POTENTIAL OF USING PLASTIC WASTES AS COARSE AGGREGATES IN CONCRETE

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ABSTRACT

Plastic wastes have represented a significant portion of municipal solid wastes and pose a serious pollution problem due to both their extended life cycle and visibility. On the other hand, rapid urbanization especially in developing countries results the depletion of natural resources for construction industry. The both problems can be mitigated by proper management such as recycling these plastic wastes into useful products, such as construction building materials. Therefore, the main objective of this paper is to assess the potential of using plastic waste as a replacement of coarse aggregates in concrete mixes. 25% and 50% of natural coarse aggregates are replaced by waste plastics in volume fraction in concrete mixes. Three different water-to-cement ratios such 0.4, 0.5, and 0.6 are considered to evaluate the fresh properties such as slump as well as compressive and tensile strength of concrete. A total of 81 speciemns were prepared and tested at the age of 28 days. Cylindrical specimens with size of 100 x 200 mm and cube specimens of 100 x 100 mm were prepared. From the test results it is observed that the addition of waste plastic aggregates in concrete mixes will have little effect on the fresh properties of concrete. However, higher percentage addition of waste plastic aggregates in a concrete mix reduces the slump values than that of the lower addition. On the other hand, compressive strength decreases as the addition of waste plastic aggregate increases. However, this reduction is prominant for the higher strength with lower water-to-cement ratios than that of the lower strength of concrete. The similar trend is shown for the cylindrical and cube specimens of concrete. For the lower grade of concrete, the addition of waste plastic aggregates shows the insignficant strength variation in comparsion to natural stone coarse aggregates. Therefore, the construction sector has the potential to incorporate these plastic wastes in concrete mixes as coarse aggregates and thereby provide feasible alternative to manage plastic waste for environmental protection and sustainable development.

Keywords: *Construction materials, coarse aggregates, plastic wastes, concrete mix, concrete properties*

1. INTRODUCTION

Plastics have become an inseparable and integral part of our lives as it shows mostly user-friendly designs and low cost. Several sectors such as packaging, automotive and industrial industries, medical and other healthcare systems, preservation and distribution of food are the main consumers of such plastics. The production and consumption of plastic have increased day by day and it results in more volume of solid plastic waste (SPW). Al-Salem et al. (2009) reported that this waste poses challenges and opportunities to societies in spite of technological advances. Bahij et al. (2020) mentioned that a total of 335 million tons of plastic were produced all around the world in 2016. They also reported that this production is estimated to be double by 2035 and quadruple by 2050.

Brooks et al. (2018) reported that an estimated total of 6.30 billion tons of plastic waste was generated from 1950 to 2015. More than 80% of these wastes are amassed in landfills or in the natural environment. Liang et al. (2021) reported that more than 50% of worldwide plastic is produced in Asia. In recent years, about 74% of the exported plastic waste in the world has entered Asia region. A report states that Bangladesh produces around 87,000 tons of single-use plastics waste annually. From this production around 86% of this waste is normally dumped in landfills. As most plastics are non-biodegradable this can stay in soil and water for a long time causing severe environmental pollution. It is eventually getting exposed to the food chain. Single-use plastics are broadly used in Bangladesh due to the extremely cheap price, lack of affordable alternatives and weak policy enforcement. In Bangladesh, a solid waste problem is raised due to the increase in the use of PET (poly ethylene-terephthalate) bottles. Silva et al. (2005) mentioned that PET bottles require longer time even more than one hundred years to degrade it into the nature. That is why, it becomes one of the major challenges in Bangladesh and strongly demands waste plastic recycling.

Bangladesh as a developing country is currently experiencing rapid urbanization and industrialization. This results a lot of infrastructure developments. However, this development is hampered by acute shortage of construction materials, higher prices and huge generated waste. It is observed that plastic is one major component of Municipal Solid Waste (MSW) which is becoming a major research issue for its disposal. Construction sectors have potential its use in concrete. There have been successful replacements or partial replacements of aggregates or filler components of concrete with industrial waste such as fly ash and wood chips in concrete. Literature has shown also successful reduction of plastic waste by recycling and using in concrete as replacements of coarse and fine aggregates. Tayeh et al. (2021) studied five concrete mixtures containing PET and PE with partial replacement for fine aggregate ranged from 0 to 40%. The obtained results show the increase in energy capacity and impact resistance of concrete at the cost of compressive strength. Aldahdooh et al. (2018) studied the potential of plastic waste aggregates as a partial aggregate replacement on properties of normal concrete. They reported that plastic waste aggregates cane be used for the production of normal strength concrete satisfactorily. Mohammed et al. (2019) conducted experimental tests on concrete made of coarse aggregate or fine aggregate partially replaced with plastic wastes. They reported that there is a chance to replace fine or coarse aggregate with plastic aggregate not more than 30% for the production of concrete with acceptable properties. Therefore, the objective of the current paper is to assess concrete properties incorporating waste plastics as a partial replacement of coarse aggregates in concrete. An experimental program was conducted to determine the concrete fresh properties such as slump and hardened properties such as compressive and tensile strengths of concrete incorporating different replacement of coarse aggregates. In this paper, concrete properties having 25% and 50% of waste plastic as replacement of coarse aggregates will be discussed.

2. MATERIALS AND METHODS

2.1 Materials

Normal strength concrete with natural stone aggregates and plastic aggregates were prepared in the current study. Two different replacements (25% and 50%) of stone aggregates in volume with plastic aggregates was used.

Particle size not more than 4.75 mm was considered as fine aggregates. Locally available Sylhet sand was used as fine aggregates in different concrete mixes. For determining particle size distribution, auto sieve shakers was used. Stone chips as coarse aggregates collected from a local company having a maximum size of 19 mm were used in concrete mixes. Particle size distribution of the coarse aggregate was obtained manually by hand operated sieve. Plastics that cannot be degraded further are being molded into a medium size which was then shredded into about 19 mm. Manual method was used for the particle size distribution of the plastic aggregates. These plastics consist mainly of Low Density Polyethylene (LDPE). Portland limestone cement CEM II/B-L 42.5N (BDS EN 197-1: 2003) was used as binder material in concrete mixes.

Figure 1 shows the different aggregates used in the present study. Figure 2 shows the particle size distribution of the aggregates used in different concrete mixes. In addition, tests on different materials were also conducted to determine various properties and results are presented in Table 1.

(a) Sylhet sand (b) Natural stone chips (c) Plastic aggregate

Figure 1: Aggregates used in different concrete mixes

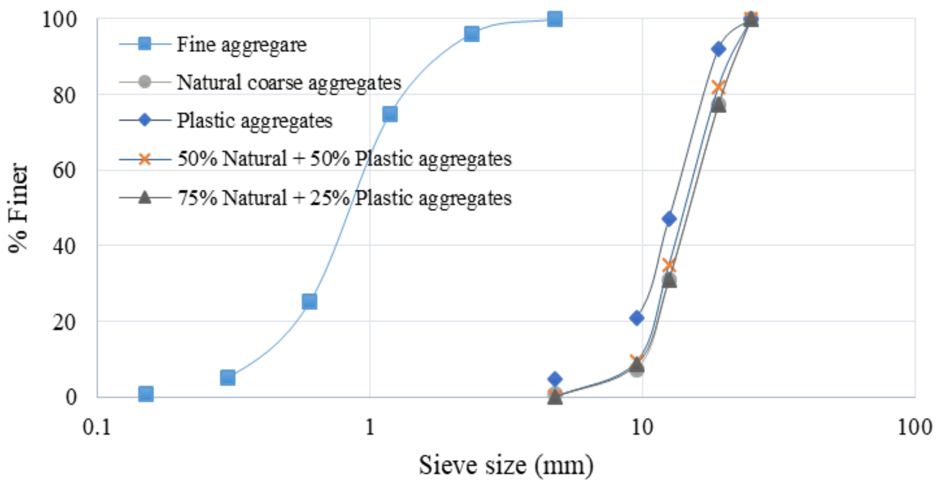

Figure 2: Particle size distribution for different aggregates used in concrete

Table 1: Material Properties of different aggregates

	Unit Wt. (kg/m^3) [ASTM C29]	**Water Absorption** [ASTM C 127, 128]	**F.M.** [ASTM C 136]	**Specific Gravity** [ASTM C127, 128]
Sand	1530	0.60	2.98	2.64
Natural stone aggregates	1580	0.86	7.84	2.56
Plastic Aggregates	560	-	7.35	0.96
75% Natural + 25% Plastic	1330	-	7.73	2.16
50% Natural + 50% Plastic	1080	-	7.83	1.76

2.2 Preparation of Sample Specimens

2.2.1 Mix Proportion

The control mix has a mix ratio of 1:2:3, 1:1.5:2.5, 1:2.5:4 (cement: fine aggregate: coarse aggregate) which was adopted for this work with a water- cement ratio of 0.4, 0.5 and 0.6, respectively. For making concrete mixes containing plastics, the amount of plastic was considered as 25% and 50% by volume of the coarse aggregate in the control concrete.

2.2.2 Mixing, Casting and Curing

In a regular concrete mix, fine aggregate, coarse aggregate were weighed first and mixed homogeneously for about two minutes in the concrete mixer. This was followed by the addition of cement and one third of total mixing water. After two minutes of mixing, remaining mixing water was added subsequently. Mixing was ceased after five minutes for all mixes when a homogenous mixture has been obtained. Before casting, all the cylindrical molds properly. The same procedure was used for preparation of concrete specimens with plastic aggregates. The molds were secured tightly to ensure that there were no gaps left on the mold which could lead to a possibility of a slurry leakage. Clean and oiled mold for each category was filled with the concrete in three layers. After tamping the molds they were then vibrated from side to side using vibrator. The vibration was stopped as soon as the cement slurry appeared on the top of the molds. The specimens were left in the steel molds covered with wet sack for 24 hours. After 24 hours the specimens were removed from the molds then kept in the curing tank containing clean water till the stipulated day of testing of mechanical and other properties. Figure 3 shows the typical concrete specimen preparation and curing steps.

Figure 3: Mixing, casting and curing of concrete

3. RESULTS AND DISCUSSIONS

In the experimental program 81 nos. specimens were prepared and were tested to evaluate the concrete properties and compared the obtained results. Cylindrical shape specimens with size of 100 x 200 mm and cube specimens with size of 100 x 100 mm were cast and tested to evaluate the concrete compressive strength as well as the tensile strength properties. Both the shape of the specimens were tested at the age of 28 days.

3.1 Workability of fresh concrete

Workability is defined as the property determining the effort required to manipulate a freshly mixed quantity of concrete with minimum loss of homogeneity. The primary characteristics of workability are consistency (or fluidity) and cohesiveness. Slump test as per ASTM C143 was used to measure the workability of freshly mixed concrete. Table 2 shows the slump test values for different concrete mixes considered in the study.

Table 2: Slump test values in different concrete mixes

W/C ratio	Concrete with natural stone	Concrete with 75% natural + 25% plastic	Concrete with 50% natural + 50% plastic
0.4	25	30	25
0.5	30	45	35
0.6	60	75	65

From the test results it is observed that addition of waste plastic aggregates increases slump values of fresh properties of concrete. However, increasing addition of waste plastic decreases slump values of the mixes.

3.2 Compressive Strength

The compression strength of concrete is a measure of the concrete's ability to resist compressive loads. It is normally measured by crushing cylindrical (ASTM C 39) and cube concrete specimens. Three standard-cured specimens made from the same concrete batch were considered to determine the average strength value. These were tested at the age of 28 days. Figures 4 and 5 show the compressive strength values for the cylindrical and cube specimens, respectively.

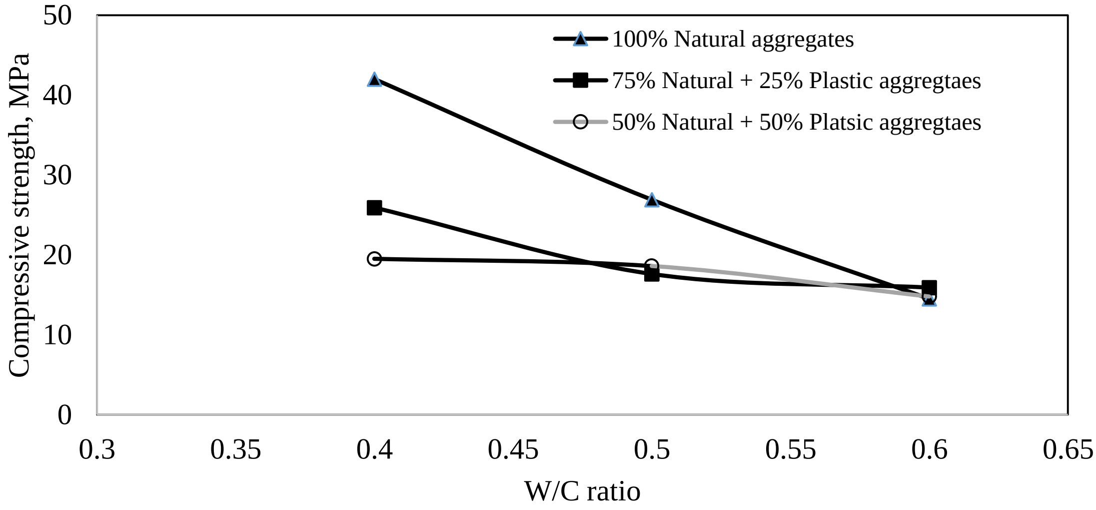

Figure 4: Variation of cylindrical concrete compressive strength with natural and plastic aggregates

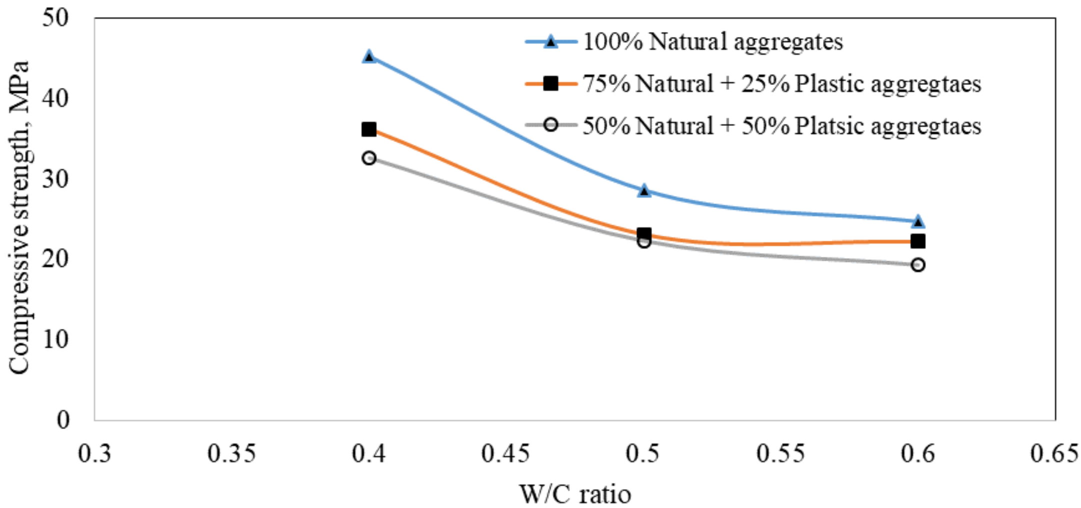

Figure 5: Variation of concrete cube compressive strength with natural and plastic aggregates

From the above figures, it is shown that incorporation of plastic aggregates in a concrete mix reduces the compressive strength of concrete. This reduction is higher for lower w/c ratio and lower for higher w/c ratios. It is also observed from the figures that for the lower grade concrete such as 14.5 MPa with w/c ratio of 0.6, the incorporation of plastic aggregates results in almost the same strength with the natural stone aggregates. Therefore, for the production of low grade concrete, plastic aggregates may be used instead of natural aggregates and thereby will reduce waste plastics in the environment.

3.3 Tensile Strength

Indirect tensile strength test on cylindrical concrete specimens was conducted at the age of 28 days. Cylindrical specimens of 100 mm x 200 mm were employed for determining the splitting tensile strength. Three specimens from the same mix were used to calculate splitting tensile strength following ASTM C496. Figure 6 shows the comparison of tensile strength of concrete with natural and plastic aggregates.

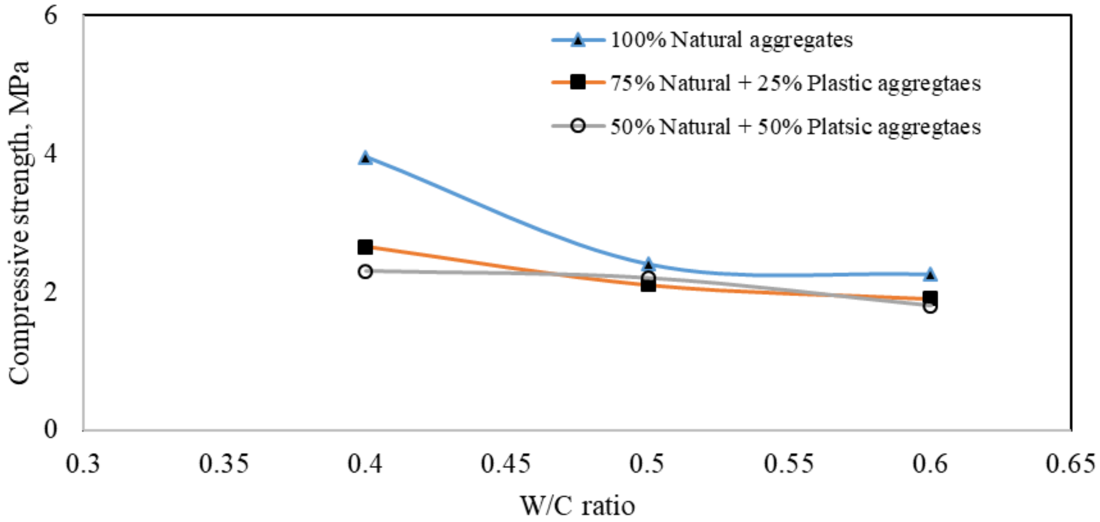

Figure 6: Variation of concrete tensile strength with natural and plastic aggregates

From the above figure, it is shown that the same trend is observed for the tensile strength of concrete. At a higher strength with lower w/c ratio, the tensile strength with plastic aggregates replacement decreases at a faster rate than that of the concrete with higher w/c ratios. A 33% reduction is shown for w/c = 0.4 while that reduction is 15% for w/c of 0.6 having the 25% natural aggregate replacement with the waste plastic aggregates.

4. CONCLUSIONS

An experimental program is conducted to assess the use of waste plastic aggregates in concrete. 25% and 50% replacement of natural stone aggregates with the waste plastic aggregates are considered in the study. Water-to-cement ratios are considered 0.4, 0.5 and 0.6 both for natural and waste plastic aggregates in concrete mixes. Fresh properties in terms of slump and hardened properties such as tensile strength and compressive strength are determined and the results are compared. From the experimental results, it is concluded that no significant variation in slump values are shown for the concrete mixes with the natural stone and plastic aggregates. Compressive strength as well as tensile strength are reduced as the waste plastic aggregates replacement are increased. However, this reduction is prominent for the higher strength concrete with lower w/c ratio and insignificant for the lower strength concrete with higher w/c ratio. Therefore, it may be concluded that for the lower grade concrete, waste plastic aggregates can be used instead of natural aggregates. Such use of waste plastic will have a great impact on the environmental sustainability.

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