The Effect of Different Shape and Perforated rHDPE in Concrete Structures on Flexural Strength

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Abstract. This research was carried out to develop a reinforcing structure from recycled HDPE plastic lubricant containers to be embedded in concrete structure. Different forms and shapes of recycled HDPE plastic are designed as reinforcement incorporate with cement. In this study, the reinforcing structure was prepared by washing, cutting, dimensioning and joining of the waste HDPE containers (direct technique without treatment on plastic surface). Then, the rHDPE reinforced concrete was produced by casting based on standard of procedure in civil engineering technique. Eight different shapes of rHDPE in concrete structure were used to determine the concrete’s ability in terms of flexural strength. Embedded round shape in solid and perforated of rHDPE in concrete system drastically improved flexural strength at 17.78 % and 13.79 %. The result would seem that the concrete with reinforcing rHDPE structure exhibits a more gradual or flexible properties than concrete beams without reinforcement that has the properties of fragile.

1. Introduction

According to Apoorv and Patel [1] cement is the most commonly used content in today’s globe in all the development performs. Youcef et al. [2] also stated that cement materials is trusted in worldwide construction industrial because of their performance in terms of mechanical strength and durability. The addition of polymeric waste to concrete corresponds to a new perspective in research activities, integrating the areas of concrete technology and environmental technology, thus can improve good quality of concrete.

Nowadays, the utilization of various sorts of sub-products in cement-based materials has grown into a universal practice in the concrete industry. According to Hannawi et al. [3], the exponential growth of plastic waste has come to an alarming rate that it is utmost important to search for alternative route to reduce and dispose these harmful and non-biodegradable plastic waste. Transforming of plastic wastes into building materials and plastic waste valorization was an interesting outlet that provides a major potential market for waste recycling. Ghernouti et al. [4] stated that the incorporation of polymeric
wastes to concrete conform to another point of view in research interests, by linking the field of concrete technology with environmental technology, thereby enhance better quality of concrete.

Reis et al. [5] emphasize 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. 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 Mustafa et al. [6] and Kumar et al. [7] in his 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. Recently, the manufacturing industry started reusing recycled plastic artifact for the fabrication of many household products like clothes hangers, toys, seeding containers etc. Polyethylene terephthalate (PET), poly vinyl chloride (PVC), high density polyethylene (HDPE), thermosetting plastics, shredded and recycled plastic waste mixtures, expanded polystyrene foams (EPS), glass reinforced plastics (GRP), polycarbonate, polyurethane foams and polypropylene fibers are the plastic wastes that usually used as partial or full substitution in the concrete manufacturing.

In an effort to participate in reducing plastic waste pollution, it is beneficial to introduce and incorporate non-biodegradable construction waste as a part of the resources used in construction. With this in mind, this research presents the development of an effective technique of creating a sustainable concrete material consisting of recycled high density polyethylene plastic. High density polyethylene (HDPE) has been chosen to study scientifically relate to the suitability of the mixture and reinforcement. The life span of the HDPE is one of the factors for selection because of its superior characteristic in terms of rust resistance, temperature resistance, chemical resistance and lightweight characteristics compared with steel reinforcement types [8][9].

Additional of plastic fibers into the concrete improved the flexural tensile strength as proved by many researchers. Based on Ramadevi and Manju [10], the concrete containing PET fibers showed gradual increased in flexural strength as the fiber content rise. The fine natural aggregate was replaced by PET fibers at 0.5 % to 6 % volume of total aggregate in concrete mixture. The flexural strength of concrete showed linear increment for fiber percentage of 0.5 % to 2 %, but the strength became stagnant as the fiber content increased from 4 % to 6 %. Nibudey et al. [11] also focused in using post consumed PET bottles to produce plastic fiber of length 25mm with aspect ratio of 35 and 50. The flexural strength of waste PET fiber reinforced concrete was increased to 5.71 MPa (AR35) and 6.00 MPa (AR50) with the addition of 1 % PET fiber in the concrete as compared to control concrete having flexural strength of 4.99 MPa. As the fiber content greater than 1 %, the flexural strength of the reinforced concrete was decreased.

Extensive review shown, it was clearly stated that there were no information available regarding on the design structure of the recycled plastic waste to be embedded in the concrete structure. The summary collected were mainly studied on utilizing waste plastic materials to produce plastic aggregate as fine and coarse aggregate substitution, and plastic fiber to incorporate in concrete structure in order to alter the properties of conventional concrete. Besides, even the results of using recycle plastic improve the flexural strength, there is no scientific research which shape, pattern, orientation and dimension for the plastic that have been used.

In this paper, the studies have focused on the effect of various forms (solid and perforated) and sample of plastic within the flexural strength of the hardened mixtures of concrete. Flexural durability is one of the most important properties of the hardened concrete that represents its load bearing potential. It is also poor in stress thus it is essential to determine the flexing of the concrete beam to avoid the failure. Therefore the flexural tensile strength of concrete should be further analyzed for a wider variety of concrete strength factors considering the lengthy term and confinement conditions of affiliates [12].
2. Materials and Method
The waste motor oil containers were cleaned and washed with soap so as to remove residue oil. The containers were then cut into sheets when the container was completely dried. Then, the rHDPE sheet was joined by adhesive or hot glued to form different shapes of reinforcing structures. In this research, there were eight designs of rHDPE reinforcing structures produced in order to compare the loading effect in concrete structure.

![Images of rHDPE reinforcing structures](image1)

**Figure 1.** Designs and shapes of rHDPE reinforcing structure: (a) square; (b) square perforated; (c) round; (d) round perforated; (e) I-beam; (f) I-perforated; (g) X-shaped; and (h) X-perforated.

All the shapes of rHDPE reinforcing structure were designed based on the basic shapes for engineering structure. The rHDPE reinforcing structures were manufactured in hollow shapes with constant width of 30 mm for all shapes and the length of the reinforcing structure was 150 mm. Among the eight designs, there were four designs of rHDPE reinforcing structures with perforated holes on it. The function of the holes was to provide greater interfacial adhesion and as a bridging system between the
rHDPE plastic and the cement paste. The diameter of the hole was 6 mm and the distance between two holes was 15 mm. Each surface of the reinforcing structure was designed with 10 holes for a 150 mm long reinforcing structure. Figure 1 showed the shapes and patterns of rHDPE reinforcing structure.

2.1 Making test beams from fresh concrete
The test beams dimension were 75 mm x 75 mm x 150 mm long based on BS 1881-109:2013. To prepare test beams, the mold was placed on rigid, smooth horizontal surface and filled with concrete in order to eliminate entrapped air as well as to generate full compaction of concrete. Then, the cement paste was filled into the mold in layers and every layer was compacted by using the compacting bar. Each layer should not be more than 50 mm thick. The strokes were distributed evenly over the surface of the concrete and every layer was compacted to its full depth. Table 1 showed the tolerances for test beam.

| Dimensions          | ± 2 mm (height); ± 1 mm (sides) |
|---------------------|----------------------------------|
| Perpendicularity    | ± 1.5 mm                         |
| Parallelism         | ± 2 mm                           |

2.2 Casting Technique
The test beams were embedded with a different shape of rHDPE reinforcing structure as shown in Figure 2. The reinforcing structure was placed at the center or the symmetry of the concrete structure. There were 27 test beams prepared for mechanical testing. Each form of the rHDPE reinforcement was cast into three test beams. The specimens were kept in a place that is free from vibration and kept in molds at ambient temperature for about 24 hours to harden before being demoulded and transferred to outside environment for curing for 28 days.

Figure 2. Location of rHDPE reinforcement in fresh concrete: (a) square; (b) round; (c) I-beam; and (d) X-beam.
2.3 Flexural Test
In this research, flexural testing used is a three-point bending method and was performed in accordance to BS 1881-118:2013. The aim of this testing was to measure the flexural strength of the 75 mm x 75 mm x 150 mm specimen dimension. Three beam concrete specimens for each shape rHDPE reinforcing design were tested for flexural strength. All loading and supporting points were uniformly contact with the test beams before load is applied. After engaged with initial load, which does not exceed approximately 20% of the failure load, test load was applied without shock such that the stress was raise continuously at a selected constant rate of ± 10% within the range of 0.04 MPa/s to 0.06 MPa/s (450 N/s). The test load was applied until no greater load can be sustained. Once adjusted, the rate of loading was maintained without change until failure occurs.

3. Results and Discussion
The flexural strength is interrelated with the bending ability of the produced concrete composite. From the testing, the flexural strength of the rHDPE reinforced concrete composite can be measured. Figure 3 depicts the flexural strength of the fabricated composites incorporated with various shapes of rHDPE reinforcing structure addition. The indicated results are the average on three specimens. The average strength of the reinforced concrete showed a slight reduction in performance of about 7% for any substitution pattern of rHDPE reinforcement as compared to control concrete. However, if we compare the flexural strength of concrete containing solid reinforcing structure with control concrete, the solid rHDPE reinforced concrete had better strength than the control concrete. The average strength of solid structure reinforced concrete is 5.192 MPa whereas the strength of control concrete is 5.062 MPa. The average strength of perforated rHDPE reinforced concrete is lower than that of the control concrete and solid rHDPE reinforced concrete for about 16% and 18%. Based on the average flexural strength of reinforced concrete (4.734 MPa), concrete with the addition of I-beam (5.834 MPa), round tube (5.962 MPa) and round perforated tube (5.76 MPa) have fulfilled the minimum required flexural strength for reinforced concrete.

![Figure 3. The effect of different shapes of rHDPE reinforcement addition into the 28-days flexural strength of concrete beam.](image)

Figure 3 shown that the flexural strength of the reinforced concretes is improved with the addition of I-beam, round tubing and round perforated rHDPE reinforcing structure with respect to control concrete. The round tube reinforced concrete showed an increment about 18% in strength, while I-beam and round perforated tube reinforced concrete showed 13% and 12% increase in the performance as compared to control concrete. However, concrete containing X-perforated beam, I-perforated beam and square perforated tubing showed 52%, 31% and 27% reduction in flexural strength compared to the
round tube reinforced concrete. Therefore, round tube reinforced concrete has the highest compressive strength while X-perforated beam reinforced concrete has the lowest compressive strength.

Based on Figure 4(a), the control concrete is split into two fractions after determination of flexural strength. The controlled concrete displayed brittle failure in the absence of reinforcement. However, the round tube reinforced concrete and I-beam reinforced concrete did not split into two pieces after testing and the observed failure were more of gradual failure or ductile type failure. The elastic nature and non-brittle characteristic of the rHDPE plastic tend to support the entire load by transferring the stress from the cementitious matrix to the reinforcing structure. The rHDPE structure is capable of resisting the load for a short period after failure and acts as a bridge that connects the crack so the concrete beam failed without full disintegration. Thus, the transferred of stress will enhance the tensile strain capacity and increased the flexural strength of the reinforced concrete.

It can be seen from Figure 4 that the crack mode of the three concrete beams is tensile mode of failure. Tensile mode is defined where the crack occurs on the plane with maximum tensile stress. The crack is initiated at the bottom and ended at the center of the upper part of the concrete beam because the bottom part is experiencing tension and concrete is weak in tension compared to compression. This tensile crack mode also applied to all the reinforced concrete regardless of the shapes of rHDPE reinforcing structures. This is because the tensile crack mode is observed for all concrete containing rHDPE reinforcing structure after the flexural test. The only difference after observing all the fractured reinforced concretes are the crack pattern, the crack either initiated from one side at the bottom of the beam and ended at the top as shown in Figure 4(b) or the cracks initiated at both sides at the bottom of the beam and ended at the top of the concrete as shown in Figure 4(c). If the concrete beams showed crack initiated at both sides it means that the stress is distributed evenly around the specimen whereas if the crack initiated at one side it means that the specimen experienced maximum stress at this side.

![Control concrete split into two fractions](image-a)

![Round rHDPE reinforced concrete](image-b)

![I-beam rHDPE reinforced concrete](image-c)

**Figure 4.** Fracture pattern of concrete beam: (a) Control concrete (b) Round rHDPE reinforced concrete (c) I-beam rHDPE reinforced concrete.

From the testing, both crack patterns can be observed for concrete beams containing similar reinforcing structure because the fractured beams of similar reinforcing structure does not showed only one crack pattern. For example, the first concrete beam containing square reinforcing tube showed crack pattern as Figure 4(b), but the second beam containing similar square reinforcing tube showed crack...
pattern of Figure 4(c). Besides that, it can be visually observed that the external surface of the produced concrete beams presented cavities and pores, or similar to the shape of honeycomb. The explanation for the reduced split tensile strength due to the internal flaws or microcracks, internal and external pores or cavities, weak interfacial bonding between rHDPE and cement matrix and orientation of the reinforcement applies to the flexural behavior of concrete too.

![Figure 5. Illustration of stress distribution in concrete beam (a) control concrete and (b) reinforced concrete.](image)

Apart from that, for 3-point flexural test, the stress is applied from the upper part and distributed to the lower part of the concrete beam. During flexural testing, the upper part of the concrete beam will be compressed while the lower part of the concrete beam is in tension. Since the concrete is weak in tension and good in compression, therefore the crack will be initiated from the bottom part of the concrete beam and grow towards the center of the upper part of the beam. For concrete beam without the addition of reinforcement, the concrete showed brittle failure and split into two fractions after the determination of strength. However, the concrete with rHDPE reinforcing structure showed more gradual or ductile type failure. This is because the applied stress is distributed to the rHDPE structure and the plastic structure is capable of resisting the load for a short period before failure. The rHDPE structure will serve as a medium for the transfer of stress between the cement matrices so that the concrete beam does not show brittle failure. Besides, the rHDPE structure will also act as a backbone to the concrete composites as it tends to support the entire load of the concrete and connect the crack surface so the concrete beam does not fracture into two sections. Figure 5 illustrates the stress distribution in control concrete and reinforced concrete.

4. Conclusions
It was found that the main benefit of adding rHDPE reinforcement into the mix concrete can improve the flexural properties based on their design structure. The following is the main conclusions and significant findings of research.

- The average flexural strength of the rHDPE reinforced concrete is 4.73 MPa whereas the flexural strength of the control concrete is 5.06 MPa. The flexural strength of the reinforced concrete showed about 6.5% reduction in strength compared to control concrete.
- The average flexural strength of concrete containing solid rHDPE reinforcing structures is 5.19 MPa while the average flexural strength of concrete containing perforated rHDPE reinforcing structures is 4.26 MPa. The solid rHDPE reinforced concretes showed 17% improvement in flexural strength compared to perforated rHDPE reinforced concretes.
- Round tube rHDPE reinforced concrete showed the highest flexural strength among the reinforced concretes that is 5.96 MPa, while the lowest flexural performance is showed by X-perforated beam reinforced concrete, with 2.89 MPa. Round tube reinforced concrete is about 51.5% better than X-perforated beam reinforced concrete.
Based on the average flexural strength of 4.73 MPa for reinforced concrete, the concrete with the addition of round tube (5.96 MPa), I-beam (5.83 MPa) and round perforated tube (5.76 MPa) have fulfilled the minimum required flexural strength of reinforced concrete.

The crack mode of the concrete beams is in tensile mode of failure because the bottom part experiencing maximum tension compared to upper part that is in compression. The crack initiated at the bottom and ended at the center of the upper part of the concrete beam. This tensile crack mode also applied to all the reinforced concrete regardless of the shapes of rHDPE reinforcing structures. The only difference fracture of all reinforced concretes are the crack pattern, either crack initiated from one side at the bottom of the beam and ended at the top side or the cracks are initiated at both sides at the bottom of the beam and ended at the top side of the concrete.

The crack initiated at both sides of concrete beam means that the stress is distributed evenly around the specimen. It occurs when the embedded reinforcement rHDPE is parallel horizontally to the concrete beam. If the crack initiated at one side, it means that the specimen experienced maximum stress at that side. It happens when the embedded reinforcement rHDPE is misaligned to the concrete beam in horizontal view.

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