Characterization of strength and toughness properties of metalized plastic waste fibre reinforced concrete

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Abstract. Recycling of plastic waste in concrete has drawn much attention nowadays. The influence of metalized plastic waste fibres on M30 grade concrete was investigated in this study. Strength and toughness properties were evaluated and compared with the control concrete made without addition of fibres. Fibre dosages 0%, 0.25%, 0.5% and 0.75% are taken as a parameter of study. The mechanical properties such as compressive strength, split tensile strength and flexural strength were analyzed to understand the performance of the metalized plastic waste fiber reinforced concrete. Load–deflection curves are plotted to estimate the toughness (energy absorption capacity) characteristics of the composite at the age of 28 days. Increase in MPW fibre content in concrete improved the split tensile strength up to 54% and flexural strength up to 58%, but marginal improvement in compressive strength is observed. MPW fibre reinforced concrete outperformed in flexural toughness and it exhibited 2.92 folds superior toughness with 0.75% fibre addition when compared to 0.25%.

I Introduction
Concrete is the most widely used construction material and conventional concrete exhibits high brittle behaviour because of its weak resistance to crack occurrence. The inherent nature of these cementitious materials shows less tensile strength and poor strain capacity [1]. Incorporation of short and randomly distributed fibres in composite improves the tensile strength, toughness and ductility performance and this Fibre Reinforced Concrete (FRC) has got extensive applications in Civil engineering. Fibres enhance the mechanical properties of concrete and they are available in various types such as metallic, polymeric and natural etc [2]. Fibre plays a significant role in enhancing the post-cracking response and toughness of the concrete and it is proven through many theoretical and experimental stand points [3]. Addition of plastic waste in concrete is a recent research and it is added in various forms namely polyethylene terephthalate bottles (PET), polypropylene and polyethylene bags etc. The development of fibre reinforced concrete with plastic waste is an effective measure in overcoming the serious shortfalls in concrete and it ensures a safe disposal of solid waste collected in huge amount. Plastic waste in concrete improves post-cracking tensile strength, brittleness and ductile behaviour of concrete.

Due to the rapid industrialization and mechanical inventions lot of waste materials are generated and among this plastic waste is non-bio degradable and it is unfit for reprocessing or reuse. Our modern food habit system generates large amount of Metalized Plastic Waste (MPW) and it is one of the recent garbage produced by the food packaging industry. These metalized plastic sheets are made...
from polymers coated with thin sheets of aluminium as shown in Figure 1[4]. It occupies 40% of the
land fill and its rate of degradation is extremely low which persist for a long period causes serious
environmental problems.
Hence utilization of this waste product in concrete will provide a better solution for the waste
management strategy worldwide. In last few decades several investigations were carried out to
explore the properties of various kinds of plastic waste in concrete. Considering the availability of
huge amount of metalized plastic waste, an effort has been attempted to study the influence of
metalized plastic waste in concrete.

![Figure 1. Metalized Plastic waste](image)

Therefore the utilization of post-consumer plastic waste such as PET bottles, polyethylene and
polypropylene bags in concrete and the influence of different types of plastic waste on various
properties of concrete are clearly understood through experimental studies. The improvement in
impact strength and mechanical properties are studied with the incorporation of 20mm long carpet
fibres at 0%-1.25% volume fractions [5]. Zhang et al. verified the addition of polypropylene fibres
decreases the durability and increases the freeze–thaw resistance with the increase in fibre volume
fraction [6]. Thorneycroft et al. studied the mechanical properties of concrete with recycled plastic
waste material as a sand replacement [7]. Foti et al. results show the possibility of PET as fibres to
improve the ductility of concrete [8]. Saikia et al. evaluated the fresh and hardened properties of
plastic aggregate concrete [9]. Yin et al. reported the excellent post-cracking performance of
recycled PP fibre in M40 grade concrete [10]. Ghermouti et al. examined the fresh and hardened
properties of plastic bag waste fibres in self-compacting concrete and concluded the presence of
these fibres delayed the location of the micro cracks. Improvement in flexural and split tensile
strength of cement composite is varied between 4% to 74% [11]. Paul Borg et al. investigated the
Shredded PET fibres in different lengths mitigated the plastic and drying shrinkage cracks in
concrete and it becomes a potential alternate material [12]. Mohammadhosseini et al. combined the
MPWfibres and palm oil fuel ash to examine the durability properties of concrete. Research results
show the positive interaction between them and significant improvement in durability performance
[4]. Fraternali et al investigated the fresh and hardened properties of recycled polyethylene
tetraphthalatetfibre reinforced concrete (RPETRC) in aggressive sea water environment and air-cured
RPETRC specimens highlighted the influence of fibres in concrete [13]. Torgal et al discussed the
effect of PET wastes and tyre rubber on fresh and hardened concrete properties [14]. However
limited studies are available on the utilization of metalized waste fibers produced from the
package of food products. Therefore, this paper focused on the effect of metalized plastic waste on
important mechanical properties such as strength, toughness and load-deflection behaviour of
concrete.

2 Materials and Methods
2.1 Raw Materials and Mixture proportions
Ordinary Portland Cement 43 grade with specific gravity 3.13 was used in this study. Manufactured Sand (M Sand) passing through 4.75 mm sieve was used as fine aggregate and the specific gravity and water absorption are measured as 2.53 and 2.66 percent respectively. Locally available angular aggregates passing through 20 mm and retained on 12mm sieve is used as coarse aggregate and it confirms to IS 383:1970 specifications [15]. Fineness modulus of coarse and fine aggregate is 4.74 and 3.24. Based on the raw material characteristic the mixture proportion of M30 grade concrete is arrived with reference to IS 10262:2000 guidelines [16]. Mixture proportion used in this investigation is 1:1.74:2.84 with a water-cement ratio 0.4. In order to facilitate the dispersion of fibres along with the cement particles a water reducing admixture FOSROCCONSPLAST WL is used in this experimental study.

2.2 Metallized Plastic waste fiber (MPW)

MPW is a waste of packaged food products like biscuit packets, chips packets, and sweet wrappers and they are coated with metallic film inside. These plastic wastes are produced by polypropylene elements and it is not suitable for any recycling process. Hence it could be utilized as a fibre in this experimental study. They are prepared by cutting the MPW collected from chips packet, biscuit packet, and sweet wrappers and it is cut into a length of 35mm using scissors and rulers is shown in Figure 2(a). The shredded metalized plastic waste fibres 35mm long used in the casting stage are shown in Figure. 2(b). The main properties of metalized plastic waste fibre are collected from earlier literature and listed in Table 1[4].

![Figure 2(a). MPW Fiber 35mm long](image)

![Figure 2(b). Shredded MPWfibres](image)

| Properties                  | Values                      |
|-----------------------------|-----------------------------|
| Resin category              | Polypropylene               |
| Plastic Type                | LDPE                        |
| Density range               | 0.925 -0.94 g/cm³           |
| Thickness                   | 0.08mm                      |
| Water vapour resistance     | Good                        |
| Oxygen permeability         | High                        |
| Tensile strength (Tested)   | 800 N/mm²                   |
| Elongation                  | 8-10%                       |
| Co-efficient of friction    | 0.45– 0.55                  |
2.3 Preparation of test specimens

Metalized plastic waste concrete specimens are prepared as per the following procedure. All the constituents are weighed and kept ready before mixing and firstly the dry aggregates are poured and mixed in the pan mixer of 40 litres capacity. Secondly, the cement is added to the mixer and thoroughly mixed for two minutes. Soon afterward water and super plasticizer are mixed together and added to the mixture. Finally, metalized plastic waste fibres are dispersed and mixing is continued for further 2 minutes to achieve the well dispersion of fibres in the concrete. Fibres are added at 0.25%, 0.5%, and 0.75% volume fractions and for each type of fibre fraction the standard size test specimens were prepared. Control concrete specimens are made without fibres. After 24 hours of casting, test specimens were demoulded and kept under immersion curing for 28 days. Specimens are labelled according to the volume fraction of fibres and they tested for various strength and toughness properties.

2.3 Test methods

In this experimental program, the hardened concrete properties are evaluated as per the relevant procedures laid in Indian standards.

2.4.1 Testing of Compressive Strength

Compressive strength test is conducted on cube specimens of size 150 x150x150mm in a compression testing machine of 2000kN capacity at the age of 28 days. Three cubes are tested for each group and the average of three is reported as the final results. Compression test on cubes is conducted as per the guidelines given in IS 516-1959[17]. Test set up is shown in Figure. 3(a).

2.4.2 Testing of splitting tensile strength

Split tensile strength test is conducted on 150mm x 300mm long cylinders to determine the indirect split tensile strength as per IS 5816:1999 procedure [18]. For each series, three specimens are tested at the age of 28 days and the testing arrangement is shown in Figure. 3(b). The ultimate load at failure is noted and the split tensile strength is calculated.

2.4.3 Testing of Flexural Strength

The flexural strength test is conducted as per IS 516 -1959[17] guideline on 500 x100x100 mm (length x width x height) prism specimens and three-point bending testing is shown in Figure 4. Three specimens are tested for each group and flexural strength is calculated and reported in Table 2.

2.4.4 Flexural toughness measurement

This test is carried out to evaluate the flexural toughness on same size prism specimens at the age of 28 days in a 600kN universal testing machine and the test setup is given in Figure 5. Specimens are tested for a three-point loading to obtain a load –deflection curve as per ASTM C 1018[19]. Mid span deflections are measured using a suitable data acquisition system provided with the universal testing machine. Load Vs deflection plots are made for all the series of tested specimens.
These curves are further analysed to obtain the energy absorption capacity (toughness) of these composites.

Figure 4. Three point bending testing  

Figure 5. Flexural toughness testing

3 Results and Discussion

The results of compressive, split tensile and flexural strength of concrete tested at 28 days are given in Table 2.

| Series    | Compressive strength MPa | Split tensile strength MPa | Flexural Strength MPa |
|-----------|--------------------------|---------------------------|-----------------------|
| CC        | 36.15                    | 4.35                      | 4.33                  |
| MPWC 0.25 | 37.30                    | 4.75                      | 4.83                  |
| MPWC 0.50 | 38.29                    | 5.57                      | 5.83                  |
| MPWC 0.75 | 39.21                    | 6.77                      | 6.83                  |

3.1 Effect of MPW fibre on compressive strength

From Table 2, it is understood that the compressive strength was influenced by the addition of MPWfibres and strength improvement is fully dependent on the dosage of fibre. The compressive strength was in the range of 36.15 MPa to 39.21 MPa and its variation is shown in Figure 6. When compared to Conventional Concrete series (CC) the compressive strength of the cube specimens reinforced with volume fraction 0.25%, 0.5% and 0.75% MPWfibres increases by 3.18%, 5.91% and 8.46% respectively. Since the MPWfibres are not as strong as aggregates to carry the compressive load applied, their improvement seems to be very marginal. No spalling is observed on the surface of the cube specimen because of the restrain offered by the MPWfibres in expanding the cracks.
3.2 Effect of MPW fibre on split tensile strength

Figure 7 shows the split tensile strength of MPW fibre concrete at 28 days. Split tensile strength was highly influenced by the fraction of MPW fibres because of the crack bridging effect and presence of these MPW fibres increases the post cracking tensile properties of the cylindrical specimens. Split tensile strength was in the range of 4.35 MPa to 6.77 MPa. When compared to plain concrete mixture the addition of 0.25%, 0.5% and 0.75% MPW fibres improves the split tensile strength by 9.19%, 28.04% and 55.63% respectively. This improvement in split tensile strength is due to the increase in crack resistance offered by the MPW fibres. After the formation of the initial crack, the tensile stresses across the failure cross section reduced the tensile displacements and improved their resistance to failure. This crack bridging mechanism under diagonal tension increases the split tensile strength to greater extent.

3.3 Effect of MPW fibre on flexural strength

Figure 8 shows the results of flexural performance of prismatic prisms tested under bending tests. Experimental results confirm the addition MPW fibre content increases flexural strength by 11.54% to 58% when compared to control concrete and changes the failure of the tested specimens from brittle to ductile. Plain concrete breaks into two pieces once the cracks occur, but the addition MPW fibres in the composite increases the tensile capacity even after the flexural cracking. This is because of the MPW fibres bridging across the cracks and reduced the width of the cracks thus proven its good reinforcing properties to the concrete.
3.4 Load -Deflection response

Table 3 summarizes the flexural toughness capacity of standard size prisms and Figure 9 represents the load deflection plot of MPWC0.75 series. For each series three specimens are tested and the area below the load–deformation curve is measured as toughness or energy absorption capacity of concrete composites. From Table 3 it is evident that the toughness improvement in Metalized Plastic Waste fibre concrete is significant when compared to control concrete. MPWC0.5 series have given as much as 1.92 folds higher than MPWC 0.25 series. Similarly, MPWC0.75 series has given 2.92 folds greater toughness than MPWC 0.25 series. So it is inferred that the tensile behaviour of the metalized plastic fibre allows the concrete composite to undergo a large amount of deformation without any sudden failure. The bridging capacity of fibres across the crack controls the crack growth and withstands a large amount of flexural load leads to the improved toughness.

| Series       | Toughness in N. mm |
|--------------|--------------------|
| CC           | Brittle failure    |
| MPWC 0.25    | 2285.98            |
| MPWC 0.50    | 4495.80            |
4 Conclusions

From the experimental investigation, the following points can be concluded:

- Fresh properties of the concrete are not affected by the inclusion of MPW fibres up to 0.75% and the mix is workable. It provides the proper dispersion of MPW fibers because of good workability.
- Addition of MPW fibres from 0.25% to 0.75% increases the compressive strength from 3.45% to 8.46% which is marginal compared to other properties. Split tensile strength increases with the addition of MPW fibres up to 55% and exhibits good resistance to tensile cracking. Flexural resistance enhanced even better than split tensile strength and 58% more than the conventional concrete.
- Toughness of MPW concrete has been improved up to 1.96 to 2.92 folds than the conventional concrete because of its ductile behaviour and large deformation.
- Since these MPW fibres are produced from the waste product they are cost-effective, when compared to other artificial fibres.

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