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MECHANICAL BEHAVIOR OF CONCRETE INCORPORATING RECYCLED PLASTIC BOTTLE FIBERS

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ABSTRACT

Concrete is a common and most widely used construction material in the world. Due to the rapid growth of concrete construction by excessive usage of natural aggregates resulted in the search for alternative source of concrete aggregate. The environmental pollution from non-biodegradable products is causing a serious problem to human lives and plastc type product is one of them. The objective of the study is to investigate the influence of two different types of recycled plastic bottle fibers on compressive strength of concrete. And mechanical properties such as ductility, toughness, cracking are also observed in this study. It is well konwon that Polyethylene Terephthalate (PET) is usually used for carbonated beverage and water bottles and fibers from these recycled bottles are used in this investigation. In this study, two types of fiber are used: straight and zigzag fiber. Fibers with lengths of 40 mm, aspect ratio of 40 and volume fractions of 0 and 0.75%, replacing the volume of coarse aggregate are used in straight fiber made concrete and zigzag fiber made concrete respectively. Design mixing ratio 1:2:3 for M20 concrete and water-cement ratio 0.58 are used in this study. Curing is done in field condition and weathering action is allowed in curing time. The experimental results show that crushing strength of plain concrete, straight and zigzag fiber made concrete are 19.84 MPa, 19.54 and 18.49 MPa respectively in case of destructive test at 28 days. The compressive strength of plain concrete, straight and zigzag fiber made concrete are 13.58 MPa, 10.36 and 8.21 MPa respectively in case of non-destructive test at 28 days. Use of fibers changes failure mode of concrete and splitting portion from straight fiber made concrete is more than zigzag fiber made concrete in failure mode. Addition of fibers decreases workability of concrete and shows toughness, cracking, ductility properties. Use of zigzag pattern fibers shows interlocking property just like deformed rebars which are used for reinforcing the concrete.

Keywords: *Recycled plastic bottle fiber, Straight plastic fiber, Zigzag plastic fiber, PET fiber, Failure mode.*

1. INTRODUCTION

Due to rapid growth of industrialization & urbanization around the world, lots of infrastructure developments are taking place and environmental pollution is occurring due to use of non-biodegradable products. Polyethylene Terephthalate, known commonly as PET or PETE is best known as the clear plastic used for water, soda bottle containers and for domestic purpose etc. As a raw material, PET is globally recognized as a safe, non-toxic, strong, lightweight, flexible material that is 100% recyclable. Plastic is a non-biodegradable product which is harmful for our environment. Plastic does not decompose in over 500 years. Bangladesh imports plastic raw materials worth Tk 2,000 crore and every day Bangladesh generates around 1,700 tonnes of plastic waste but only half of the plastic waste is recycled and annually around 3 lakh tonnes of plastic waste is dumped in the open areas (Ayan, 2018). So, plastics should be disposed properly to save our environment. Ismail & Al-Hashmi (2008) insured that reusing waste plastic as a sand-substitution aggregate in concrete gives a good approach to reduce the cost of materials and solve some of the solid waste problems posed by plastics.

It is well known that concrete is strong in compression and has high brittle property. But concrete is weak ductility and toughness. With addition of fibers and allowing little variation in compressive strength from plain concrete, these disadvantages can be overcome. It is also known that deformed rebar is used for reinforcing the concrete because deformed rebar gives interlocking property and gives a good bonding between rebar and concrete. In this study, straight fibers where no deformed shape is given and deformed shape zigzag pattern type fibers are used with concrete to study the mechanical properties of concrete reinforcing with recycled plastic fibers.

2. METHODOLOGY

Extensive laboratory testing has been carried out to evaluate the properties of coarse aggregate, fine aggregate, cement and plastic. There are 3 cases have been considered in the present study to understand the effect of plastic fiber on the compressive strength of concrete. Plain concrete (control case) which is 0% fiber by volume of coarse aggregate and concrete made with straight and zigzag plastic fiber respectively by 0.75% volume of coarse aggregate, are the total 3 cases are being considered to understand the effect of recycled plastic bottle fiber replacement on the compressive strength of concrete. Other mechanical behavior: toughness, cracking resistance and ductility are also observed. Volume of recycled plastic fibers is multiplied by its density to get the weight of fibers in grams and then it was replaced with the amount of coarse aggregate. According to ACI 211.1-91, design mix 1:2:3 of M20 concrete is determined. Water cement ratio (w/c) = 0.58 is used. All cases of specimen have been tested at the age of 28 days curing under weathering action to understand the effect of the compressive strength of both plain and recycled plastic fiber made concrete.

2.1 Materials

Portland composite cement (PCC), locally available fine sand and crushed stones were used for casting concrete specimens. Recycled plastic bottles were collected for making plastic fibers.

2.1.1 Coarse Aggregate

Crushed stones were used as coarse aggregate. Maximum size of aggregate was 20mm and gradation of coarse aggregate was done confirming to ASTM C33. Specific gravity, unit weight and absorption capacity were found 2.584, 1539.362kg/m^3 and 0.838% respectively.

2.1.2 Fine Aggregate

Locally available sand was used as fine aggregate. Specific gravity, unit weight, absorption capacity and fineness modulus were 2.136, 1602.373kg/m^3, 6.383% and 2.756 respectively. Gradation of fine aggregate was done confirming to ASTM C33.

2.1.3 Binder

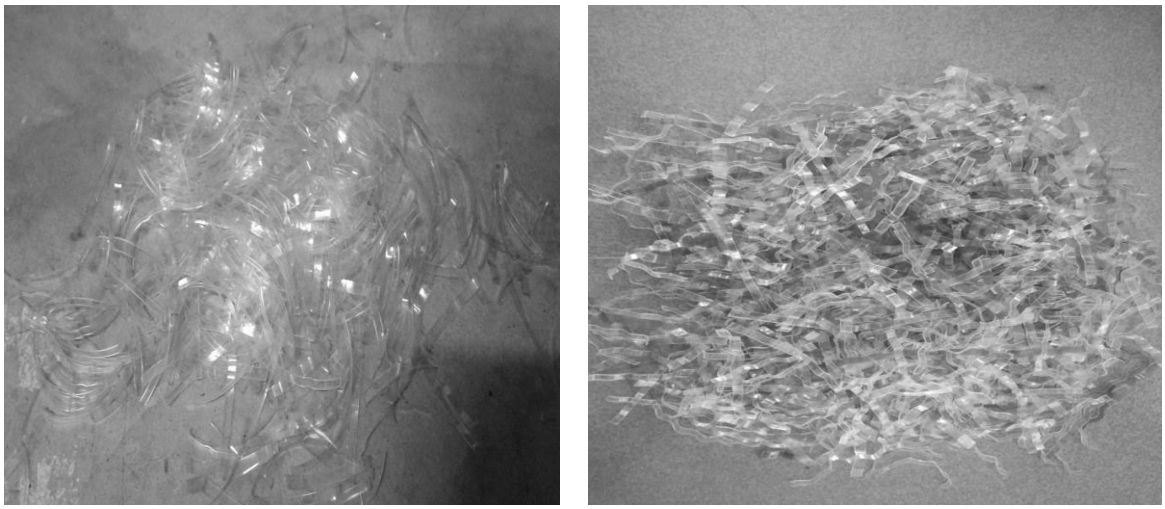
The binding material was Portland composite cement (PCC) which contains 65%-79% clinker, 0-5% gypsum, slag, fly ash, limestone 21%-35%. Specific gravity, initial setting time, final setting time and normal consistency were found 3.15, 125min, 210min and 28.5% respectively.

2.1.4 Recycled Plastic Fibers

Fibers having length 40mm, width 4mm, thickness 0.2mm and equivalent diameter 1mm were used both for straight and zigzag fibers. Aspect ratio (L/D) was 40. Unit weight of fiber was 1370kg/m^3. Plastic bottle cutter and zigzag pattern making device were used to give the fibers proper shape. Equivalent diameter of plastic fiber was determined by equation (1).

$$T \times B = (\pi/4) \times D^2 \quad (1)$$

Where, L = Length of fiber
T = Thickness of fiber
B = Width of fiber
D = Equivalent diameter of fiber
And figure 1 shows two types of fiber.



(a) (b)

Figure 1: (a) Straight plastic fibers (b) Zigzag plastic fibers

2.2 Concrete Mix Design

The mix was designed as per ACI 211.1-91 for M20 grade concrete with 0.58 water-cement ratio. Concrete mixes were prepared by 0% and 0.75% volume replacement of coarse aggregate with straight and zigzag fibers respectively. The percentage of volume of coarse aggregate was taken and it was multiplied with unit weight of fiber and thus weight of fibers was taken. Then weight of coarse aggregate was replaced by weight of fibers. Table 1 shows mixing proportion of concrete.

Table 1: Mix proportion for each m^3 of concrete

S.N.	% of CA replacement	Cement(kg)	Sand(kg)	Stone(kg)	Water(kg)	Fiber(kg)
1	0% PF	360	801.19	1154.52	145	-
2	0.75% ST PF	360	801.19	1146.81	145	7.71
3	0.75% ZZ PF	360	801.19	1146.81	145	7.71

PF = Plastic fiber, ST = Straight and ZZ = Zigzag, CA= Coarse Aggregate

2.3 Test Specimens and Test Procedures

For compressive strength test, cylindrical specimens of 4in diameter and 8in height were used. Total six sets of specimens were casted, three sets for destructive test and other three sets for non-destructive test. Three specimens were used for each set and average value of compressive strength was used. Compressive strength for each specimen was determined by destructive and non-destructive Rebound Hammer test according to ASTM C39 and ASTM C805 respectively. Workability measurement was done according to ASTM C143.

3. RESULTS & DISCUSSIONS

3.1 Results of Fresh Concrete Properties

There are many properties of fresh concrete. In this study, only workability measurement is done. From table 2, it can be seen that the addition of fibers decreases workability. Reduction of workability of concrete made with zigzag fibers is a little bit more than concrete made with straight fibers.

Table 2: Slump test

% of CA replacement	Slump value in inch		
	Plain concrete	Concrete with straight fiber	Concrete with zigzag fiber
0	5	-	-
0.75	-	4.6	3.8

3.2 Results of Hardened Concrete Properties

In this study, compressive strength test (DT) and Rebound Hammer test (NDT) are performed. From table 3 & 4, it can be said that addition of fibers decreases compressive strength of concrete because of poor bonding between plastic fibers and cement-sand paste. Compressive strength of concrete obtained by non-destructive Rebound Hammer test shows lower values than that of destructive test. Due to exposure of curing to environment, weathering actions such as rain, sunlight variation, change in temperature, growth of organic content affect hydration process of concrete and strength gaining process of concrete.

Table 3: Destructive compression test

% of CA replacement	Crushing Strength in MPa		
	Plain concrete	Concrete with straight fiber	Concrete with zigzag fiber
0	19.84	-	-
0.75	-	19.54	18.49

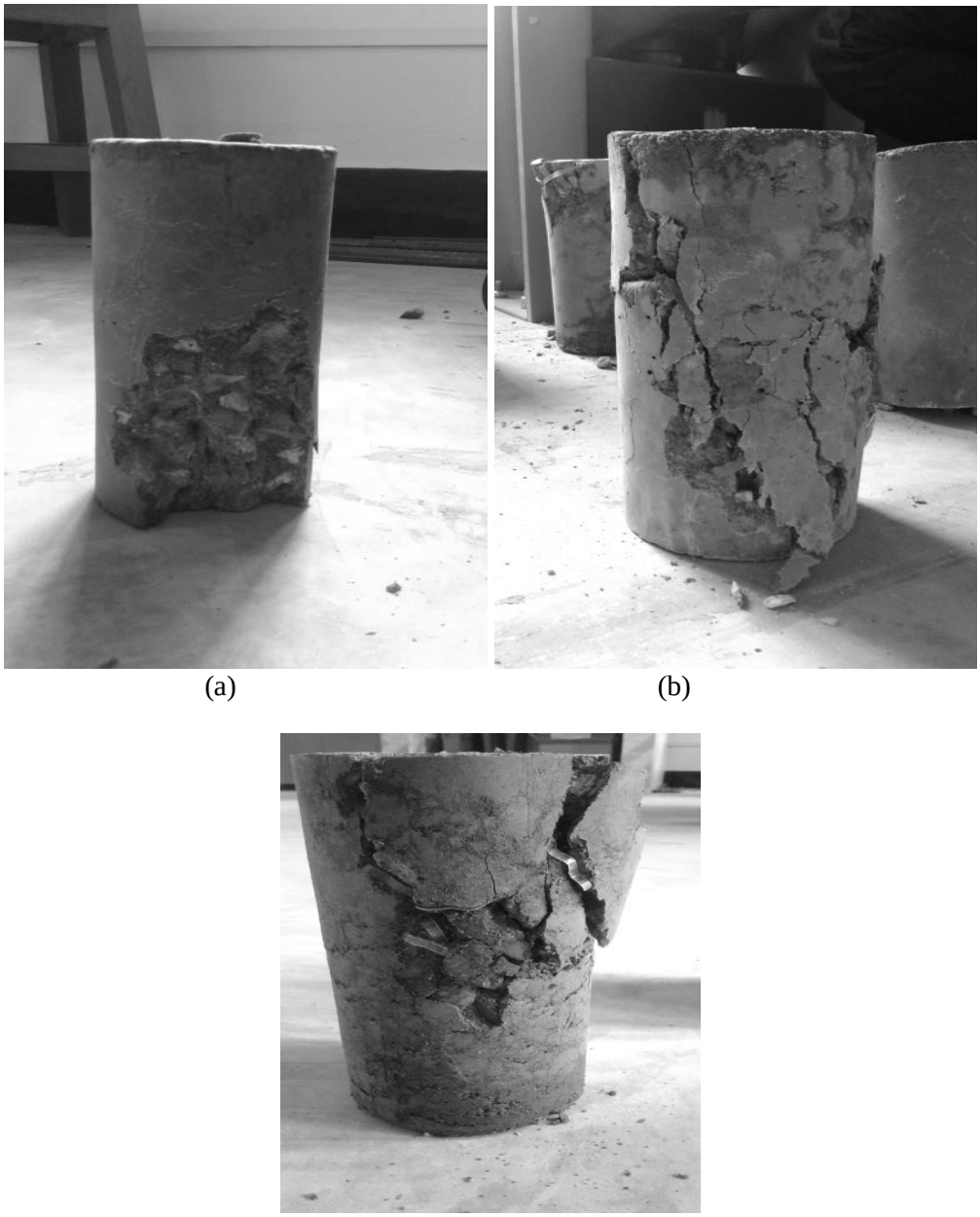
It is well known that a concrete with low strength and low stiffness will absorb more energy to yield in a lower rebound value. Results from table 4 obtained by Rebound Hammer test, it can be said that addition of fibers helps concrte to absorp energy that means concrete will show toughness property. So, allowing a little variation in crushing strength of concrete from plain concrete, both straight and zigzag plastic fibers can be used.

Table 4: Rebound Hammer test

% of CA replacement	Crushing Strength in MPa		
	Plain concrete	Concrete with straight fiber	Concrete with zigzag fiber
0	13.58	-	-
0.75	-	10.36	8.21

3.3 Failure Surface of Concrete

The presence of fibers changes the mode of failure. Shear fracture occurs in plain concrete. Axial split occurs in concrete made with straight and zigzag fibers respectively. From figure 2, it can be said that concrete with fibers shows some ductility property but plan concrete shows brittle property. Splitting portion from concrete made with straight fibers is more than concrete made with zigzag fibers. Zigzag fibers in concrete hold some concrete portion during concrete failure and thus it provides interlocking property with concrete.



(a) (b)

(c)

Figure 2: (a) Plain concrete (b) Concrete with straight fibers (c) Concrete with zigzag fibers

4. CONCLUSIONS

Based on the results and discussions, following conclusions are drawn

i. Overflow of water, variation of sunlight, growth of organic content is found, as curing is exposed to environment and these factors affect hydration process and strength gaining process of concrete.

ii. The workability of concrete decreases by using plastic fibers.
iii. The presence of plastic fibers changes the mode of failure.
iv. Addition of fibers decreases brittle property of concrete but increases ductility and toughness of concrete.
v. Low amount of plastic fibers should be used in concrete so that variation in compressive strength becomes negligible.
vi. Deformation of fibers in zigzag pattern provides interlocking property with concrete.
vii. Compressive strengths of concrete made with straight and zigzag fibers at 0% and 0.75% replacement with coarse aggregate by volume are 19.84MPa, 19.54MPa, 18.49MPa in case of destructive test and 13.58MPa, 10.36MPa, 8.21Mpa in case of non-destructive test.

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