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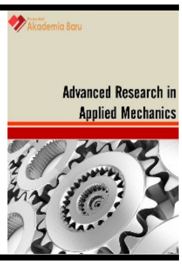


# A review on different forms and types of waste plastic used in concrete structure for improvement of mechanical properties

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**ABSTRACT**

How to dispose the solid waste is a major problem for every country in the world. It is important to take immediate action on how to reduce the plastic waste as a strategy in solid waste management, especially from inorganic materials since it is essential to the welfare of the society and the environment. There are tons of plastics disposal around the world and until now has not yet optimize discover or recycle for engineering usage. The quantities of disposal plastics are growing day by day and it takes hundreds of years for plastics material to degrade. Scientific research now has used the recycling approach by producing useful substances from the recycle plastic as a secondary strategy to replace natural substance. The reuse of plastic wastes plays an important role in sustainable solid waste management to help saving natural resources that are not replenished, it decreases the pollution of the environment and it also helps to save and recycle energy production processes. This paper presents an overview and discussing of published research paper regarding different form and types of recycle plastic used in concrete structure. The influence of waste plastic materials on the properties of concrete are also reviewed and presented in this paper.

***Keywords:***
Recycle plastic, Natural substance, concrete structure



## 1. Introduction

According to the statistics issued by the Solid Waste and Public Cleansing Management [1], plastic waste is the second highest or 24 % of the solid waste composition in Malaysia in year 2005 after the food waste at 45 %. The amount of solid waste per day increased in parallel with the increase of the

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number of the residents. Therefore, it is very important to do something on how to reduce the plastic waste.

Reis et al [2] emphasized that plastic waste is a worldwide concern, solutions are searched to minimize the impacts caused by the use and disposal of these materials because they generate several environmental problems. The production of this waste has increased significantly, making it a challenge for the world's wealthiest countries in environmental, economic and social terms. The environmental impact is reduced, as is the consumption of virgin plastics, when post-consumed polymeric materials are reused. The majority of the petroleum-based single polymer plastics have an easy recycling process. Therefore, with an efficient collection, separation and recycling system, discarded plastics can be recycled into new products with only the addition of energy.

This supported by few researchers [3,4] in their recent research, stated that the solutions are possible except for land-filling, recycling of waste plastic tend to produce new elements, such as concrete ingredients and cost savings for raw materials. It seems to be as one of the best solution for losing the plastic waste, due to its economical and environmental advantages.

Ramadevi et. al. [4] also revealed that flexural durability improved with replacement of alternative thermoplastics in concrete ingredients. Recently, the manufacturing industry started reusing recycled plastic artifact for the fabrication of many household products like clothes hangers, toys, seeding containers etc. More recently and because of the high increase of plastic waste in the world, the use of shredded plastics has known a growing interest as recycled materials in civil engineering construction. The incorporation of waste in concrete provides additional advantages in terms of environmental and potential economic considerations.

This paper aims to provide a compressing review of the existing reports on the use of recycled plastics in concrete. The reports were reviewed and classified into many forms and types of recycle plastic dealing with concrete. Some of the waste plastics are in forms of fiber, long strip, short strip, aggregates and many other forms are used in daily life such as plastic bottle, packaging, plastic bag and electric insulation cable. Different types of plastic have been investigated these recent years: polyethylene terephthalate (PET), high-density polyethylene (HDPE) and polypropylene (PP). These studies have focussed on the effect of plastic addition in the mechanical strength of the hardened mixtures of concrete. In this paper, the material properties of plastic and the influence of plastic materials measured by compressive strength and flexural tensile strength on the properties of concrete are summarized clearly.

## 2. Different form & types of plastics

This paper focuses on the results obtained by various researchers in measurement of compressive strength and flexural tensile strength after adding various forms of plastic to concrete. Most research shows that the addition of plastic affects the workability, compressive strength, modulus of elasticity, split tensile strength, thermal conductivity and slightly enhances the abrasion and flexural strength.

Generally, two forms of plastics, plastic aggregate (PA) and plastic fiber (PF), are used in concrete. Recycled PA is extracted from different types of plastic waste. These methods typically involve direct mechanical recycling or melting. The former is an efficient and economical way to obtain recycled PA and PF, while the latter yields materials with more uniform size and properties.

**Table 1**
Properties of Recycle Plastic As Reported In Literature

| No | References | Form of Plastics | Types of Plastics | Dimension | Density (kg/m$^3$) | Specific Gravity (g/cm$^3$) | Mixture Proportions |
|---|---|---|---|---|---|---|---|
| 1 | [4] | Hollow bars, long strips and shorter strips bottle | Polyethylene terephthalate (PET) | Hollow bar (24 mm external diameter, 22.8 mm internal diameter and 48 cm long), long strip (800 mm x 50 mm x 6.6 mm), short strip (400 mm X 40 mm X 0.6 mm) | 1380 | -NA- | 1% fine aggregate sand was replace by PET |
| 2 | [3] | Spherical balls from trash bag | High density polyethylene (HDPE) | Aggregate sizes between 14 mm - 20 mm | 172 - 286 | -NA- | 0%, 15%, 30%, 45%, and 60% HDPE waste volumetric |
| 3 | [5] | Particle size | Polyurethane formaldehyde (PUF), high-density polyethylene (HDPE) | PUF range 4.0 mm - 8.5 mm, HDPE range 4 mm -12 mm | 13 (PUF) & 960 (HDPE) | -NA- | 10%, 15%, 20% and 25% of total volume of the sample |
| 4 | [6] | Particles size from plastic bag | Plastic Bag Waste (PBW) | 1 mm - 10 mm | 530 | 0.87 | 10%, 20%, 30% and 40% by substitution of sand |
| 5 | [7] | Granules plastic | High density polyethylene HDPE | 1 mm | 460 | 0.46 | 0% ,25% , 50% , 75% , 100 % sand being replaced with Pulverized plastic material |
| 6 | [8] | Plastic bag waste fibers | -NA- | Length of 2 cm, 4 cm , 6 cm & diameter of 1.6 mm - 2 mm | -NA- | 0.87 | 1, 3, 5 and 7 kg/m$^3$ |
| 7 | [9] | Pieces of waste plastic bags | -NA- | -NA- | -NA- | -NA- | 0.2%, 0.4%, 0.6%, 0.8%, 1% by weight of concrete |
| 8 | [10] | Circular fibre cut from bottle | Polyethylene terephthalate (PET) | Width of 5 mm | -NA- | -NA- | 1% by weight of concrete |
| 9 | [11] | Fabriform | 80% Polyethylene and 20% polystyrene | Length of 0.15 mm - 12 mm and width of 0.15 mm – 4 mm | 386.7 | -NA- | 0%, 10%, 15%, 20% weight of concrete |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 10 | [12] | Lightweight aggregates from bottle | Polyethylene terephthalate (PET) bottles | Range of 5 mm - 15 mm | 1390 | -NA- | 0%, 25%, 50%, and 75% by volume of fine aggregate |
| 11 | [13] | Lightweight aggregate from bottle | Polyethylene terephthalate (PET) | Particles range 0.26 mm - 1.14 cm | -NA- | -NA- | 10% and 20% by volume of fine aggregate (sand) |
| 12 | [14] | Embossed fibers from bottle (supplied in roll) | Polyethylene terephthalate (PET) | Dimension 0.2 mm x 1.3 mm and length of 50 mm | 1380 | -NA- | 0.5%, 0.75%, 1.0% fiber volume fraction |
| 13 | [15] | Segregation of the electric cable protective sheath | Polyethylene (PE) and PVC | -NA- | -NA- | -NA- | 0%, 2.5%, 5%, 10% and 20% of waste untreated plastics |
| 14 | [16] | Pellet-shaped & flaky-shaped | Polyethylene terephthalate (PET) | -NA- | 1340 & 1360 | -NA- | 5%, 10% and 15% in volume of plastics |

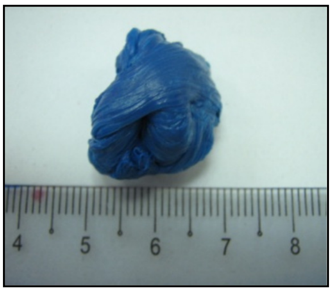
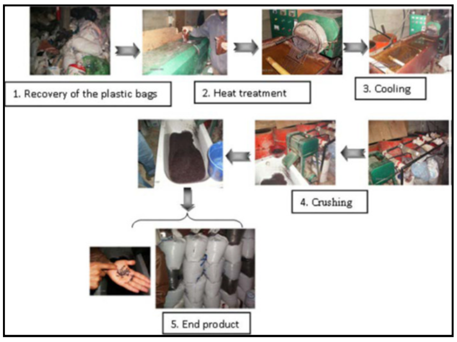
## 3. Preparation of testing sprecimen

Plastic aggregates are generally produced from big sized plastic waste materials. Therefore both coarse and fine sized natural aggregate can be replaced by plastic aggregates. Both partial and full substitutions of natural aggregates by plastic aggregates were reported in various references. In several studies, fine natural aggregate of cement mortar and concrete was replaced by coarse sized plastic waste aggregate and some studies just mixture waste plastic without consideration natural aggregates as a replacement.

Generally, the design, preparation and casting of concrete mix containing plastic aggregate are similar to the normal concrete mix design and done according to various standard specifications. However, designing and curing of some concrete mixes containing plastic aggregate were done by slightly different approaches than for normal concrete mix design.

**Table 2**
Specimen Preparation Based On Literature Review

| No | References | Description | Discussion |
|---|---|---|---|
| 1 | [4] |  **Fig. 1.** PET Long Strip and Short Strip | Totally 7 types of concrete beam specimens of size 50 x 10 x 10 cm were used for the research. Control beams are those which were made with plain concrete without any reinforcement are the first type designated as CB |

<table>
<tr><td>2</td><td>[3]</td><td><br>**Fig. 2.** Sample After Heating</td><td>To evaluate the mechanical properties of concrete, such as compressive by age and mixing ratios, concrete test specimens were prepared in accordance British Standards and Malaysian Standards. After the mixing process, samples were made in cubic molds (100 mm x 100 mm x 100 mm) and as a beam (100 mm x 500 mm x 100 mm) and air dried for one day. Then, the samples were removed from the molds and cured for 28 days inwater so that they were at the required age.</td></tr>
<tr><td>3</td><td>[5]</td><td>-NA-</td><td>To prepare the fresh concrete, calculated amount of cement, sand, stone chips, waste plastic (HDPE) and water were mixed following a method and technique as prescribed by ASTM C 31-84. Then, the fresh concretes were cast into 152.4 mm cube molds with vibration following the procedure prescribed by ASTM, C31-84. The concrete specimens were separated out from the mold after 24 hours of molding and kept in water for 7-28 days for curing.</td></tr>
<tr><td>4</td><td>[6]</td><td><br><br>**Fig. 3.** Stages Of Obtaining Waste Of The Plastic Bags</td><td>After mixing concrete, the molds (cylindrical and prismatic) are met in three phases. For each phase, a vibration of the mold was carried out using a mobile stripe for 20s. For each series, three cylindrical specimens (160 mm x320 mm) and three prismatic specimens (70 mm x70 mm x 280 mm) were prepared by using the same composition. After demolding, the specimens were deposited in a water vat for 28 days.</td></tr>
<tr><td>5</td><td>[7]</td><td><br>**Fig. 4.** Pulverized Plastic Material</td><td>Mix design was performed using IS Code method of mix design as per IS: 10262-2009, but it was difficult to find the water absorption value of Plastic material since it had a specific gravity much lower than that of water. So proportioning of the mix by volume was adopted & a ratio of 1:1:2 mixes was adopted.</td></tr>
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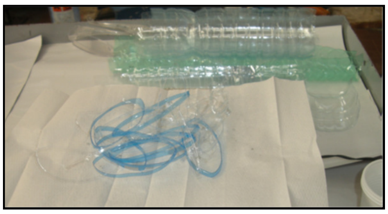
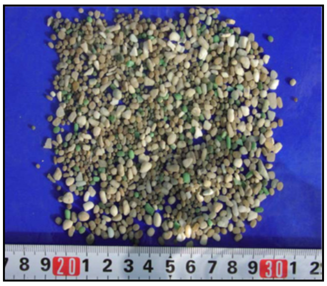
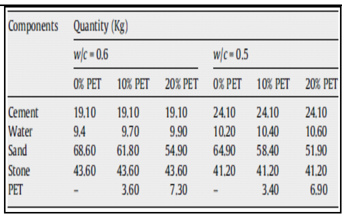
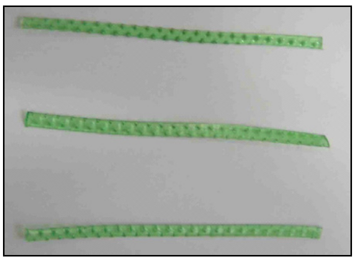
<tr><td>7</td><td>[9]</td><td><br>Fig. 6. Polyethylene Bags</td><td>Control mix concrete and modified concrete with varying percentages of pieces of waste plastic bags (commonly used for the packaging and carrying goods) were prepared according to M20 grade of concrete with w/c ratio 0.45.</td></tr>
<tr><td>8</td><td>[10]</td><td><br>Fig. 7. Circular PET Fibers</td><td>Tests on concrete specimens reinforced with circular fibers of PET (1% by weight of concrete), and added with superplasticizers. The specimens are made with a concrete mix added with circular fibers the last obtained cutting waste bottles orthogonally to their longitudinal axis.</td></tr>
<tr><td>9</td><td>[11]</td><td><br>Fig. 8. Sample Of Waste Plastic</td><td>70 cubes of concrete of 150 mm x 150 mm x 150 mm were molded for compressive strength, and fresh and dry density tests. 54 prisms of 70 mm x 70 mm x 38 mm were cast for flexural and toughness strength tests.</td></tr>
<tr><td>10</td><td>[12]</td><td><br>Fig. 9. Shape Of WPLA</td><td>Mixture proportions of concrete were prepared that the water–cement ratios were 45%, 49%, and 53%, and the replacement ratios of waste polyethylene terephthalate (PET) bottles lightweight aggregate (WPLA) were 0%, 25%, 50%, and 75% by volume of fine aggregate.</td></tr>
<tr><td>11</td><td>[13]</td><td><br>
<table>
<tr><th>Components</th><th>Quantity (Kg)</th><th></th><th></th><th></th><th></th><th></th></tr>
<tr><td></td><td>w/c = 0.6</td><td></td><td></td><td>w/c = 0.5</td><td></td><td></td></tr>
<tr><td></td><td>0% PET</td><td>10% PET</td><td>20% PET</td><td>0% PET</td><td>10% PET</td><td>20% PET</td></tr>
<tr><td>Cement</td><td>19.10</td><td>19.10</td><td>19.10</td><td>24.10</td><td>24.10</td><td>24.10</td></tr>
<tr><td>Water</td><td>9.4</td><td>9.70</td><td>9.90</td><td>10.20</td><td>10.40</td><td>10.60</td></tr>
<tr><td>Sand</td><td>68.60</td><td>61.80</td><td>54.90</td><td>64.90</td><td>58.40</td><td>51.90</td></tr>
<tr><td>Stone</td><td>43.60</td><td>43.60</td><td>43.60</td><td>41.20</td><td>41.20</td><td>41.20</td></tr>
<tr><td>PET</td><td>-</td><td>3.60</td><td>7.30</td><td>-</td><td>3.40</td><td>6.90</td></tr>
</table>
Fig. 10. Mix Design Of The Blends With Different PET Contents And Different Water/Cement Ratios Determined Through A Hydro Balance.</td><td>Fine aggregate (sand) was replaced with 10 and 20 vol/% of PET with particle sizes of 0.26 and 1.14 cm and a 50/50 mix of both sizes. The mix design is presented in Table for two different water/cement ratios, which were determined through a hydro balance</td></tr>
<tr><td>12</td><td>[14]</td><td><br>Fig. 11. Geometry Of The Recycled PET Fiber</td><td>Recycled PET strands are given the desired surface configuration, and then fiber surface is coated with maleic anhydride grafted polypropylene. The surface coating improves the bonding strength and dispersion characteristics of the recycled PET fiber. Fiber concrete cylinders of 100x200 mm were tested at an age of 28 days</td></tr>
</table>

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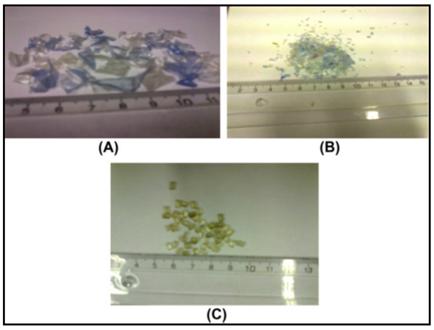
| | | | according to Korean Standard 2405 method. |
| 13 | [15] |  **Fig. 12.** Samples Morphology Coming From The Recycling Of Electric Cable Sheath | Mortar samples preparation was performed according to Spanish standard UNE 83821. In brief, the design of dosage for the case of mortar has been carried out taking into account the following assumptions. It has been kept the sand/cement ratio constant at 3/1 and the same type of sand was used for all the samples. |
| 14 | [16] |   **Fig. 13.** PET Aggregate Types Used In This Work | The concrete mixes were prepared and cast using standard procedures. Slump and density were determined immediately after preparation of the mixes. They were then poured into predefined moulds and their air content was reduced by using a vibrator. The specimens were kept in moulds at ambient temperature for about 24 h to harden before being demoulded and transferred to a humidity chamber for curing for specific time-periods. The 150 mm x 150 mm x 150 mm cubic specimens were prepared for compressive strength and 150 mm x 150 mm x 600 mm prismatic specimens were prepared for flexural strength determination. |

## 4. Effects of replacement plastics

Various researchers have studied the use of various forms of waste plastic. The effects of replacing or adding plastic on the properties of concrete in the green state and the mechanical properties of concrete such as compressive strength and flexural strength studied by various researchers are discussed in this section.

As the chemical nature of plastic aggregate is completely different from that of natural aggregate i.e. one is organic and the other is inorganic and therefore a big difference in aggregate in terms of mechanical properties. It can be stated that the standard procedures used to evaluate properties like compressive strength and flexural tensile strength of concrete can be used to evaluate these parameters in plastic aggregate with slight modifications.

### *4.1. Compressive strength*

The compressive strength of concrete and cement mortar is a fundamental property that is thoroughly studied in almost all research works related to plastic aggregate. Neville stated in [13] that it is important to notice that the compressive strength at the age of 28 days, in most cases, is near the values corresponding to 60 days, since it is known that concrete reaches 75–80% of its total strength during the first 28 days

**Table 3**
Mechanical Properties of Compressive Strength Based On Literature

| No | References | Description | Discussion |
|---|---|---|---|
| 1 | [3] | Fig. 14 | The compressive strength of the sample cubes ranged from 11 to 19 MPa. Concerning strength, the basic trend in the behaviour of plastic waste coarse aggregate concrete was not significantly different from that of the conventional crushed stone aggregate for lightweight concrete. |
| 2 | [5] | Fig. 15 | It is found experimentally that the highest HDPE content that can be introduced in the concrete composition is 25 vol% and the highest introducible PUF content in poly blocks is 90 vol%. More than these amounts in respective compositions creates problem in mixing and bonding, and hence the study is made up to the 25 vol% of HDPE for concrete and 90 vol% of poly bubble for poly blocks. |
| 3 | [6] | Fig. 16 | A reduction in the mechanical strength according to the increase in percentage of plastic bag waste in the concrete, but remains always close with this last for the case to the percentages 10 and 20% when we recorded a fall of compressive strength at 28 days of about 10 and 24% respectively. |
| 4 | [7] | Fig. 17 | The ultimate as well as the yield strength of concrete at 7th day decreased by about 3 to 3.2 N/mm2for 25%replacement & 4 to 6.5 N/mm2 for higher replacements of Plastic when compared to conventional concrete. |
| 5 | [8] | Fig. 18 | The concrete based on polypropylene fibers (PFSCC), has the same compressive strength value at 28 days that the reference concrete (SCC). In this study, the increase of compressive strength of specimens concrete based on plastic bag waste fiber (WFSCC) is about 13% maximum, compared to the reference SCC and PFSCC in the case of the mix containing a large amount of fibers (7 kg/m3).<br>The comparison of WFSCC with RSCC allows assessing the gains in strength and deformability of concrete. From these figures, it can be seen that SCC contain a large amount of PBWF (5 or 7 kg/m3) with a fiber length of 6 cm, gain about 7% and 10% in compressive strength respectively and more are characterized with a large phase of plastic deformation. This can be explained by the effect of fiber length which prevent and retard the propagation of cracks.<br>Nevertheless,the majority of the researches realized on reinforced concretes indicated that plastic fiber reinforced concretes have a negligible evolution of the compressive strength [38,39]. The possible reason for this behavior is the bad homogeneity of the concrete, the high ratio of water or the weak compactness of the concrete caused by the excess of fibers content. |
| 6 | [9] | Fig. 19 | Compressive strength test were carried out on 150 mm X 150 mm X 150 mm specimen for that three cube were prepared for each mix. Strength of each cube was evaluated after 3, 7 and 28 days respectively. The compressive strength of concrete goes on reducing with increase in percentage of plastic pieces but the rate of reducing compressive strength is very low. This reduction in strength is may be due reduction in bonding due introduction of plastic pieces. |
| 7 | [11] | Fig. 20 | By increasing the waste plastic ratio, the results show a tendency for compressive strength values of waste plastic concrete mixtures to decrease below the plain mixtures at each curing age. This trend can be attributed to the decrease in adhesive strength between the surface of |

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| | | | the waste plastic and the cement paste, as well as the particles size of the waste plastic increase. All of the compressive strength values are higher than the minimum compressive strength required for structural concrete which is 17.24 MPa. |
| 8 | [12] | Fig. 21 | The 28 day compressive strength decreases as the replacement ratio increases. The 28-day compressive strength of concrete with WPLA of 75% is reduced about 33% compared to that of control concrete in the water–cement ratio of 45%. It indicates that the compressive strength probably reaches an upper level for the aggregates, and the strength does not benefit much from further improvement in the matrix strength. This may be attributed to the influence of WPLA. |
| 9 | [13] | Fig. 22 | It can also be seen that the PET addition decreased the concrete resistance when compared to the conventional material at different curing ages, since the recycled PET does not contribute to the strength of the concrete as does the natural fine aggregates. However, even though there is a loss in strength, the blends with 10% of recycled PET presented a high grade of compressive strength. In addition, the concrete blends with 20% of PET, specifically those with the big particle size of (1.14 cm), present very low values of compressive strength. |
| 10 | [14] | Fig. 23 | The recycled PET specimens exhibited strength decreases of 1–9% compared to the non-reinforced specimens. A slight reduction in the mechanical strength according to the increase in percentage of plastic bag waste in the concrete. |
| 11 | [15] | Fig. 24 | 0% of compressive values are still evolving at 120 days from the production date while the 10% and 20% PVC containing compounds are almost stabilized. Compressive properties values are in average 5 times lower in the case of 20% PVC containing samples as compared to control samples. It is clear that the gap between the mortar control values and the mortar plastic compounds increases with time (only in the case of the 5% samples compared to the 10% samples the difference is reduced with time). |
| 12 | [16] | Fig. 25 | Results show that, regardless of the type of PET aggregate and curing time, the compressive strength decreases as the content of PET aggregate increases. The 28-day compressive strength of concrete containing PP at all substitution levels and of concrete containing 5% of PF is more than 75% of the compressive strength of reference concrete. But the figures for concrete with 10% and 15% PF are respectively 71% and 59%, and for concrete with 5%, 10% and 15% PC they are respectively 73%, 52% and 35%. |

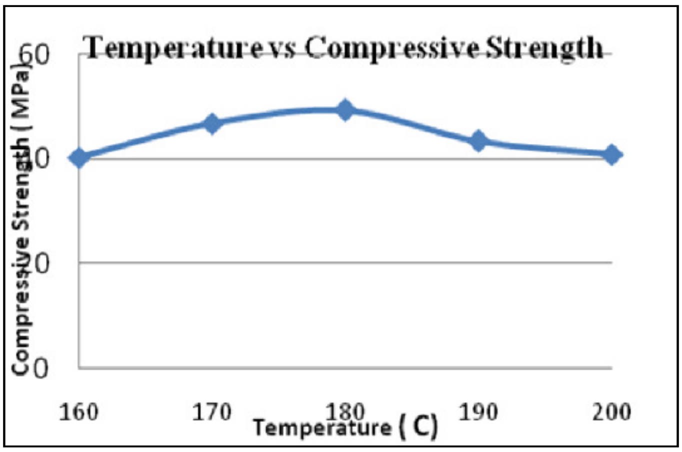


**Fig. 14.** Compressive Strength for Various Heating Temperatures

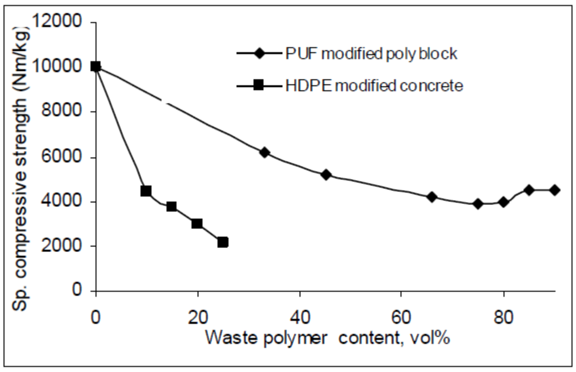


**Fig. 15.** Dependence of Recycled Polymer Materials (PUF and HDPE) Content on the Compressive Strength of the Poly Block and Concrete

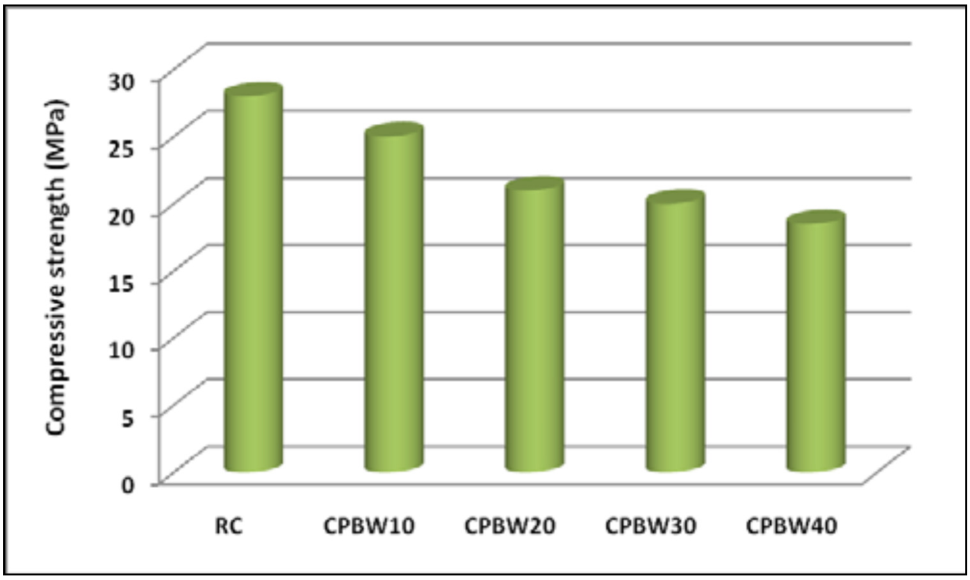


**Fig. 16.** Evolution of Compressive Strength of All Mixtures as Function of Content Plastic Bag Wastes

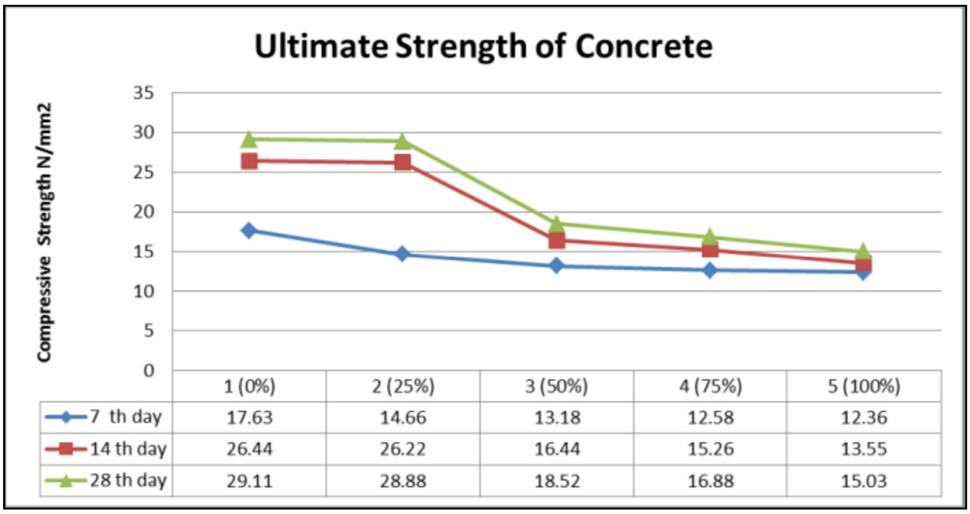


**Fig. 17.** Comparison of Ultimate Strength of Cubes Having Different Proportions of Plastics at 7, 14, And 28 Days

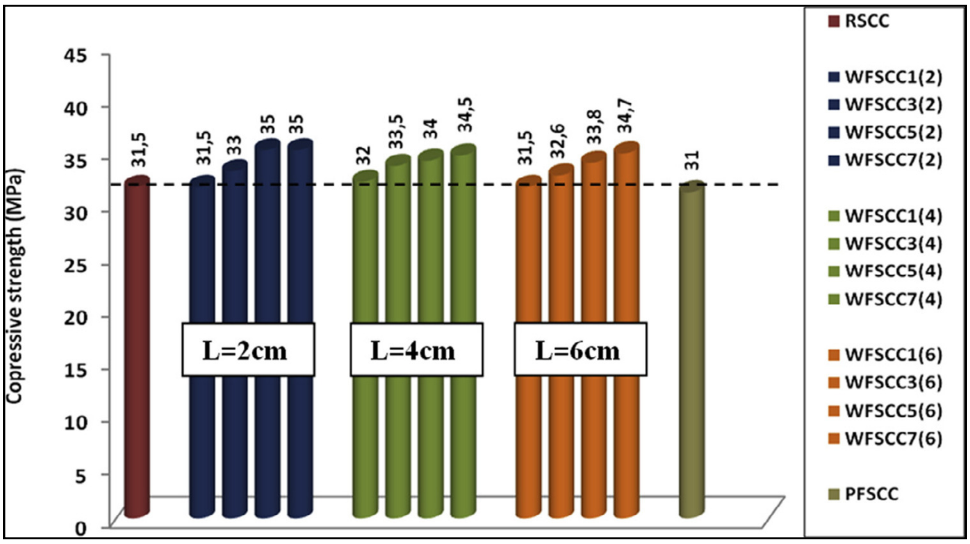


**Fig. 18.** Compressive Strength Values for All Mixtures at 28 Days

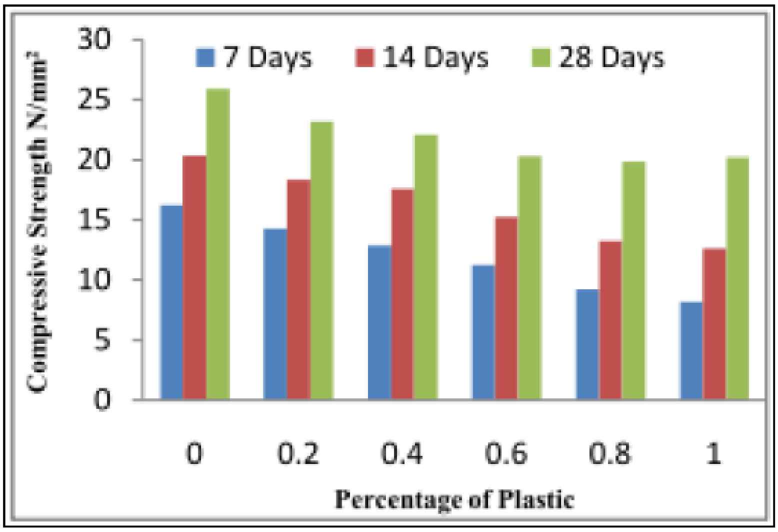


**Fig. 19.** Variation of Compressive Strength

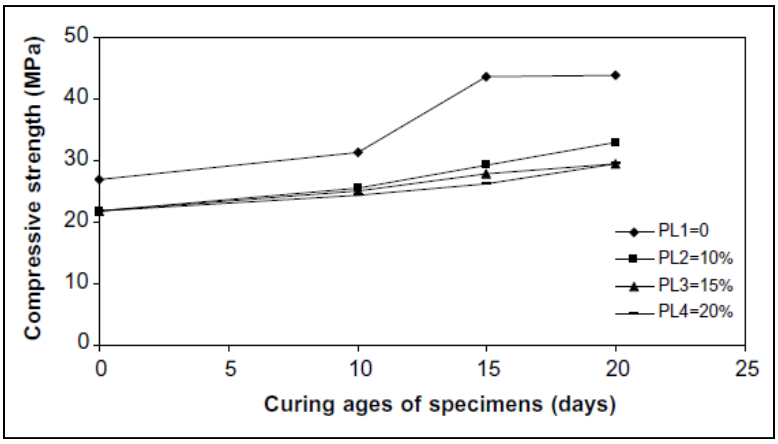


**Fig. 20.** Compressive Strength

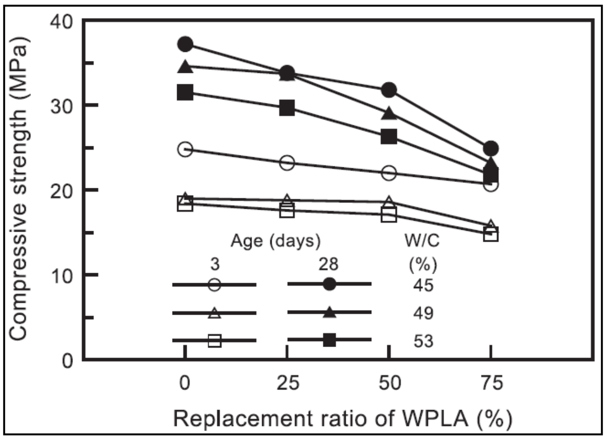


**Fig. 21.** Relationship between Compressive Strength and Replacement Ratio of WPLA

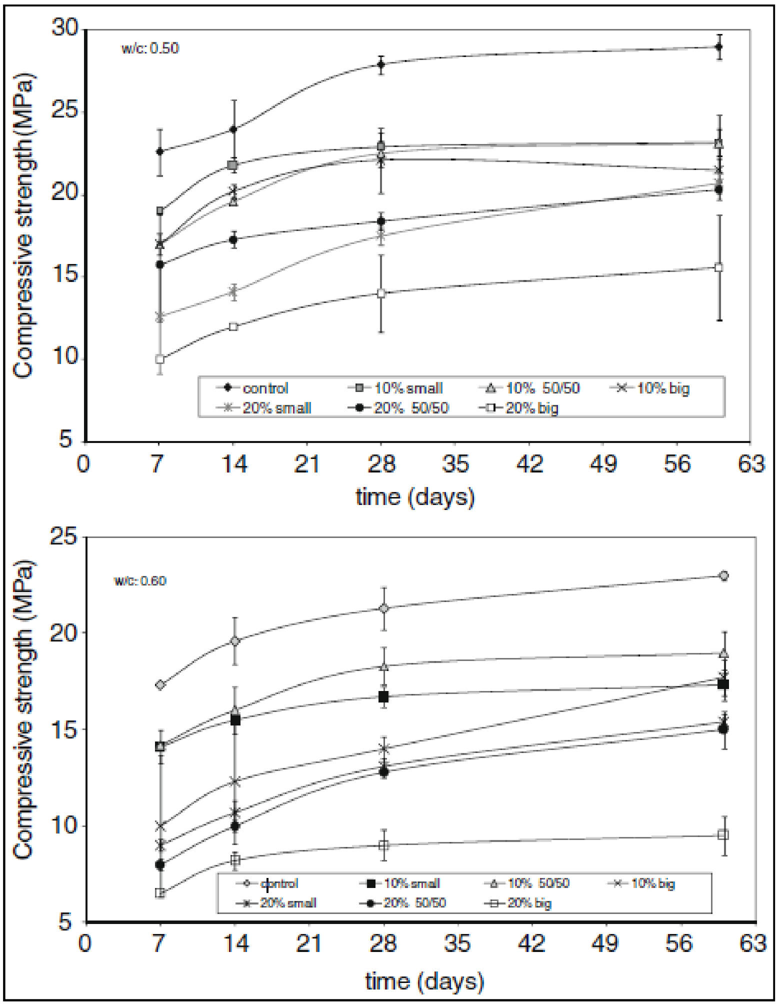


**Fig. 22.** Compressive Strength of Concrete-PET Blends versus Curing Age at Different Water/Cement Ratios

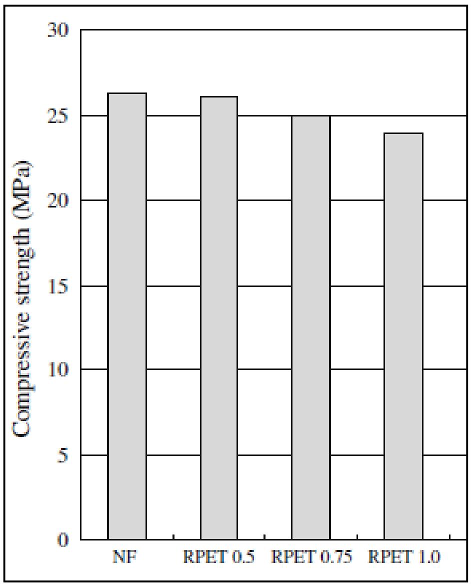


**Fig. 23.** Specimen Type

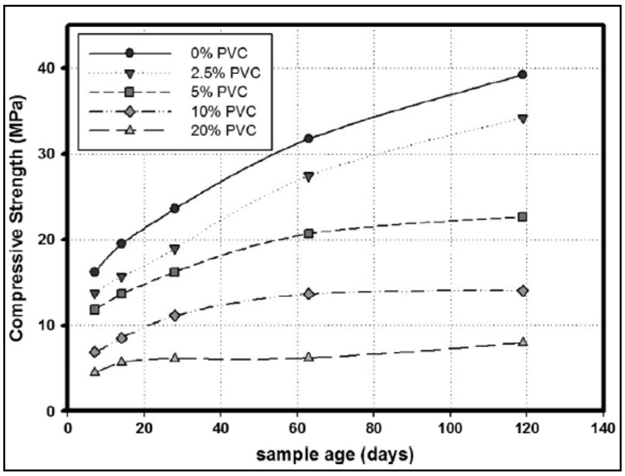


**Fig. 24.** Compressive Strength Temporal Evolution Measured for Mortar-PVC Samples

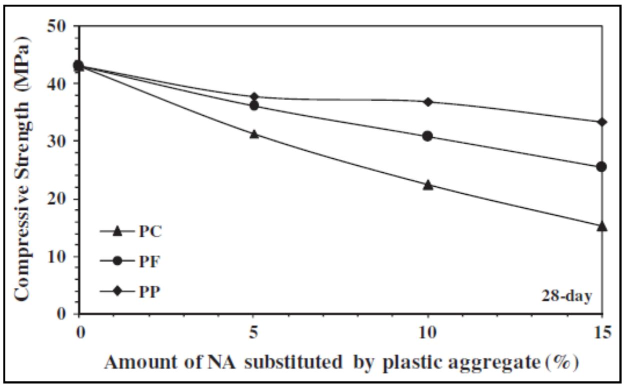


**Fig. 25.** Compressive Strength of Concrete versus Incorporation of PET-Aggregate to Replace NA at Different Ages

### 4.2. Flexural tensile strength

Flexural strength is defined as the material's ability to resist deformation under flexural load and is measured in terms of stress. It represents the highest stress experienced within the material at the collapse load. The transverse bending test is most frequently employed, in which a specimen with either a circular or rectangular cross-section is bent until fracture using a three or four point flexural test technique.

**Table 4**
Mechanical Properties of Flexural Tensile Strength Based On Literature

| No | References | Figures | Discussion |
|---|---|---|---|
| 1 | [4] | Fig. 26 | There is not much difference in flexural strength of control beam is compared to that of PET concrete beam RP1B and concrete beam reinforced with two PET bars RP2B, whereas the flexural strength of concrete beam reinforced with one PET bar (RP1B) is slightly less than that of the control beam. The flexural strength of concrete beam reinforced with steel bars (RSB) is almost similar to that of concrete beam reinforced with steel and PET bars (RSPB) and the flexural strength of beams reinforced with both steel and PET long Strips (RSPSB) exhibited exceptionally higher strength in flexure and flexural strength of these beams is far greater than that of control beams (CB), PET concrete beam (PC), concrete beams reinforced with only PET bars (RP1B). The maximum flexural strength is attained by concrete beam reinforced with steel and PET long strips (RSPSB) above all the beams casted in the present investigation i.e. nearly 25 $N/mm^2$. |
| 2 | [3] | Fig. 27 | The flexural strength varied from 9 to 15 MPa. The variations in flexural strength between plastic waste concrete and conventional concrete were very small. From the surface of the fractured samples, it was apparent that the plastic waste did not have strong, interlocking bonds with the cement. |
| 3 | [6] | Fig. 28 | A reduction in the mechanical resistance according to the increase in percentage of plastic bag waste, which remains always close to the reference concrete. |
| 6 | [8] | Fig. 29 | The test results of 28 days flexural load for all studied mixtures are shown in Fig. As a first result, it can be observed that the flexural load of all reinforced fiber concrete mixtures is higher than that of the control concrete. This improvement varies from 0% to 14%, and it depends on the type, the amount and the length of fibers. The incorporation of short PBWF with 2 cm length in SCC does not affect the flexural strength whatever the amount of fiber used. In general, the incorporation of plastic bag waste fibers in the SCC has not a significant effect on flexural strength. For a PBWF amount of 7 kg/m3, the flexural load is improved about 14% and 11% for mixtures with 4 cm and 6 cm in PBWF length, respectively (Fig. 17), compared to the reference concrete (RSCC). This can be explained by the strong bond between the fibers and the cementitious matrix and the local constraints given by the presence of these fibers which occur in an oblique and vertical way against the microcracks. |
| 7 | [10] | Fig. 30 | The value varies from a minimum of PET 1% to a maximum of PET 0.75%. It means that a high percentage of fibers improve the concrete behavior but it cannot be highly incremented because the circular fibers loose their adherence with the concrete as it becomes less workable. |
| 8 | [11] | Fig. 31 | These results show that the flexural strength of waste plastic concrete mixtures at each curing age is prone to decrease with the increase of |

| | | | |
|---|---|---|---|
| | | | the waste plastic ratio in these mixtures. This trend can be attributed to the decrease in adhesive strength between the surface of waste plastic particles and the cement paste, as well as the hydrophobic nature of plastic material which may limit the hydration of cement. Therefore the hydration developed slightly with time. When the w/c ratios are higher, there is an excess of water that does not participate in the water-cement reaction, so channels with very small diameters like capillaries are produced and when the water evaporates, those empty spaces rest resistance to the concrete. |
| 9 | [13] | Fig. 32 | The flexural strength decreases regardless the PET particle size, being this decrease more significant when PET content is 20% since the slabs present more porosity (holes) which act as stress concentration sites. This occurs since the PET is more susceptible to temperature than the natural fine aggregate. |
| 10 | [14] | Fig. 33 | The RPET specimens with fiber volume fractions of 0.5%, 0.75%, and 1.0% had ultimate strength increases of 25%, 31%, and 32%, respectively, compared to the concrete specimens without fiber reinforcement. The PP fiber reinforced concrete specimens showed similar trends observed in recycled PET fiber reinforced concrete specimens. |
| 11 | [15] | Fig. 34 | It is clear at a first sight that the higher the plastic content the lower the values of strength. It seems also that the time interval from the flexural initial value to the stabilized one is reduced as plastic content is increased. It is clear that the gap between the mortar control values and the mortar plastic compounds increases with time (only in the case of the 5% samples compared to the 10% samples the difference is reduced with time). |
| 12 | [16] | Fig. 35 | It is concluded that as the amount of any type of PET-aggregate in concrete increases the flexural strength decreases. The explanation for the loss of compressive and tensile strengths and the lowering of the modulus of elasticity of concrete due to the incorporation of PET aggregate applies to the flexural behaviour of concrete too. The reference specimen splits into two pieces after failure, the concrete beams containing PC and PF did not split into two after failure. The PC and PF particles bridged the crack and prevented brittle failure of the specimen during the test. |

| S.No. | Constituent | Designation | Flexural Sterngth ($N/mm^2$) |
|---|---|---|---|
| 1. | Control specimens | CB | 8.4 |
| 2. | Concrete beams reinforced with steel bars | RSB | 18.3 |
| 3. | Concrete beams reinforced with PET one bar | RP1B | 6.7 |
| 4. | Concrete beams reinforced with PET two bars | RP2B | 7.5 |
| 5. | Concrete beams reinforced with steel and PET bars | RSPB | 18.9 |
| 6. | Concrete beams reinforced with steel and PET long strips | RSPSB | 23.96 |
| 7. | PET concrete( with short strips) | PC | 7.39 |

**Fig. 26.** Flexural Strength Test Result

| Mix | w/c | Cement content ($kg/m^3$) | Types | Slump (mm) | Compressive Strength ( MPa ) | Flexural Strength ( MPa ) |
|---|---|---|---|---|---|---|
| 100% Waste | 0.5 | 380 | Cubes | 13 | 11.79 | |
| 80:20 ( Waste:Gravel ) | 0.5 | 380 | Cubes | | 13.37 | |
| 60:40 ( Waste:Gravel ) | 0.5 | 380 | Cubes | | 19.85 | |
| 100 % Gravel | 0.5 | 380 | Cubes | 55 | 29.19 | |
| | | | | | | |
| 100% Waste | 0.5 | 380 | Beam | 13 | | 9.37 |
| 80:20 ( Waste:Gravel ) | 0.5 | 380 | Beam | | | 12.56 |
| 60:40 ( Waste:Gravel ) | 0.5 | 380 | Beam | | | 15.47 |
| 100% Gravel | 0.5 | 380 | Beam | 55 | | 17.56 |

**Fig. 27.** Properties of Plastic Waste Coarse Aggregate Concrete and Conventional Concrete Mix at 28 days

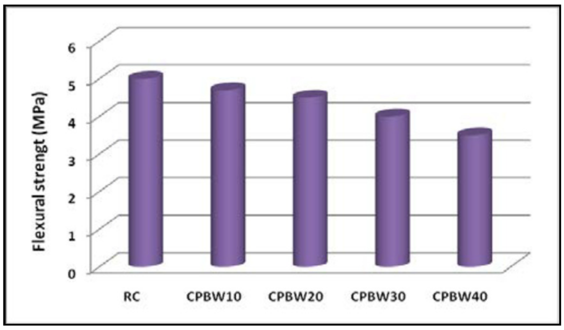


**Fig. 28.** Evolution of Slump Test Value of All Mixtures as Function of Content Plastic Bag Wastes

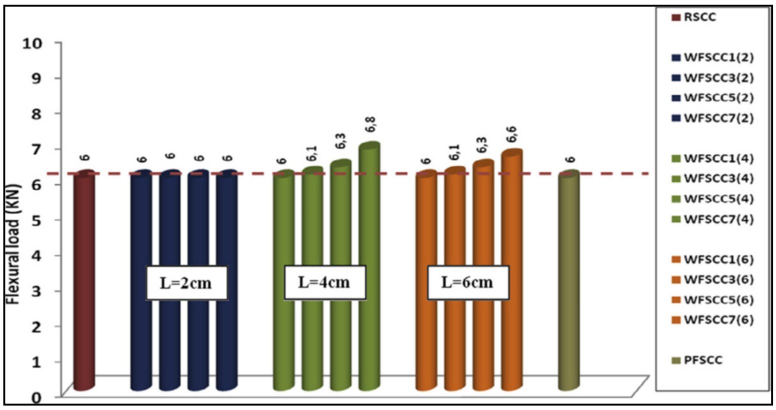


**Fig. 29:** Values of Flexural Load at 28 Days for All Mixtures

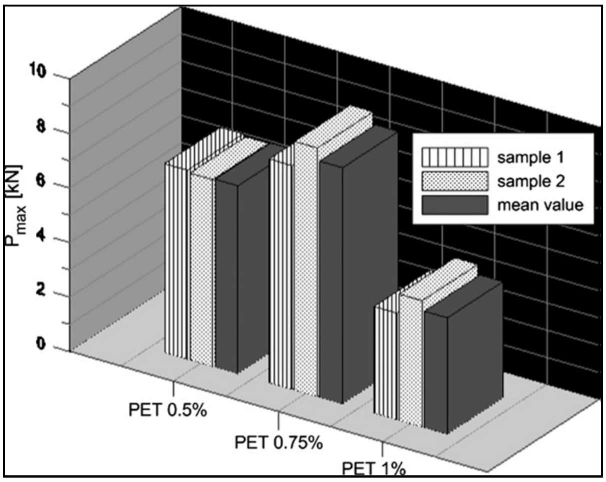


**Fig. 30.** Peak Load at Cracking for Three Different Fiber Contents. Positioning of the Fibrous Reinforcement

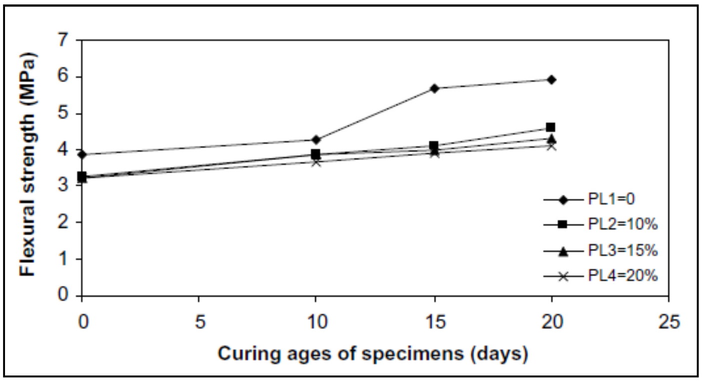


**Fig. 31.** Flexural Strength

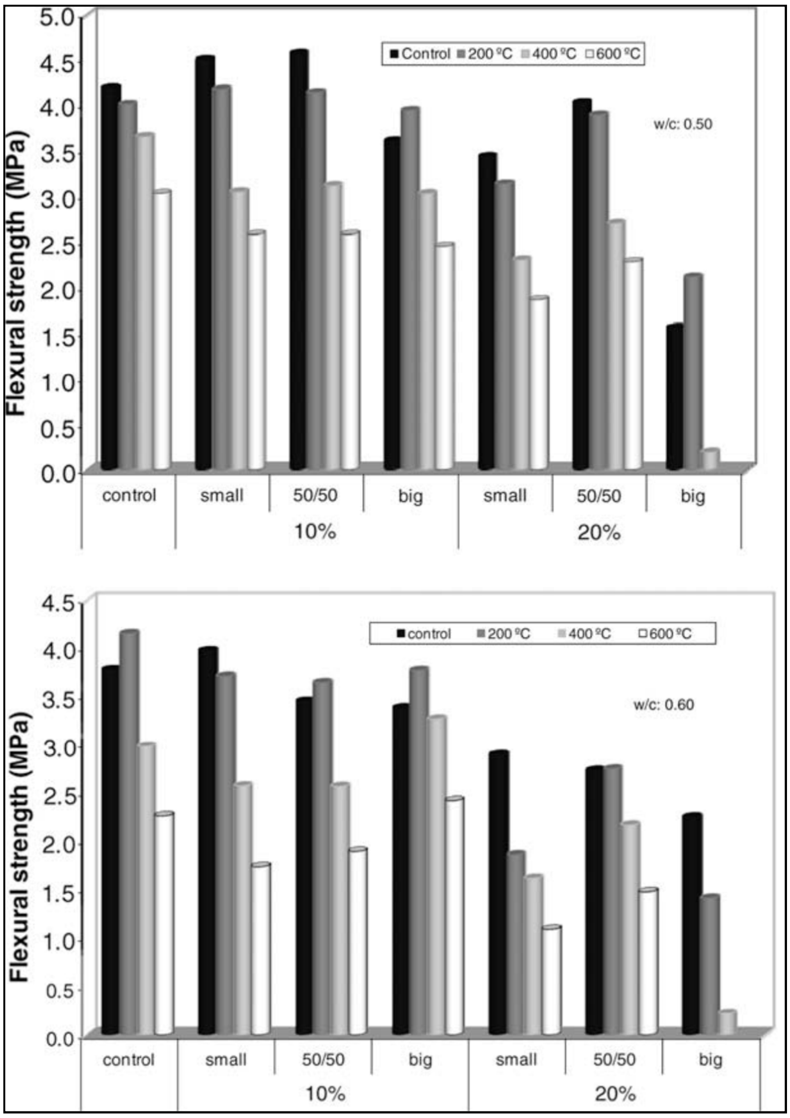


**Fig. 32.** Flexural Strength of Concrete-PET Blends at W/C Ratios of 0.50 and 0.60 Exposed to Different Temperatures

Summarized flexural strength test results.

| Specimens | $P_{cr}$ (kN) | $\Delta_{cr}$ (mm) | $P_y$ (kN) | $\Delta_y$ (mm) | $P_u$ (kN) | $P_u/P_{unf}$ (%) | $\Delta_u$ (mm) |
|---|---|---|---|---|---|---|---|
| NF | 32.6 | 1.01 | 101.4 | 4.80 | 121.6 | 100 | 16.94 |
| RPET 0.5 | 24.8 | 0.43 | 109.0 | 4.52 | 152.6 | 125.5 | 165.0 |
| RPET 0.75 | 22.0 | 0.51 | 108.8 | 4.67 | 159.8 | 131.4 | 141.36 |
| RPET 1.0 | 32.4 | 0.62 | 107.8 | 5.31 | 160.4 | 131.9 | 143.36 |
| PP 0.5 | 32.8 | 0.75 | 108.2 | 4.93 | 154.0 | 127.0 | 140.07 |
| PP 0.75 | 28.0 | 0.69 | 106.3 | 5.21 | 150.4 | 123.7 | 149.16 |
| PP 1.0 | 25.6 | 0.61 | 106.6 | 4.71 | 156.6 | 128.6 | 144.22 |

**Fig. 33.** Summarized Flexural Strength Test Results

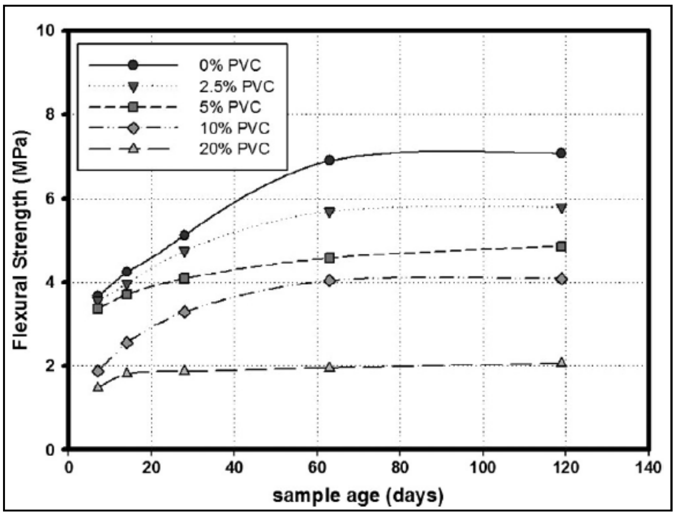


**Fig. 34.** Flexural Strength Temporal Evolution Measured for Mortar-PVC Samples

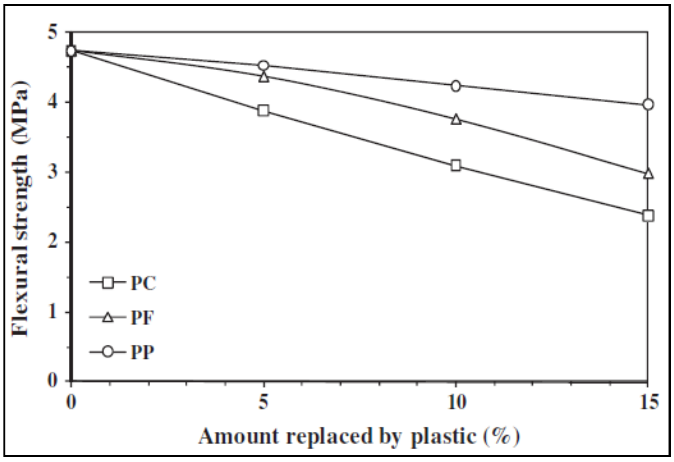


**Fig. 35.** Influence of Various Types of PET-Aggregate on the Flexural Strength of Concrete

## 5. Conclusion

The following conclusion can be made from the current findings;

1. It is also known that, even for reinforced concrete, in the first phase the compressive and tensile stresses are primarily absorbed by the concrete. When the load increases, the concrete cracks increase and the reinforcement in the cracked sections perform its function, absorbing all the tensile stresses itself. Therefore, with the aim to avoid or at least delay the appearance of cracks in the structures, it is important not only to employ conglomerates of greater compressive strength and, also of tensile strength, but to try to limit the occurrence of macro or micro shrinkage cracks, which could trigger the most visible cracking phenomena.
2. Recycle plastic fibers in the concrete mix do not increase the compressive and tensile strength significantly; however, they are still useful to limit the cracks, especially those caused by shrinkage, and also to give the concrete more ductility. The fibers exert an action of sewing the surfaces where the cracks occur. In other words, they prevent the brittle and sudden fracture of

a material that, depending on the type and quantities of fibers used, may show a further post-peak deformation.

3. Straight plastic fibers typically have low bond strength with the concrete matrix, and therefore do not provide the intended crack resisting ability of fiber concrete. To improve bond strength between the recycled plastic fibers and concrete matrix, the fiber geometries are deformed into one of several patterns. Generally, the manufactured fibers are of crimped, twisted, and embossed patterns. Different deformation patterns have been found effective for other fiber materials that can ncreased ductility and ultimate strength of the concrete. Ductility and ultimate load capacity increased respectively, when comparing the recycled plastic fiber-reinforced specimens to those without plastic fiber reinforcement.
4. Recycle plastic could be considered as reinforcement of concrete in substitution of steel. More detailed studies are needed; however, the results of the tests performed so far give hope in its future, profitable use. Summarizing, the use of PET fibers and strips as proposed in the present paper shows the following important advantages such as reduction of the plastic waste, reduction of the production cost and reduction of structural degradation due to steel corrosion.
5. The compressive strength values and the flexural strength values of all waste plastic concrete mixtures tend to decrease below the values for the reference concrete mixtures with increasing the waste plastic ratio at all curing ages. This may be attributed to the decrease in the adhesive strength between the surface of the waste plastic and cement paste. In addition waste plastic is hydrophobic material which may restrict the hydration of cement.
6. Most of the concrete structures mixed with recycle plastic presented low mechanical properties, which can be easily enhanced by improving the matrix properties. The decrease in mechanical properties cannot be explained only by the presence of plastic and porosity. The use of plastic waste is an interesting way to extend life of non-reusable plastics in civil engineering applications providing mortars and concretes with low mechanical properties but increased thermal insulation properties.
7. It is also show that recycle plastic aggregate cannot interact with cement paste and therefore the interfacial transition zone (ITZ) in concrete containing plastic aggregate is weaker than that in the reference concrete, which lowers the resulting compressive strength. Differences in the size, shape and texture of plastic aggregates affect the water to cement ratio as well as the slump of fresh concrete mixes, which ultimately change the mechanical behaviour.
8. This research also has potential application for the production of lightweight concrete, cost savings for raw materials, for minimizing the amount of polymer wastes in landfills, and the creation of decorative, attractive landscaping products. If waste recycle plastic were reused as lightweight aggregates for concrete, positive effects are expected on the recycling of waste resources and the protection of environmental containment.
9. However, the available information on the use of plastic waste as aggregate in concrete is not always adequate. Information is still lacking on several properties of concrete containing plastic waste. The shape and size of the aggregate have a significant influence on both fresh and hardened concrete properties. No thorough study is available on the effect of the shape of plastic aggregate on the properties of resulting concrete.

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