture quantity for recycled plastic concrete mixes.

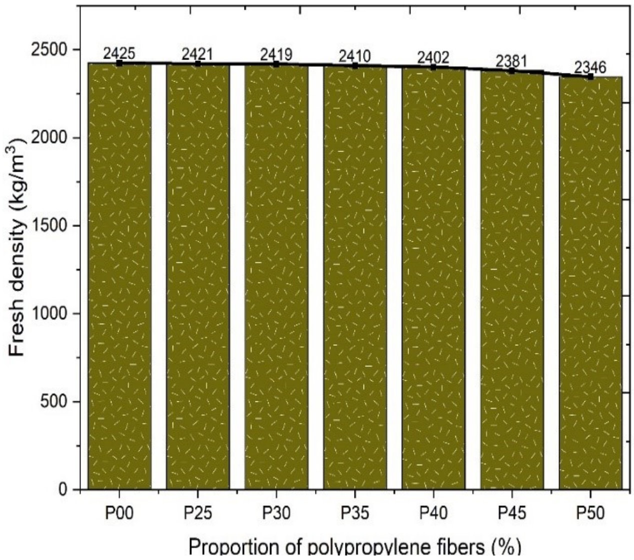

Fig. 10. Bulk density of fresh concrete

3.1 Fresh Bulk Density

The fresh bulk density of PP concrete mixes is depicted in FIGURE 9. The precise figure indicates that the density decreases as the quantity of fine aggregate substituted with PP rises. At 0.25% and 0.5% substitution levels, the loss in fresh density is 0.16% and 3.25%, correspondingly. Recycled plastic has a specific gravity of 0.91, less than fine aggregates (2.61). As a result of the lower specific gravity of waste PP, it may be attributed to the lower density of PP concrete.

3.2 Compressive Strength

FIGURE 10depicts the investigation carried out at 7, 28, and 60 days of water-cured compressive strength of recycled plastic fiber concrete. The performance of force improved to various extents in supplementing fiber content. FIGURE 10shows that adding fiber to concrete mix affirms the positive effect in strength in P35 fiber content w.r.t magnitude of 8% and 11%, 10.5% for 7, 28, and 60-daysrecycled plastic fibers compared to control mix strength, respectively. The strength increment might be due to good bonding with microfilaments concrete over the control mix, resisting the sudden failure. The researchers Topcu(Topçu and Canbaz, 2007) and Kakooei(Kakooei et al., 2012) tested on 2 kg/m^{3} of recycled plastic fiber added to the conventional mix. They observed a significant increase of strength up to sustain proportions. The utilization of microfilament fibers could reduce the crack formation and thus lead to increased strength. Grdic(Grdic et al., 2012) also reported that the strength increment was noticed at an average of 7% and 8% when adding 12mm microfilaments fibers. Hsie(Hsie et al., 2008) scrutinized the monofilament and staple fibers increase the proportion of 3kg/m^{3}, 6kg/m^{3}, and 9kg/m^{3} can increase strength by 4.65%, 9.12%, and 13.24%, respectively. This growth of strength due to monofilament fiber has a high modulus of elasticity and stiffer rough shape of hybrid fiber when these fibers are at high content.

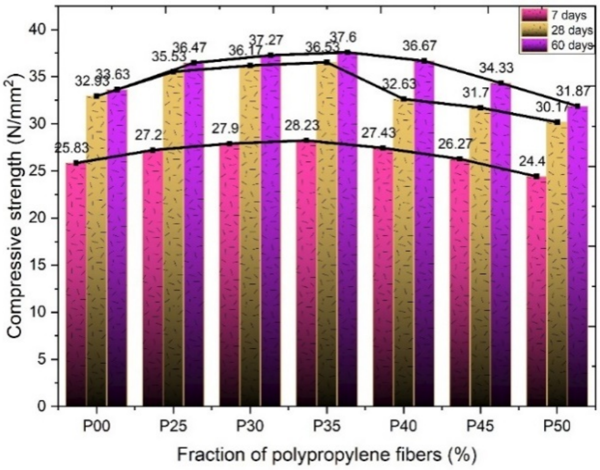

Fig. 11. Compressive strength of fiber concrete

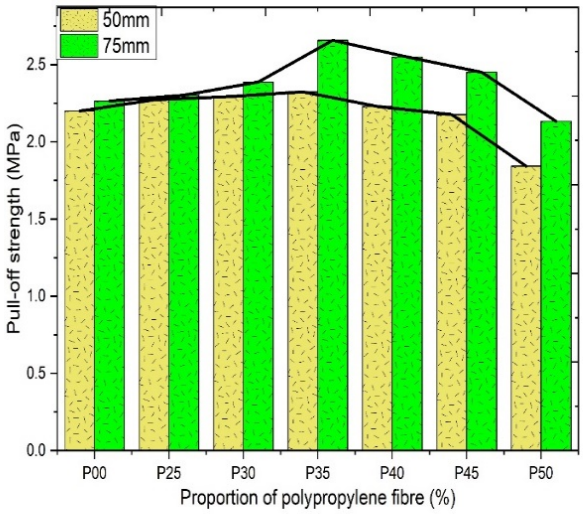

Fig. 12. Pull-off strength for concrete

Table 9.Pull-off strength for recycled plastic fiber concrete at 50 and 75mm core cut

Mix Designation	50mm	75mm
P00	2.20	2.26
P25	2.27	2.30
P30	2.30	2.39
P35	2.32	2.66
P40	2.23	2.55
P45	2.18	2.45
P50	1.84	2.13

The fire durability insists on (a) structural stability, (b) integrity, and (c) thermal insulation with the concrete mix PPC designed as M25 grade of concrete along the water-to-cement ratio of 0.4. Table 6 restricts the concrete and reinforcement characteristics of the furnace fire raised by a few hours in the test area at a disguised power of 0.65Gcal/h. A heating capacity of 0.4Mcal/h at the bottom and surface top at 0.25Mcal/h were adjusted. The structural fire, according to Equation (1).

$$\theta_g\text{-}\theta_g(0) = 345 \log(8t + 1) \quad (1)$$

where: θg = temperature of atmospheric gases at the moment t, in ºC; $\theta_g(0)$ = temperature of atmospheric gases at the moment t=0, in ºC; and t = time, in minutes. Fire resistance is the performance measurement of a full system or structure when subjected to normal heating conditions. It is not the attribute of a specific material. When evaluating and selecting a passive fire prevention system, three important performance characteristics, stability, integrity, and insulation, are assessed (Lu et al., 2016; Ramachandra Murthy et al., 2012).

The structural stability was performed by Indian codes IS:3809 (BIS:3809, 2014), IS:1642 (BIS:1642, 1998), and IS (SP):7 (Indian Standards Institution., 1970), which consists in applying an impact load in a pendulum movement in providing the energy of 20J. The impact test is done at distinct places and at various times. Further, the samples are analyzed for deformation, the occurrence of collapse, and any indication of instability or damage. The impact test validates stability by perceiving deformations, strain anomalies, cracks, and corresponding stresses.

3.3 Ultimate Characteristics

At the belief of hearth place, panels have been decoupled from the vertical furnace to carry out a visible inspection. It turned determined that the cloth used to seal the joints of the panels, for all samples, withstood nicely to hearth place trying out and offered adjustments most effective in appearance. Before exposure, it had plastic and form reminiscence form; after deformation, the cloth lowered back to its normal state. FIGURE 36 offers the very last aspects of the samples, in which it is miles viable to word the prevalence of concrete spalling on the models with PC and RC panels in addition to immoderate deformation.
Through the observations in FIGURE 16, it is miles viable to word that the pattern with PC panels, the concrete cowl of the prestressed tendons turned into completely spalled in a greater extreme prevalence close to the pinnacle of the panel, in which substantial loss reached the panel's complete pass segment. The pattern with RC panels offered the floor concrete spalling, exposing the reinforcement bars in

Table 10.Summary of specimen characteristics

Type of panel	Panel size (m)	Concrete (MPa)	Fiber	Reinforcement
Prestressed concrete (PC)	0.3 x 0.3 x 0.1	25	None	Tendons of 12mm
Reinforced concrete (RC)	0.3 x 0.3 x 0.1	25	None	Diameter 2-25mm
Recycled plastic Reinforced concrete (PRC)	0.3 x 0.3 x 0.1	25	2 kg/m³	Two steel bars diameter of 25mm

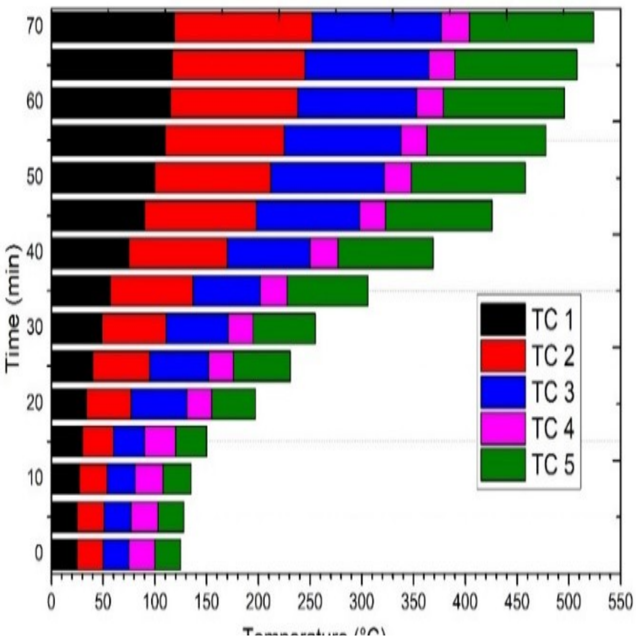

Fig. 13. Temperature measurements of external surface with PC panels

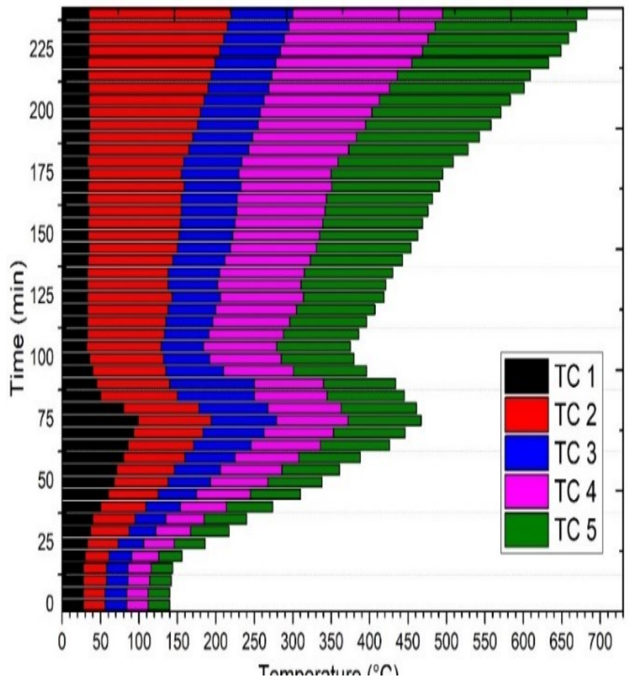

Fig.14. Temperature measurements of external surface with RC panels

locations with extra intensity, particularly on the lowest plate (Moghal et al., 2017). On the other hand, the pattern with PRC panels offered the prevalence of superficial spalling in a few points, not using a lack of detail segment and keeping its structural stability. From the above Equation (Eq. 1), the unknown quantity is θ_g. Initial temperature considered $\theta_g(0)$ is 200°C at time t=0. FIGURE 14shows the computational calculation at various time (minutes) intervals changing in the radiation (θ) obtained. It has been observed that up to 600°C, a slight increment was observed due to the sustainability of concrete. When it comes to 800°C, the deformations increased rapidly.

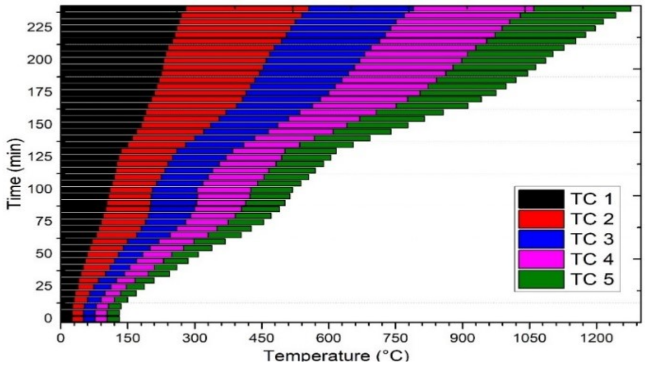

Fig. 15. Temperature measurements of sample external surface with PRC panels

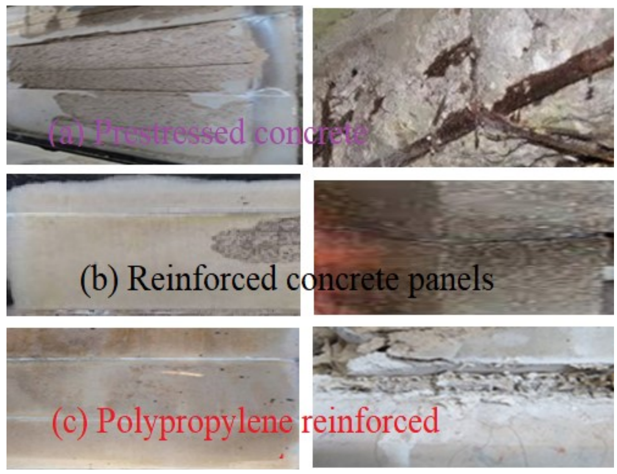

Fig. 16.Test samples after fire

4. Conclusions

The mechanical, durability, and microstructural tests were performed, and subsequent conclusions are drawn below based on the experimental investigation.

1. The workability (flowability of the mix) and fresh density drop as the percentage of fibrillated mesh-type recycled plasticfibers in the concrete increases. The flowability of the recycled plasticfibers decreases due to their low specific gravity and large surface area.
2. The compressive strength of fiber concrete increases by increasing fiber content up to 0.35%. It is due to the excellent bonding of microfilaments and concrete mix, and it could resist the suddenly applied loads when the optimum percentile (0.35) of fibers was present.
3. The flexural strength of fiber concrete improved compared with non-fiber concrete mix. It might be due to the utilization of fiber playing a role in bridge action between pores and arresting the growth of the cracks.
4. The density of recycled plastic concrete decreased slightly with an increase in additional levels. It is due to the less specific gravity of recycled plasticfiber than the fine aggregate.

Disclosures

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