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Evaluation on Compression Properties of Different Shape and Perforated rHDPE in Concrete Structures

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Abstract. The purpose of this study was to develop a concrete structure by incorporating waste HDPE plastic as the main reinforcement material and cement as the matrix via standard casting technique. There are eight different shapes of rHDPE reinforcing structure were used to investigate the compression properties of produced concrete composites. Experimental result shown that the highest shape in compressive strength of rHDPE reinforcing structure were the concrete with the addition of X-perforated beam (18.22 MPa), followed by X-beam (17.7 MPa), square perforated tube (17.54 MPa), round tube (17.42 MPa) and round perforated tube (16.69 MPa). In terms of their compressive behavior, the average concrete containing rHDPE reinforcement was successfully improved by 6 % of the mechanical characteristic compared to control concrete. It is shown that the addition of waste plastic as reinforcement structure can provide better compressive strength based on their shape and pattern respectively.

1. Introduction

Concrete is the most extensive used construction material found worldwide, mainly of its superior properties and economically efficiency compared to other materials. Besides that, these cement-based materials are easy to handle, prepared and formed into various shapes and structural configurations before the curing process. Concrete is very strong in compression but it exhibits very low tensile strength and flexural strength. The main contributor to this low strength of concrete is the quasi-brittle characteristic, associated with their rigid properties, that tends to form micro cracks and propagates when an applied load is subjected [1]. Hence, there is a need to strengthen the concrete by narrowing the defect size or flaws that present inside the concrete so as to create better performance. To improve the tensile and flexural strength of concrete, reinforcing steel is often used.

Apart from the traditional steel reinforcement, there are other types of fibers that can be incorporated into the concrete, including steel fiber, glass fiber, natural fiber as well as synthetic fiber to overcome the strength and toughness challenges found in conventional concrete. The use of fibers to raise the flexural and tensile performance of the concrete matrix, as well as the capability to improve the durability has attract the interest of researchers to developed more new materials to produce fibers. In fact, the adoption of fibers in the concrete matrix can effectively control and prevent crack development, thereby avoid plastic and dry shrinkage crack, maintain concrete integrity, and transform the concrete into much more tougher material with improved crack resistance and ductility. The fibers should possesses high tensile strength and elastic modulus to fulfill as a reinforcement [2].

These days, the utilization of various types of sub-products in cement-based materials has turn 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.

High density polyethylene (HDPE) is known to be the third-largest commodity plastic material used worldwide, after polypropylene (PP) and low density polyethylene (LDPE) in terms of volume. HDPE is a crystalline structure and has very little or no branching. Hence, HDPE has strong intermolecular forces and tensile strength. It possess superior characteristic if compared to LDPE, in terms of hardness and temperature resistance [5].

In Malaysia, it is found that the plastic waste is the second highest solid waste after food waste. One of the major applications for HDPE that can found in Malaysia is motor oil container or fuel tank for vehicles. It is found that the large quantity of waste HDPE motor oil container has not yet been fully discovered or recycled for other useful engineering purposes. Therefore, it is utmost important to find an alternative route to dispose and recycled this plastic waste.

There are many researchers have been utilizing the recycling approach to discover more useful substances from the non-biodegradable recycled high density polyethylene (rHDPE) to reduce the environmental impact. The reason why rHDPE is chosen to study scientifically is because of its long life span, lightweight, chemical resistance, and strength [6]. However, there is no scientific research regarding the types of shape, pattern, orientation and dimension for the direct rHDPE that have been used as a reinforcing structure. In this paper, the design structures of the size, thickness and orientation of rHDPE as a constant variable were emphasized. These studies have focused on the effect of different shape and pattern of plastic in the compression strength of the hardened mixtures of concrete. The reports were summarized and classified into many shape of recycle plastic dealing with concrete.

2. Materials and Method

The waste motor oil containers was 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. 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

Once the workability of the fresh concrete was measured (by slum test), the concrete was cast into predefined molds to prepare test specimens for compression test. The 150 mm size test cubes were made based on BS 1881-108:2013 because the aggregate size used in this study is less than 20 mm. The mold was located on a smooth and firm horizontal surface and filled with concrete in order to eliminate the entrapped air and to generate full compaction of the concrete. Then, the cement paste was filled into the mold in layers about 50 mm deep and every layer was compacted. The minimal number of strokes per layer needed to yield full compaction was 25 strokes for 150 mm cubes. The stroke was circulated evenly over the surface of the concrete and each layer was compacted to its full depth. The excess concrete above the upper edge of the mold was removed and levelled using a float.

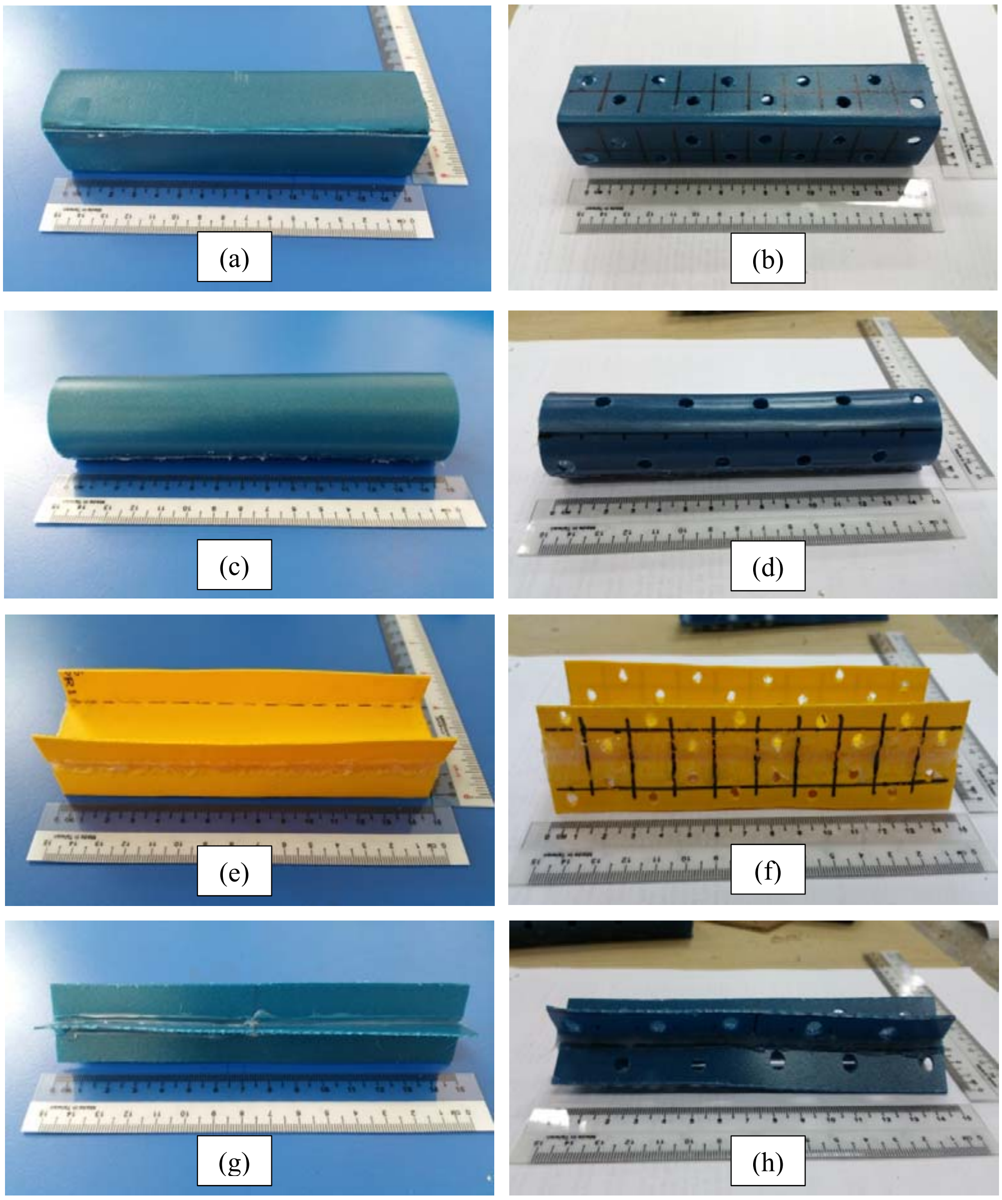

Figure 1. Designs and shapes of rHDPE reinforcing structure: (a) square; (b) square perforated; (c) round; (d) round perforated; (e) I-beam; (f) I-perforated; (g) X-shaped; and (h) X-perforated.

2.2 Casting Technique

The test cubes 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 cubes prepared for compression testing. Each form of the rHDPE reinforcement was cast into three test cubes. 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.

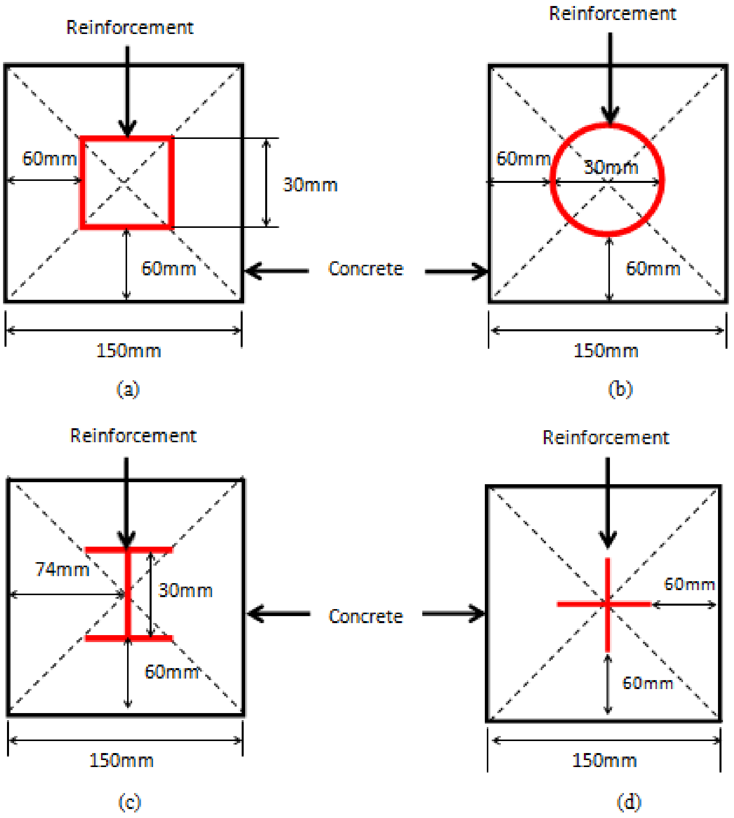

Figure 2. Location of rHDPE reinforcement in fresh concrete: (a) square; (b) round; (c) I-beam; and (d) X-beam.

2.3 Compression Test

The compressive testing performed in this research was using compression machine brand Controls at Politeknik Merlimau Melaka and the test was accordance to the British standard BS 1881-116:2013. Compressive testing is a testing which used to measure a material's ability to withstand compressive forces, where the specimen is squeezed laterally. In this research, the 150 mm x 150 mm x 150 mm test cubes were tested. All cubes were visually inspected. Any cube having broken edge with 20 mm or more were noted. Every test cubes were examined to confirm they are following the perpendicularity requirement based on BS 1881:108:2013. The cross-sectional area of the cube was calculated from the measured dimension. Auxiliary platens were used between the cube and machine platens. The cube specimen was precisely centered on the lower platen. The troweled surface was vertical. Then, the load was applied attentively without shock in such a way so that the stress was raise until no greater load can be sustained. Three concrete specimens for each rHDPE reinforcement design were tested to obtain the average compressive strength. The compressive strength of the cube was calculated by dividing the maximum load by the cross-sectional area. The result should be expressed to the nearest 0.1 MPa.

3. Results and Discussion

Compressive strength is the most important strength for concrete composite. The strength of concrete generally depends on the strength of aggregate, strength of cement, and the bond strength between reinforcement and cement matrix or the interfacial transition zone (ITZ). Albano *et al.* [7] states that the 28-day compressive strength value is approximately equal to 60 days because the concrete attained 75 % to 80 % of its total strength during the first 28 days. According to the ACI 318 Standard (Section 19.2.1.1), the minimum specified compressive strength of a structural lightweight concrete at 28 days should be 2500 psi or 17.24 MPa.

Figure 3 depicts the compressive strength of the fabricated composites incorporated with various shapes of rHDPE reinforcing structure addition. The indicated results are the average of three specimens. The results showed a significant improvement in performance for any substitution pattern of rHDPE reinforcement. The compressive strength of the control concrete is 15.693 MPa whereas the average compressive strength of the reinforced concrete is 16.685 MPa, which is about 6 % increment in strength. However, when we compare the strength of solid structure reinforced concrete (16.464 MPa) and perforated structure reinforced concrete (16.906 MPa) with the control concrete (15.693 MPa), both types of reinforced concrete showed about 5 % and 7% increment in compressive strength. Besides that, the strength of concrete containing perforated rHDPE structure is 3 % higher compared to concrete with solid rHDPE structure addition. Based on the average strength of the reinforced concrete with 16.685 MPa, concrete with the addition of round tube (17.42 MPa), round perforated tube (16.69 MPa), X-beam (17.70 MPa), X-perforated beam (18.22 MPa) and square perforated tube (17.54 MPa) have fulfilled the minimum required compressive strength for reinforced concrete composites.

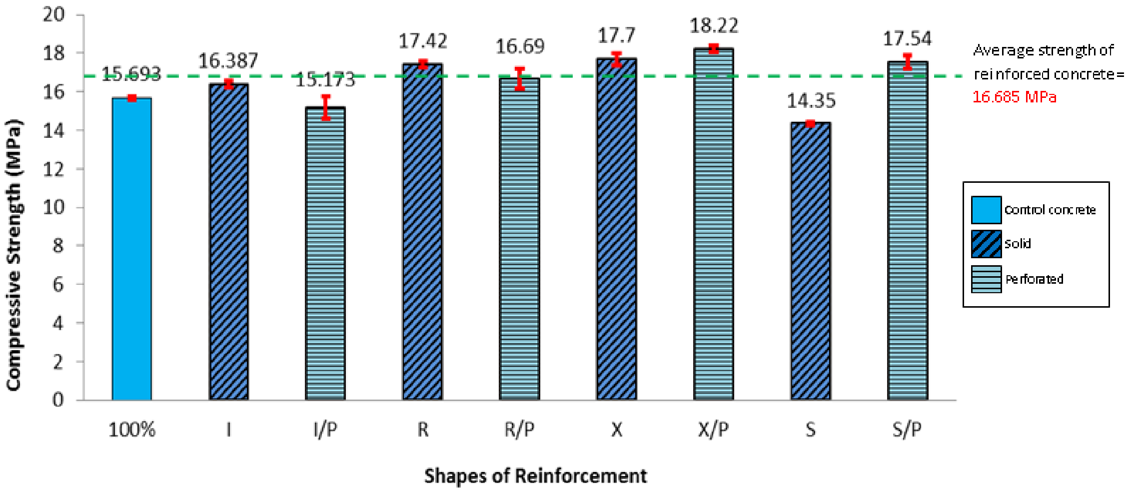

Figure 3. The 28-day compressive strength of different shapes of rHDPE reinforcement addition.

Concrete containing X-shaped perforated reinforcing structure showed the highest compression strength of 18.22 MPa and the lowest strength was observed for concrete containing square reinforcing tube with 14.35 MPa. Based on overall compressive results of reinforced concrete, perforated reinforcing structures promotes better strength than the non-perforated structures in resisting compression. This result proved that the bridge effect does provide better interfacial bonding between the rHDPE plastic and cement matrix. This bridging action tends to transfer the stress from the cement matrix to rHDPE reinforcement. Moreover, the rHDPE reinforcing structure was embedded vertically to direction of maximum applied stress, hence the reinforcement is 360° supported by its entire body from upper to lower part. Therefore, the reinforcement was able to resist the load for a short period before disintegration or split into two fractions. The reduced strength for non-perforated structures reinforced concretes were due to the weak interfacial bond strength resulted from hydrophobic nature of rHDPE plastic surface that impede cement hydration reaction [8]. Thus, the weak interfacial transition zone does not aid in transferring the stress from cement matrix to rHDPE reinforcement. The stress was carried by the cement matrix and if the compressive stress exceeded the ultimate strength of cement matrix, the cement failed.

Figure 4 displayed the typical fracture pattern of the normal concrete at front view. The failure mode observed in normal control concrete was meeting the standard crack pattern as stated in BS 1881-116:2003 where all the four exposed faces cracked almost equally after the determination of compressive strength and showed small damage to faces in contact with the platens (upper and bottom of the cube). However, the reinforced concrete did not showed the similar failure mode as observed from the control concrete. The reinforced concrete fractured at the corner or edge of the cube rather than peeling off of the exposed faces.

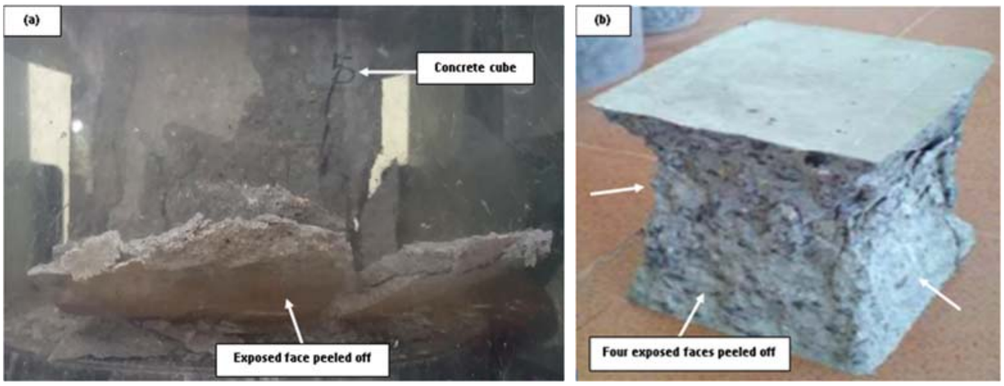

Figure 4. Typical compression failure mode of normal concrete (a) during, (b) after.

Figure 5 shown that the reinforced concrete composites had the similar failure pattern. All the fractured reinforced concretes were split into two halves and the rHDPE reinforcements were remained embedded at one half of the fractured concrete. Besides that, from the fractured surface, there are many pores present in the concrete that may affect the compression strength of the concrete. Apart from that, the fractured surface microstructure showed that the coarse aggregates were broken along the fracture surface. This means that the failure occurred at a direct path through the matrix and aggregates as shown in Figure 6. This scenario was found in concrete where the delayed crack propagation without significant micro-cracks formation and the cracks propagate unhindered and quickly by releasing high amount of energy.

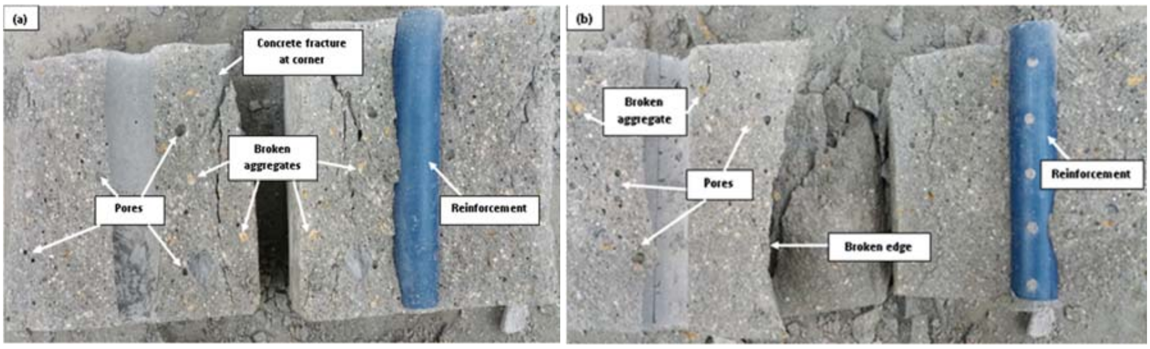

Figure 5. Failure mode of reinforced concrete containing (a) round tube and (b) round perforated tube.

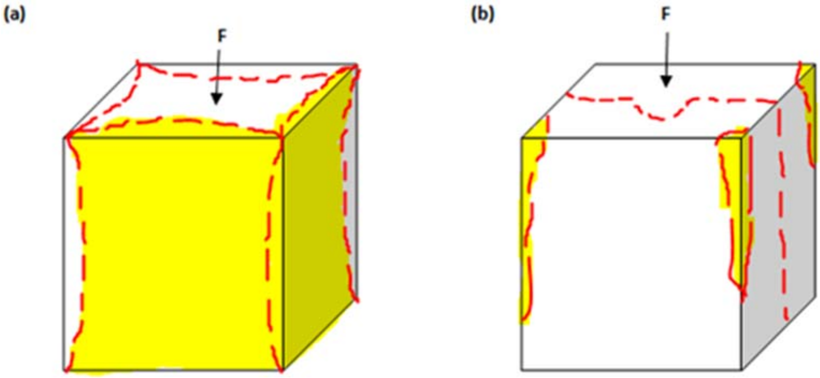

Figure 6. Illustration of fractured pattern of concrete cube (a) control concrete and (b) reinforced concrete.

The failure pattern of the concrete cube without rHDPE structure showed peeling off of the four exposed faces under loading. The fractured concrete cube will displayed curve pattern at the four exposed faces as shown in Figure 6(a). However, for reinforced concrete, the concrete cube fractured at the edges or at the corners of the cube and split into two fractions after the determination of strength. The crack will initiate at the interfacial zone between the plastic surfaces and cement matrix due to the weak interfacial bonding strength as shown in Figure 6(b). The crack line followed the cross-section of the rHDPE reinforcing structure and split into two halves.

4. Conclusions

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

- The average compressive strength of the rHDPE reinforced concrete is 16.69 MPa whereas the compressive strength of the control concrete is 15.69 MPa. The compressive strength of the reinforced concrete showed 6 % increment compared to control concrete.
- The average compressive strength of the concrete containing perforated rHDPE reinforcing structures is 16.91 MPa while the average compressive strength of the concrete containing solid rHDPE reinforcing structures is 16.46 MPa. The strength of the perforated rHDPE reinforced concrete showed about 2.6 % improvement compared to solid rHDPE reinforced concretes.
- The addition of perforated rHDPE reinforcement and solid rHDPE reinforcement showed 7 % and 5 % increment in compressive strength compared to control concrete.
- X-perforated rHDPE reinforced concrete showed the highest compressive strength of 18.22 MPa among the reinforced concretes, while square tube rHDPE reinforced concrete showed the lowest compressive strength of 14.35 MPa. The X-perforated reinforced concrete showed 21 % increment in strength compared to square tube reinforced concrete.
- Based on the average compressive strength (16.69 MPa) for reinforced concretes, the concrete with the addition of X-perforated beam (18.22 MPa), X-beam (17.7 MPa), square perforated tube (17.54 MPa), round tube (17.42 MPa) and round perforated tube (16.69 MPa) have fulfilled the minimum required compressive strength of reinforced concrete.

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