Effect of Waste Plastic Shreds on Bond Resistance between Concrete and Steel Reinforcement

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Abstract: This paper investigates the effect of waste plastic shreds on steel-concrete bond. Forty RILEM test specimens with 16mm and 20mm diameter high-yield reinforcing bars were cast and tested. Fifteen specimens with 16mm and 20mm each were cast with the addition of waste plastic shreds at varying percentages of 1%, 1.5% and 2%; another ten RILEM specimens with 16mm and 20mm diameter bars at 0% of waste plastic shreds were cast as reference. Nine 150mm cubes, with three taken from each batch of various percentages of waste plastic shreds, were used to monitor the concrete strength. From the test results and analysis, the compressive strength of concrete was found to reduce with increased percentages of waste plastic shreds, while the waste plastic shreds material was found not to improve the bond resistance between concrete and steel. However, though lower than normal concrete, there was an increase in the bond resistance with increase in the percent of plastic shreds. The bond resistance of 16mm was also found to be higher than that of 20mm in all the specimens tested.

1. Introduction
The use of plastic has grown substantially all over the world in the recent years, and this has created huge quantities of plastic waste in the environment. Plastic waste cannot be dumped in landfills because of its bulk and slow degradation rate; incorporation of plastic waste into concrete if found suitable could be one of the solutions for disposing it.

The use of methylcellulose (0.4% to 0.8% by weight of cement) as an admixture in cement paste or concrete was reported in [1]. This was found to increase the shear bond strength with steel rebar, steel fibre or carbon fibre to the values attained by using latex (20% by weight of cement) as an admixture. The bond strength increased with increasing methylcellulose amount. The combined use of silica fume

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(15% by weight of cement) and methylcellulose (0.4% by weight of cement) as admixtures was found to give concrete, apart from high bond strength to steel rebar, high tensile modulus, tensile ductility, flexural strength and flexural toughness.

Experimental investigations to study the suitability of the use of re-engineered plastics as fibres for road pavements were carried out in [2]. The properties studied include compressive strength, tensile strength, flexural strength under reversed cyclic loading, impact resistance, plastic shrinkage and abrasion resistance, etc. Efforts to compare it with steel fibres showed that the improvement of concrete properties at lower cost is obtained with re-engineered plastic shred reinforced concrete.

A laboratory experimental study carried out to utilize waste plastics (in the form of strips) obtained from milk pouches in the pavement construction was reported in [3]. Results of the study indicate that by adding plastic strips in the soil, shear strength, tensile strength and CBR values of the soil increased. In this study, plastic or polythene sheets having thickness of 0.5mm and which were made up of high density were used. Three types of plastic strips were used in the study to act as a reinforcing material. The first one was cut into 20mm x 40mm size, second one was 25mm x 50mm size and the third one was of 30mm x 60mm size. These plastic strips have innumerable advantageous properties like high tensile strength, low permeability etc. These plastic strips act as a good barrier to gases and liquids and are unaffected by cycles of wetting and drying. For all the strips used in the experimental work, an aspect ratio of 2 was maintained.

An investigation on the improvement of bond strength of epoxy coated bars using stirrups was reported in [4]. Three beam sizes (300mm x 230mm, 300mm x 200mm, and 300mm x 180mm) were used with 28mm, 20mm, 16mm diameter high yield bars, the stirrups used were 8mm and 10mm diameter high yield bars. It was found that stirrups improved the bond efficiency of epoxy coated bars, it was also reported that application of coating materials in sequence and as a mixture on coated bars improved bond strength. Epoxy was applied first and then tyrolin was later applied. The two materials were also mixed together and applied; the results gave higher bond efficiency. Simple lap spliced beams were used in a four point loading system. The two methods improved bond but application in sequence gave higher bond strength.

Polyethylene terephthalate and high density polypropylene (disposable glass) fibres were studied in [5]. The parameters investigated were workability, compressive strength and flexural peak load of concrete. The cubes of size 150 mm and slabs of size 740mm x 740mm x 50mm were cast to determine the compressive strength and flexural peak load respectively. It was observed that slump and compaction factor was increased on addition of 1% of HDPP fibres and 2% of PET fibres. The compressive strength of cubes was increased by 4.2 % with 1% HDPP fibres and 5.63 % with 1% PET fibres. The flexural load before failure was also increased by using both the fibres. The bond strength was not studied.

Experimental work on compressive strength of cubes and cylinders, were used in [6] to study their behaviour under test. It was concluded that plastic strips have potential to act as a secondary reinforcement. From the above study, it was also concluded that the fibres made of recycled polyethylene terephthalate (PET) are appropriate for concrete reinforcement. The mixing ability of PET fibre is excellent and it is a promising material to reinforce the concrete. In view of this, attempt is being made to investigate the bond strength of such concrete.

The effect of increased cover on bond efficiency of coated reinforcing bars was studied in [7]. Increased concrete cover was found to increase bond efficiency of coated reinforcing bars, but the increase was not proportional to the additional cover thickness.
Pullout test was used in [8] to analyze the bond behaviour between different kinds of carbon and glass Fibre Reinforced Plastic (FRP) bars with different surface configurations and two concrete strengths. The result confirmed the trend of rebars with larger diameter developing lower bond strength, especially for high concrete strength series. An increase in bond strength and change in failure surface were observed when concrete compressive strength was increased.

The effects of fibre surface area on the bond properties of the fibre were studied in [9]. It was shown that significant increase in surface area can be achieved by changing the cross-sectional shape, which in turn leads to an increase in bond strength. Fibre crimping further increases the bond strength. More importantly, it was also found out that crimped macro-synthetic fibres with modified cross sections (cross, star, etc.) can attain a bond stress versus bond slip relationship similar to that of steel fibres, characterized by a steep and linear elastic frictional bond component, followed by a “bend-over point” and a subsequent parabolic increase to the maximum bond stress.

Bond behaviour between steel reinforcement and recycled concrete was studied in [10]. It was concluded that the bond strength decreases with the increase of the percentage of recycled coarse aggregate used. Transverse reinforcement was reported in [11] to improve the bond strength of coated bars and the ductility of the beams.

The effect of fibre content on the interfacial bond properties of ultra-high performance fibre reinforced concrete was investigated in [12]. Test results showed that 3% steel fibre by volume yielded the best performance in terms of compressive strength, elastic modulus, shrinkage behavior and interfacial bond strength. These parameters improved as the fibre content was increased up to 3% volume. Flexural behaviours such as flexural strength, deflection, and crack mouth opening displacement at peak load had pseudo-linear relationships with the fibre content. Through inverse analysis, it was shown that fracture parameters including cohesive stress and fracture energy are significantly influenced by the fibre content: higher cohesive stress and fracture energy were achieved with higher fibre content.

This study is part of the continuing effort to investigate the bond properties of fibre-like materials with a view to generating data and improving knowledge on bond strength between concrete and steel, attempt to investigate the effect of waste plastic shreds on bond resistance between concrete and steel reinforcement, in order to see if it would improve bond. It is desirable and worthwhile.

2. Materials and methodology

2.1. Materials and samples preparation
The plastic waste was collected from a dump site, washed and shredded into fibre-like shape, figure 1. Ordinary Portland cement was used in this study. Fine aggregates used were river sand, while crushed granite of maximum nominal particle size of 12.5mm was used as coarse aggregate. The grading for the aggregate was done according to BS 1377 Parts 1 and 2. The uniformity coefficients (Cu) for the sand and granite were 5 and 5.4 respectively while their coefficients of curvature (Cc) were 1.36 and 1.0 respectively, figure 2. Potable water was used in producing the concrete mixture. The compressive mix ratio used was 1:2:4 (cement, sand and granite) with a water/cement ratio of 0.55. The waste plastic shredded material was added at varying percentages 0%, 1.0%, 1.5% and 2% by weight of concrete respectively.
Figure 1. Waste plastic shredded material.

| CLAY | fine | medium | coarse | SILT |
|------|------|--------|--------|------|
|      |      |        |        |      |
| SAND |      |        |        |      |
| GRAVEL |      |        |        |      |
| COBBLES |      |        |        |      |

Figure 2. Grain size distribution for sharp sand and coarse aggregate.
2.2. Preparation of steel reinforcement
The reinforcements used were high yield steel rods (16mm and 20mm) which were cut into lengths of 1100mm each to allow for effective gripping of the steel rod. The reinforcements were wire brushed and dusted. The cut length for 16mm and 20mm diameter bars was 1100mm (that is; 160mm within the cube, 50mm for the shorter end that resist pull and 890mm for the longer end where pull was applied). The encased region of the reinforcement as given by RILEM is 10D, where D is the diameter of bar. Half of this length (5D) was wrapped up with double layers of polythene to prevent bond between concrete and steel while the other half was left bare (unwrapped) in order to provide adhesion between the concrete and the reinforcement.

2.3. Testing of specimens
Before the commencement of the pull-out test, the RILEM specimens were kept under room temperature after the completion of the 28 days curing in water. Thereafter, each of the RILEM specimens and the strength cubes were weighed before they were finally taken to the machine for the pull-out and the compression testing.

In order to determine the bond resistance between concrete and steel reinforcement with waste plastic, the specimens were placed in the machine one after the other and it was carefully centralized between the upper and lower plates inside the frame, after which the tensile machine was loaded, and the reading at the time of pull out was recorded. The failure load was recorded for each of the specified variables, 0%, 1%, 1.5%, and 2% of each waste material (polypropylene plastic), including the reference. In the course of testing, at the point of failure, some of the RILEM specimens failed by splitting while some failed by slipping.

3. Results and discussion

3.1. Effect of waste plastic shredded material on compressive strength of concrete
The results of the compressive strength of 0% addition of waste plastic shreds material (polypropylene plastic) as compared to that of the 1%, 1.5% and 2% addition of waste plastic shreds is summarized in figure 3, table 1. For the normal concrete (0% plastic waste), the average cube strength is 27.48N/mm$^2$. For 1%, 1.5%, and 2% addition of plastic shreds, the observed average strengths are 23.85, 17.25 and 17.13N/mm$^2$ respectively. This reducing cube strength may be because the adhesion between polypropylene plastic and concrete depends largely upon the surface energy of the plastic. Metals in general have a high surface energy and are easier to bond with concrete, whereas plastics have a lower surface energy and are harder to bond with concrete. Hence, the decrease in compressive strength has been observed as waste shredded plastic content increases in the concrete mix.
Figure 3. Compressive strength of concrete at 0%, 1%, 1.5% and 2% addition of waste plastic shreds (Polypropylene plastic).

Table 1. Compressive Strength ($f_{cu}$) of Concrete at 28 days with varying percentages of waste plastic shreds (150mm x 150mm x 150mm).

| % of Plastic Shreds | Specimens ID | Maximum load (kN) | Cube Strength (N/mm$^2$) | Average Strength (N/mm$^2$) |
|---------------------|--------------|-------------------|--------------------------|----------------------------|
| 0                   | R01          | 680               | 30.00                    | 27.48                      |
|                     | R02          | 520               | 23.11                    |                            |
|                     | R03          | 660               | 29.33                    |                            |
|                     | P01          | 530               | 23.55                    |                            |
| 1.0                 | P02          | 555               | 24.67                    | 23.85                      |
|                     | P03          | 525               | 23.33                    |                            |
|                     | Q01          | 365               | 16.22                    |                            |
| 1.5                 | Q02          | 400               | 17.77                    | 17.25                      |
|                     | Q03          | 400               | 17.77                    |                            |
|                     | X01          | 295.5             | 13.13                    |                            |
| 2.0                 | X02          | 455.5             | 20.24                    | 17.13                      |
|                     | X03          | 406.0             | 18.02                    |                            |

3.2. Crack pattern
Various crack patterns were recorded with different sizes of reinforcement (16mm and 20mm) at varying percentages of addition of waste plastic shreds material to the concrete mix. The RILEM concrete specimens with addition of plastic waste shredded material for 16mm and 20mm diameter steel reinforcing bars failed majorly by slipping, figure 4, while that for normal concrete (0% waste shredded inclusion) failed majorly by splitting, figure 5. Slip failure was observed, this may have been due to waste plastic shredded material finding its way across the path of the crack, and also the
shredded plastics may have clustered around the steel reinforcement. The specimen tend to fail by slipping because the steel reinforcements slip off from the waste plastic shredded material due to the low energy surface of the plastic material and therefore the concrete did not bond to the steel reinforcement properly, hence slipping failure was observed during pull-out. The concrete with plastic shreds reached its maximum strength early due to the low friction between the plastic, concrete and the reinforcing bar.

3.3. Bond resistance of reinforced concrete with waste shredded plastic material
The results obtained from the tests gave the value of average bond stress of 1.61N/mm$^2$ for the specimens without addition of waste plastic shredded material (polypropylene plastic) with a few specimens failing by slipping, while the majority of the specimen failed by splitting. For the specimens with polypropylene plastic waste material the average bond stress of 0.85N/mm$^2$ was recorded at 1%, with all samples failing by slipping. The average bond stress of 1.1N/mm$^2$ at 1.5% addition of waste plastic shredded material was recorded, with all the samples failing by slipping, the average bond stress of 1.43N/mm$^2$ at 2% addition of waste plastic shredded material was recorded, with all the samples also failing by slipping. The results of samples cast with 20mm diameter bars gave the value of average bond stress of 0.79N/mm$^2$ at 1% addition of waste plastic shredded material, with all failing by slipping. The value of average bond stress of 1.09N/mm$^2$ at 1.5% addition of waste plastic shredded material (polypropylene plastic) was recorded with all the specimens failing by slipping, the value of average bond stress of 1.37N/mm$^2$ at 2% addition of waste plastic shredded was recorded with all the specimens failing by slipping, see figures 4 and 5, tables 2 and 3.

It was seen from the test results that the bigger the size of the specimens the lesser the bond strength. Samples with (200mm cube) 20mm diameter bars have bond resistance lesser than the samples (160mm cube) with 16mm diameter bars. This may be due to air pockets which settle below the steel bars during vibration which were with bigger diameter because of the bigger surface area. The graphs of bond stress for different percentages (0%, 1%, 1.5%, and 2%) are shown in figure 6.
Table 2. Bond Resistance and Crack Pattern of RILEM Specimens containing Plastic Shreds with 16mm Diameter bar.

| % Plastic Shreds | Specimen ID (160x160x160mm) | Bond Failure (kN) | Bond Resistance (N/mm²) | Average Bond Resistance (N/mm²) | Crack Pattern |
|------------------|------------------------------|-------------------|-------------------------|-------------------------------|---------------|
| 0                | R01                          | 80.442            | 1.82                    |                               | Split         |
|                  | R02                          | 86.328            | 1.95                    |                               | Split         |
|                  | R03                          | 77.499            | 1.75                    | 1.61                          | Split         |
|                  | R04                          | 51.012            | 1.15                    |                               | Slip          |
|                  | R05                          | 60.822            | 1.38                    |                               | Slip          |
| 1.0              | S01                          | 35.316            | 0.92                    |                               | Slip          |
|                  | S02                          | 29.924            | 0.78                    |                               | Slip          |
|                  | S03                          | 35.316            | 0.92                    | 0.85                          | Slip          |
|                  | S04                          | 33.354            | 0.87                    |                               | Slip          |
|                  | S05                          | 28.449            | 0.74                    |                               | Slip          |
| 1.5              | Y01                          | 33.354            | 1.20                    |                               | Slip          |
|                  | Y02                          | 31.392            | 1.13                    |                               | Slip          |
|                  | Y03                          | 29.430            | 1.06                    | 1.10                          | Slip          |
|                  | Y04                          | 26.487            | 0.96                    |                               | Slip          |
|                  | Y05                          | 31.392            | 1.13                    |                               | Slip          |
| 2.0              | Z01                          | 50.031            | 1.80                    |                               | Slip          |
|                  | Z02                          | 40.221            | 1.44                    |                               | Slip          |
|                  | Z03                          | 36.297            | 1.30                    | 1.43                          | Slip          |
|                  | Z04                          | 39.240            | 1.41                    |                               | Slip          |
|                  | Z05                          | 33.354            | 1.20                    |                               | Slip          |

Table 3. Bond resistance and crack pattern of RILEM specimens. Containing plastic shreds with 20mm diameter bar (table 3. continues on next page).

| % Plastic Shreds | Specimen ID (200x200x200mm) | Bond Failure (kN) | Bond Resistance (N/mm²) | Average Bond resistance (N/mm²) | Crack pattern |
|------------------|------------------------------|-------------------|-------------------------|-------------------------------|---------------|
| 0                | A01                          | 98.141            | 1.42                    |                               | Split         |
|                  | A02                          | 108.701           | 1.57                    |                               | Split         |
|                  | A03                          | 128.511           | 1.86                    |                               | Split         |
|                  | A04                          | 110.500           | 1.60                    | 1.58                          | Slip          |
|                  | A05                          | 98.716            | 1.43                    |                               | Slip          |
| 1.0              | B01                          | 46.588            | 0.78                    |                               | Slip          |
|                  | B02                          | 46.891            | 0.78                    |                               | Slip          |
|                  | B03                          | 44.755            | 0.75                    | 0.79                          | Slip          |
|                  | B04                          | 48.738            | 0.81                    |                               | Slip          |
|                  | B05                          | 51.012            | 0.85                    |                               | Slip          |
With the failure load, the bond stress was determined using the following relationship in [13].

$$\tau_P = (0.00637F \times 25) \times 10^3 / \Omega^2 \times f_{cu},$$  \hspace{1cm} (1)

Where:

- $\tau_P$ = bond strength, (N/mm$^2$);
- $F$ = Failure load, (kN);
- $\Omega^2$ = Bar diameter, (mm$^2$);
- $f_{cu}$ = Compressive strength of concrete, (N/mm$^2$).
From the test results and analysis carried out, waste plastic shredded material incorporated in the concrete mix was found to immediately reduce the bond resistance between concrete and steel reinforcement when only 1% plastic shred was introduced. However, with increase in the percent of plastic shred, the bond resistance increased, when 1.5% and 2% of the plastic shred was added. This was due to the low force of adhesion between polypropylene plastic and concrete as adhesion depends largely upon the surface energy of the plastic, the surface energy of solid varies with its chemical make-up. Plastic has a lower surface energy and is harder to bond with concrete. Hence, low bond resistance was observed.

The bond resistance of waste plastic shred was also compared with that of other waste materials like steel, aluminium and wood [14], [15] and [16] to confirm the most effective material that can enhance the improvement of bond resistance, using 20mm steel reinforcing bars. The results are shown in figures 7.

![Figure 7. Comparison of bond resistance of various waste materials using 20mm bar.](image)

4. Conclusions
Based on the results and the analyses carried out the following conclusions are drawn:

- It was observed that compressive strength of the concrete mix decreases as waste plastic shredded percentage increases.
- RILEM concrete specimens with addition of waste plastic shredded material for 16mm and 20mm diameter steel reinforcing bars failed majorly by slipping while that of 0% waste plastic shredded material failed majorly by splitting.
- Plastic shredded material does not at any percentage improve bond resistance between concrete and steel. However, bond resistance improved with increase in the percentage of plastic in the concrete from 1% addition, but was still lower at 2% when compared to concrete without any percentage of plastic shreds.
5. References

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