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Bond-Slip Behavior of Steel Bar Embedded in Lightweight Concrete Using Sand Coated Polypropylene Coarse Aggregate

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Keywords: Plastic coarse aggregate, compressive strength, polypropylene, sand coating, bond-slip behavior, plain and deformed steel bars.

Abstract. Plastic waste as coarse aggregates in concrete making is part of efforts to reduce environmental pollution. In one hand the use of plastic as aggregates can provide lighter weight of concrete than those using natural aggregates. Accordingly, a comprehensive experimental study on the concrete-steel bond behavior of structural waste polypropylene (PP) lightweight coarse aggregate concrete (WPPLAC) was carried out using different composition, aggregate gradation, type of bar and size diameter of bar. Pull out tests are conducted for three kind of plain and deformed steel bars having diameter 10, 12 and 16 mm respectively, which are embedded in concrete cubes made by the two mixtures to know local bond-slip relation. Two mixtures of sand coated polypropylene (PP) coarse plastic aggregates, sand as fine aggregates, water and Portland Composite Cement with a water-cement ratio of 0.264 are conducted. The first mixture contains 100% of 25 mm sand coated coarse aggregate while the second mixture contains 70% of 25 mm and 30% of 20 mm sand coated coarse aggregates. Bond strength versus steel displacements results in general show that higher bond strength is found for steel bar having larger diameter while steel displacements approximately follow the scale of bar diameter.

Introduction

The study of natural and artificial light aggregates to produce lightweight concrete has been conducted in some country. Natural lightweight aggregates include diatomite, pumice, volcanic scoria, sawdust, oil palm shells, bottom ash, starch based aggregate etc. Artificial aggregates include expanded shale, slate, perlite, sintered fly ash, bonded fly ash and vermiculite. Beside these aggregates, plastic waste is also used for the manufacture of lightweight concrete.

Plastic waste is used goods that have been unsuitable. These materials can be derived from waste products in household consumption, automotive and electronics. In the world, the production of plastic has reached nearly 150 million tons of plastic per year, which means that nearly 4.8 tons per second and per capita production of 25 kg/year by the central Pollution Control Board [1]. According to Indonesia Solid Waste Association (InSWA) the amount of plastic waste in Indonesia in 2008 reached 5.4 million tons per year, or 14 percent of total waste production. This phenomenon is in consequence of plastic that has many advantages such as light weight, easy to use, strong, not easily damaged by weathering and low-cost manufacturing process.

In the latest developments, new perspectives in research activities that integrate the field of concrete technology and the environment have become a major concern worldwide. Some researchers are conducting studies on the production of lightweight concrete aggregate plastic waste. Among them are [2, 3, 4, 5, 6, 7, 8], who have similar goal to produce lightweight concrete that is more friendly to the environment, known as green concrete. The research was mainly focused on obtaining the mechanical properties of the base as previously conducted [2, 3, 4, 5, 6, 7, 8, 9] as well as a preliminary study to define the ability of adhesions [10, 11].

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The plastic aggregate used as a construction material can reduce environmental pollution caused by plastic waste that accumulates on the surface of the soil. Recent research also confirms the potential use of plastic aggregates to produce lightweight concrete with satisfactory results are obtained by a lighter weight of nearly 30% of normal concrete [6]. Lack of information about bond characteristics of lightweight concrete using waste plastic aggregate is one of the main barriers to acceptance in the construction industry. This led to limited understanding of bond strength between reinforcing bars and lightweight concrete plastic aggregate. Therefore, this paper initiated the research on bonding characteristics of plain and deformed bars in WPPLAC. Increased knowledge on bond characteristics of WPPLAC can contribute to the modification or performance validation of existing Code based formulation and other available equations as well as to check the effectiveness of Code based provisions for lightweight concrete.

Experimental Detail

In this research, the main objective is to study the bond strength characteristics of lightweight aggregate concrete with polypropylene aggregate. Aside from that, compressive strength of the concrete is also needed to fulfill the criteria so the lightweight concrete can be used for structural purposes. The first step of this research is to prepare the material needed for concrete mix design. One of the important material is the lightweight plastic coarse aggregate.

Materials. Portland Cement Composite is used to satisfy Indonesian Standard (SNI 15-7064-2004) and European Standard (EN 197-1:2000 (42.5 N & 42.5 R). The sand that is going to be used, comes from Cianjur, a small city located at West Java Province in Indonesia. On the other hand, it will be used also as coating material for the lightweight polypropylene aggregate. The percentage of passing is within the limits as per SNI 03-2834-2000. The lightweight aggregate for this experiment will be made from waste of Polypropylene (PP) plastic. There are two types of aggregate that are produced with varied size of 25 mm and 20 mm. The shape of the aggregate produced is generally the same as the plastic developed by [6] as shown Fig. 1.

Mix Proportion of Concrete and Designation. Proportion of materials is determined using mix design method that is based on SNI 03-3449-2002 and ACI 211.2-98 with slight adjustment. From trial mixes, it is obtained series of material mix proportion of concrete containing plastic aggregate, denoted by "PP" type of mix proportion is shown in Table 1. Water to cement ratio (W/C) used are 0.264. Superplasticizer (SP) is used to have better workability in mixing the materials for PP1 and PP2 proportion. The superplasticizer type used in this study is Conplast SP337 by Fosroc. In this study, the variables chosen were the type of reinforcing bar and diameter embedded in lightweight concrete with the content of two different plastic aggregate sizes in Table 2.

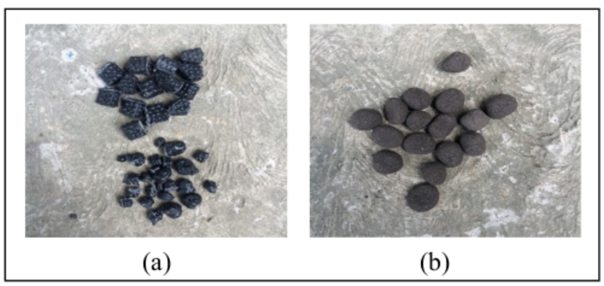


Fig. 1. Lightweight coarse aggregate, (a) Shape of uncoated plastic aggregate, (b) Plastic aggregate coated with sand

Table 1. Concrete mix proportion

Type	W/C	Cement (kg)	Sand (kg)	Plastic Aggr. 20 mm (kg)	Plastic Aggr. 25 mm (kg)	Water (kg)	SP (kg)
PP1	0.264	500	688	0	391	132	7
PP2	0.264	500	688	117	273	132	7

Table 2. Mix designation

Mix Code	Mix-1 Size aggregate (20 mm)		Mix Code	Mix-2 Size aggregate (20 + 25 mm)	
	Bar dia. (mm)	Type Bar		Bar dia. (mm)	Type Bar
PP1-a-10	10	Plain	PP2-a-10	10	Plain
PP1-a-12	12	Plain	PP2-a-12	12	Plain
PP1-a-16	16	Plain	PP2-a-16	16	Plain
PP1-b-10	10	Deformed	PP2-b-10	10	Deformed
PP1-b-12	12	Deformed	PP2-b-12	12	Deformed
PP1-b-16	16	Deformed	PP2-b-16	16	Deformed

Fig. 2. Moulds and specimens for bond test

Mechanical Properties of Concrete Specimen. The compressive strength test of concrete was carried out on 150 mm diameter x 300 mm height cylinder specimens in accordance with ASTM C-873. Compressive test is done by following ASTM C-39. The test is conducted only at the 7th day and 28th day.

Pull Out Test. Based on modifications to RILEM 7-II-128 "Bond Strength for Reinforcing Steel Pull Out Test", the bond test was carried out on the concrete specimens through the pull-out test, as illustrated in Fig. 2. In accordance with the variables used in this study, the reinforcing bar was embedded concentrically in concrete cube of sizes 100 x 100 x 100 mm^3, 120 x 120 x 120 mm^3 and 160 x 160 x 160 mm^3. To ensure uniform slip distribution, the bonded length was maintained at five times the reinforcing bar diameter at mid-height of the specimen while the remainder of the reinforcing bar was enclosed using a PVC tube to act as a bond breaker. All the bond tests were carried out at a concrete age of 28-d. The free un-bonded length of the reinforcing bar was gripped and subjected to concentric tension pull-out force via hydraulic jack with a modified pull out testing machine from RILEM standard. During testing, the loaded-end slip of the reinforcing bar relative to the concrete was measured continuously through the use of one dial gauge, and the reading taken as the slip value. The tension force is applied at the longer end (bottom one) of the steel bar while the dial for measuring the displacement is placed at the shorter end of the steel bar (upper one). The specimen is subjected to vertical load until it reaches pull out failure. The relation between applied force (P) and displacement (Δ_O) is then calculated to find the adhesion of the concrete specimen. The axial tension force and the dial gauge readings were recorded simultaneously at load control through the use of software bundled from load cell and dial gauge. The set-up for the bond test is shown in Fig. 3.

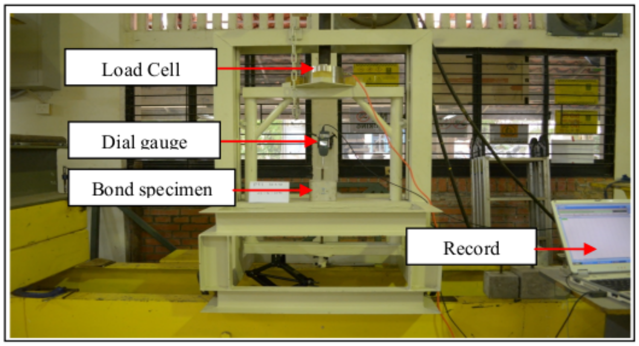
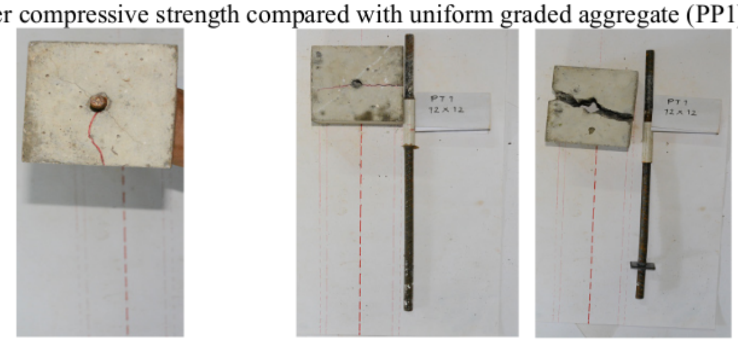


Fig. 3. Pull Out test set up

Results and Discussion

General Observation. In the study, the pullout type failures on the concrete cubes are found for all plain bars and most of the deformed bars embedded in WPPLAC. Only a few cubes of concrete with deformed bars embedded in that, show splitting failure. Fig. 4 shows pull out and splitting failure on the cube embedded with deformed reinforcement of the diameter of 12 mm, and splitting cracks were observed on the sides of the WPPLAC specimens.

Bond strength of steel reinforcement in lightweight concrete using mixture-PP2 has a greater value than that of steel reinforcement in lightweight concrete using mixture-PP1. This condition is attributed to the compressive strength of lightweight concrete with mixture-PP2 greater than that of lightweight concrete with mixed-PP1 as presented in Table 3. This is corresponding with the results achieved by [12, 13]. According to [14], the mixture of concrete with gap graded aggregate (PP2) exhibited better compressive strength compared with uniform graded aggregate (PP1).



(a) (b)

Fig. 4. Failure mode of bond specimens, (a) Pull out failure, (b) Splitting failure

Table 3. Bond strength between steel and lightweight concrete used waste polypropylene as coarse aggregate (average from 3 sample)

Bar diameter (mm)	Compressive strength (MPa) – 28 d		Density (kg/m^3)		Bond Strength (MPa)			
					Plain bar		Deform bar	
	PP1	PP2	PP1	PP2	PP1	PP2	PP1	PP2
10	24.66	25.85	1783	1829	1.37	1.79	11.36	12.18
12	24.66	25.85	1783	1829	1.38	2.64	14.13	14.39
16	24.66	25.85	1783	1829	2.53	2.54	14.72	15.41

Bond Strength-Slip Relation and Failure Mode (Deformed Bars Case). Several specimens only with deformed reinforcement embedded, to a diameter of more than 10 mm failed due to splitting, whereas the specimen with a bar diameter of 10 mm failed due to pullout.

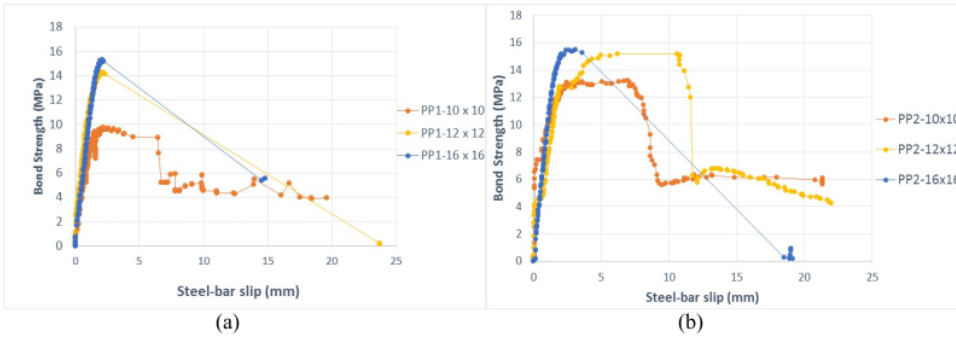


Fig. 5. Typical load–slip curves associated with pullout failure of deformed bars, (a) Mixture-PP1, (b) Mixture-PP2

Typical bond strength–slip curves associated with pullout failure at different bar diameter for both concrete mixture of the specimens embedded with deformed bar are shown Fig. 5.
Load–slip curves show a rapid rise to the peak value, and once the adhesive bond is broken, the bond stress drops off quickly and the further resistance to pullout is provided primarily by friction. The peak load was higher in the case of specimens with mixed PP2 but for specimen with both PP1 and PP2 concrete mixture show similar before and after peak response. The condition occurs in reinforcement with a diameter of 12 mm and 16 mm from PP1 specimen and PP2 specimen only at a diameter of 16 mm.

Bond Strength-Slip Relation and Failure Mode (Plain Bars Case). Fig. 6 compares typical bond strength–slip curves associated with pullout failure at different bar diameter for both concrete mixture of the specimens embedded with plain bar. All the specimens with plain smooth bars failed due to pullout and showed no sign of splitting of concrete or bar yielding as it was designed to have pullout failure. A pullout type failure was characterized by a gradual increase of load-versus-slip up the maximum (peak) load followed by a gradual softening. This type of failure was observed at different diameter as well as with concrete mixture. It was also observed that the slip at peak load for pullout failure of plain bar did not vary too much for both PP1 and PP2 specimens (ranges between 1.3 and 5 mm). The bond strength–slip curve showed similar trend of variations for both PP1 and PP2. However, for PP1 specimens the peak load was lower and slip at peak load was slightly higher compared to PP2 specimens.

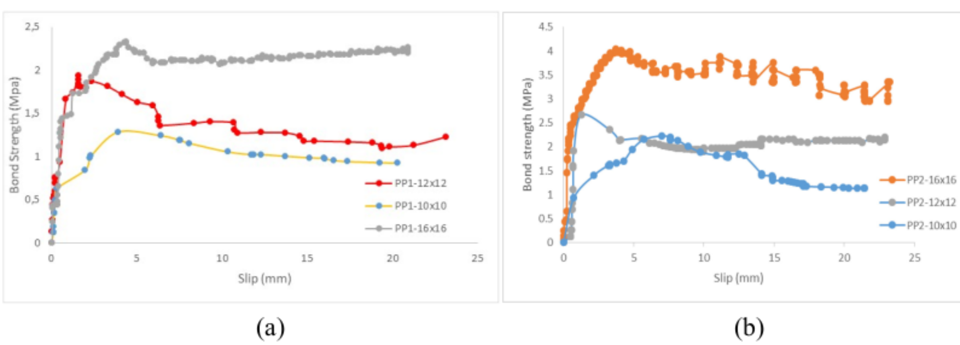


Fig. 6. Typical load–slip curves associated with pullout failure of plain bars, (a) Mixture-PP1, (b) Mixture-PP2

Conclusion

The bond characteristics of plain and deformed bars embedded in waste polypropylene lightweight aggregate concrete (WPPLAC) are presented based on the results obtained from pullout tests. In this study, it is concluded that high bond strength can be transferred in WPPLAC dependent on the compression strength of concrete, size diameter of bar and type of bar. For the same of concrete quality and bar diameter, the bond strength of deformed bar embedded in WPPLAC is greater by almost 5-8 times the bond strength of the plain bar in WPPLAC. On the other hand, for the two compositions PP1 and PP2 concrete mixtures was observed exhibit similar shape of the bond-slip curve and no significant differences are observed for slip on maximum bond strength.

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