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Investigation on the Use of PET Waste Plastic as Coarse Aggregate for Lightweight Concrete

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***Abstract*— *Plastic waste and its low recycling rate make a significant contribution towards the pollution of the environment. Plastic waste is utilised in different applications, such as aggregate in concrete. The development of new construction materials using recycled plastics is important to both the construction and the plastic recycling industries. This paper emphasizes on using the plastic waste PET (Polyethylene Terephthalate) to substitute the coarse aggregates in concrete to lower the density of concrete. The shredded waste plastic was used in concrete with partial replacement of 10%, 20%, 30% and 40 % by weight of conventional coarse aggregate. Five types of concrete specimens including one without plastic aggregate, for comparison purpose, were prepared. All the concrete specimens were tested for compressive strength after a curing period of 7, 14 and 28 days.*

***Keywords*— *Plastic Waste, PET Aggregate, Concrete, Compressive Strength, Density.*

I. INTRODUCTION

Plastic have become an integral part of our lives. Its low density, durability, lightweight and low cost are the factors behind such phenomenal growth. Reduction of waste produced around the world is a major challenge which society is facing today. According to the Central Pollution Control Board, the world produces nearly 150 million tonnes of plastics per year, which is nearly 4.8 tonnes per second and a per capita production of 25 kg/year (Al-Salam et al. 2009).

Different forms of the common materials, using waste plastic granules as lightweight aggregates in the production of lightweight concrete has attract much attention from the researchers. Lightweight aggregates are generally used to reduce the unit weight of concrete by replacing the conventional aggregates. Nowadays, there are many lightweight concrete applications made with natural of artificial lightweight aggregates are found in the literature. Several studies have been conducted on the use of plastic waste in concrete. The works of (Youcef Ghernouti, Balia Rabehi, Brahim Safi and Rabah Chaid) showed that the use of plastic bag waste as fine aggregate improves the workability and the density, reduced the compressive strength of concrete containing 10 and 20 % of waste by 10 to 24 % respectively. Also, researchers MB Hossain, P Bhowmik and KM Shaad (2016) used PET aggregate content (5, 10, 20% by volume) and the particle sizes of 4.75 to 9.5 mm. The results found that the compressive strength at 10 % volume of PET aggregates can be effectively used in producing lightweight concrete. Anju Rameson, Shemy S.Babu and Aswathy Lal (2015) attempted to substitute 0% to 40% of coarse aggregate in concrete with HDPE (High Density Polyethylene) aggregates. The researchers found that the workability of concrete increased by 50 % for a mix containing 40% plastic aggregate. The compressive strength and splitting tensile strength of concrete increased till 30% replacement of natural aggregate with plastic aggregate. The optimum percentage replacement of natural coarse aggregate using plastic aggregate was obtained as 30%.

The present study attempted to utilize the waste PET aggregate as partial replacement of conventional coarse aggregate in concrete. Various physical properties of constituent materials and mechanical properties of concrete were evaluated incorporating different percentage of plastic aggregate on concrete properties have also been analyzed and discussed.

II. MATERIALS AND METHODS

A. Waste Plastic Aggregate

In this study, the PET plastic waste aggregates were collected from plastic recycling plant in Aye Thar Yar Industrial Zone, Shan State. The plant mainly recycles PET bottles that come from urban and industrial collection sites. PET waste mostly consists of dirty PET bottles, which are usually contaminated with other materials and with some non-PET containers such as PVC, HDPE, LDPE and poly propylene bottles. In this plastic waste treatment plant, several steps are adopted to recycle waste plastic. The coarse flakes were obtained after mechanical grinding of PET wastes followed by cleaning (Figure 1). The maximum size of plastic waste in this plant was 19 mm. The specific gravity of PET is around 1.3-1.4 (Van Krevelen, 1990). In this study the specific gravity of plastic aggregate used was found to be 1.31. The grading of the plastic aggregate is presented in Table 1.

Fig. 1. PET Waste Plastic Aggregate

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TABLE 1. Sieve analysis of PET aggregates

Sieve No.	Sieve Opening (mm)	Wt. Retained (g)	Percentage Retained (%)	Accumulated Percentage Retained (%)	Percent Finer (%)
3/4in	19	0.3	0.3	0.3	99.7
3/8in	9.5	60.3	60.3	60.6	39.4
4	4.75	33.8	33.8	94.4	5.6
8	2.36	5.6	5.6	100	0
16	1.18	0	0	100	0
Pan	-	0	0	-	-
Total		100	100	355.3	

B. Cement

a. Fineness of Cement Test

Fineness of cement is measured in terms of the percentage of the cement retained on ASTM No.200 sieve. This should not be more than 10%. Table 2 shows the result of fineness test for KBZ cement according to the ASTM standard.

TABLE 2. Fineness of KBZ Cement

Test No.	Sieve No.	Shaking Time (min)	Percent Retained (%)
1	ASTM No.200	15	1.4
2	ASTM No.200	15	1.7
3	ASTM No.200	15	1.5
Average(%)		1.53	

The fineness of KBZ cement is 1.53 % and it is less than 10% that is within the standard limit.

b. Normal Consistency of Cement

Neat cement paste of a standard consistency is used to determine the initial setting time, final setting time and soundness test. The consistency is determined by Vicat apparatus. The depth of penetration reaches 5 to 7 mm from the bottom of Vicat mould, the water content required gives the standard consistency.

The standard consistency is expressed as a percentage by mass of dry cement, the usual range of these values are between 26 and 33. The result of normal consistency for KBZ cement is shown in Table 3.

TABLE 3. Normal Consistency of KBZ Cement

Test No.	Wt. of cement (g)	Wt. of water (g)	Standard Consistency (%)	Normal Consistency (%)
1	400	122	30.5	23.79
2	400	121	30.25	23.6
3	400	120	30	23.4
Average (%)			30.25	23.6

Normal consistency of KBZ cement is 23.6% that is within the standard limit.

c. Specific Gravity of Cement

Specific gravity is not an indication of the quality of cement but it is used in calculation of mix proportion. This test is determined according to ASTM Standard. The specific gravity of good Portland cement should be between 3 and 3.25. The specific gravity test result of KBZ cement is described in Table 4.

TABLE 4. Specific Gravity of KBZ Cement

Test No.	1	2	3
Wt. of cement (W) (g)	20	20	20
Wt. of specific gravity bottle (W_1)	65.4	62.3	62.1
Wt. of bottle + kerosene (W_2)	144	141	140.8
Wt. of bottle + kerosene (W_2) + cement (W3)	158.4	156.1	156
Weight of bottle + kerosene (W2) + cement (W2+ 20)	164	161	160.8
20cc kerosene (W2+20-W3)	5.6	4.9	4.8
Specific gravity of kerosene (W2-W1)/100	0.786	0.787	0.787
Specific gravity of cement (W2-W1) /5(W2+20-W3)	2.81	3.21	3.28
Average specific gravity of cement	3.1		

The specific gravity of KBZ cement is 3.1 that is around 3.15 ASTM standard.

d. Setting Time of Cement

Setting time is used to describe the stiffening of the cement paste. Setting refers to a change from a fluid to a rigid state. The initial setting time is the time period until 1 mm diameter needle penetrates to a point 5mm from the bottom of a mould. Minimum setting time for Portland cement is 60 min (ASTM 150-05). Final setting time is when the needle does not sink visibly into the paste. Maximum final setting is 10 hours. Table 5. shows the result of setting time of KBZ cement.

TABLE 5. Setting Time of KBZ Cement

Test No.	1	2
Wt. of Cement (g)	400	400
Wt. of Water (g)	104	104
Starting Time of Supply of Water (hr:min)	2:35	1:15
Time Observed Initial Setting Time (hr:min)	4:10	2:48
Initial Setting Time (min)	95	93
Average Initial Setting Time (min)	94	
Time Observed Final Setting Time (hr:min)	6:39	5:15
Final Setting Time (min)	244	240
Average Final Setting Time (min)	242 (4 hr 02 min)	

The initial setting time and final setting time of KBZ cement are within the standard limits.

C. Fine Aggregates

Readily available natural pit sand from Balilin region (Taunggyi) of fineness modulus 2.96 was used as fine aggregate. Gradation of fine aggregate was accomplished by sieve analysis method.

a. Sieve Analysis Test for Fine Aggregates

This test is used to determine the particle size distribution of fine aggregates. The grading of fine aggregates affects the workability of concrete. The standard specification of fineness modulus for fine aggregates is between 2.3 and 3. Table 6 and show the test results of sieve analysis of fine aggregates.

TABLE 6. Sieve Analysis of Fine Aggregates

Sieve No.	Sieve Opening (mm)	Wt. Retained (g)	Percentage Retained (%)	Accumulated Percentage Retained (%)	Percent Finer (%)
4	4.75	0.7	0.14	0.14	99.9
8	2.36	117.1	23.42	23.56	76.4
16	1.18	108.6	21.72	45.28	54.7
30	0.6	75.5	15.1	60.38	39.6
50	0.3	76.2	15.24	75.62	24.4
100	0.15	78	15.6	91.22	8.78
Pan	-	43.9	8.78	-	-
Total		500	100	296.2	

Fineness modulus is 2.96 that is within typical values range from 2.3 and 3.0.

b. Specific Gravity and Water Absorption of Fine Aggregates

The specific gravity and water absorption tests were determined according to ASTM C 127 standards. The majority of natural aggregates have an apparent specific gravity of between 2.6 to 2.7. The water absorption is determined by measuring the decrease in mass of a saturated surface-dry sample after oven drying for 24 hours. The water absorption of fine aggregate ranges from 0 to 2%. The test result for specific gravity and water absorption of fine aggregates is shown in Table 7.

TABLE 7. Specific Gravity and Water Absorption of Fine Aggregates

Test No.	1	2
Weight of sample SSD (g)	1000	1000
Weight of bottle + water (g)	1270	1272
Weight of bottle + water + sample (g)	1900	1904
Weight of sample (OD) (g)	990	995
Bulk specific gravity (SSD)	2.7	2.72
Average Bulk specific gravity (SSD)	2.71	
Bulk specific gravity (OD)	2.68	2.689
Average Bulk Specific Gravity (OD)	2.68	
Water Absorption (%)	1.01	0.503
Average Water Absorption (%)	0.76	

D. Coarse Aggregates

Locally available natural crush coarse aggregate from Payaphyu region (Taunggyi) was used in this study. Gradation of coarse aggregate was accomplished by sieve analysis method.

a. Sieve Analysis Test for Coarse Aggregates

Table 8 shows grading of coarse aggregate according to ASTM C33.

b. Specific Gravity and Water Absorption of Coarse Aggregate

The specific gravity and water absorption tests were determined according to ASTM C 128 standards. The test result for specific gravity and water absorption of fine aggregates is shown in Table 9.

TABLE 8. Sieve Analysis of Coarse Aggregates

Sieve No.	Sieve Opening (mm)	Wt. Retained (g)	Percentage Retained(%)	Accumulated Percentage Retained (%)	Percent Finer (%)
¾ in	19	95.5	9.55	9.55	90.5
3/8 in	9.5	700.7	70.07	79.62	20.4
4	4.75	202.3	20.23	99.85	0.15
8	2.36	1.5	0.15	100	0
16	1.18	0	0	100	0
Pan	-	0	0	-	-
Total		1000	100	403.02	

TABLE 9. Specific Gravity and Water Absorption of Coarse Aggregates

Test No.	1	2
Weight of bottle + water (g)	1275	1275
Weight of bottle + water + sample (g)	1905	1900
Weight of saturated sample (g)	630	625
Weight of sample SSD (g)	995	990
Weight of sample (OD) (g)	990	985
Bulk specific gravity (SSD)	2.726	2.712
Average Bulk specific gravity (SSD)	2.719	
Bulk specific gravity (OD)	2.712	2.699
Average Bulk Specific Gravity (OD)	2.71	
Water Absorption (%)	0.505	0.508
Average Water Absorption (%)	0.506	

c. Rodded Bulk Density of Coarse Aggregate(ASTM C 29)

Determination of the unit weight of coarse aggregates in a compacted condition. This test method is applicable to aggregates not exceeding 15 cm (6 in.) in nominal size. The unit weight so determined is necessary for the design of a concrete mixture by the absolute volume method. Table 10 show the rodded bulk density of coarse aggregate.

TABLE 10. Rodded Bulk Density of Coarse Aggregate

Test No	1	2	3
wt of sample + container (kg)	28.37	28.315	28.01
wt of container (kg)	7.985	7.985	7.985
wt of sample (kg)	20.385	20.33	20.025
Volume of Container (m^3)	0.013	0.013	0.013
Rodded Bulk Density (kg/m^3)	1575.9	1571.7	1548.1
Average Rodded Bulk Density(kg/m^3)	1565		

III. PREPARATION OF CONCRETE SPECIMENS

In this research, the proportion of cement, sand and coarse aggregate are calculated for non-air entrained concrete by using ACI 211.1.91. The coarse aggregate was replaced by 10%, 20%, 30% and 40% weight with plastic aggregates. Five types of concrete specimens were prepared maintaining the same water-cement ratio of 0.56 according to specified strength of 20 MPa and cured for 7, 14 and 28 days. The specimens were designated as C0PA, C10PA, C20PA, C30PA and C40PA having 0%, 10%, 20%, 30% and 40% plastic aggregate by weight respectively. The mix proportions of all the mixes are shown in Table 11.

TABLE 11. Mix Proportions Per Meter Cubed of Concrete

Mix- designation	W/C ratio	Water (kg)	Cement (kg)	Fine aggregates (SSD) (kg)	Conventional Coarse Aggregates (kg)	Recycled PET Aggregates (kg)
C0 PA	0.56	186	332	868	943	0
C10 PA	0.56	186	332	868	849	46
C20 PA	0.56	186	332	868	754	91
C30 PA	0.56	186	332	868	660	136
C40 PA	0.56	186	332	868	566	182

IV. RESULTS AND DISCUSSION

A. Compressive Strength

Cylinder compressive strengths of concrete made with recycled plastic aggregate with water cement ratio of 0.56 at 7, 14 and 28 days are shown in Figure 2. Compressive strength is gradually decreased at 10%, 20%, 30% and 40% replacement of natural aggregate with plastic aggregate. At each percentage replacement, the compressive strength of concrete increased as the concrete aged. At all ages, the compressive strength of concrete reduces as the percentage replacement increased.

The 28 day strengths of concrete with 30 % and 40% replacement were within the range of 0.3-40 Mpa, satisfying the criteria for the classification as lightweight aggregate concrete. Compared to the concrete without plastic aggregate, the 28-day compressive strengths of concrete with plastic aggregate contents of 10%,20%,30% and 40% reduced by 48.3%, 86%,93.5% and 94% respectively.

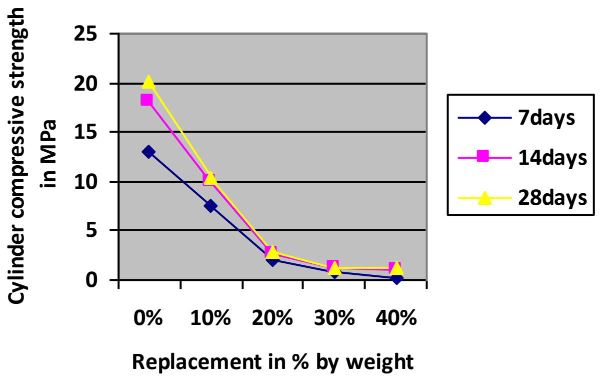

Fig. 2. Cylinder Compressive Strength of Concrete With and Without Plastic Aggregate

B. Unit Weight

A decreasing trend was observed in the case of density of concrete. Plastic being a light weight material tends to decrease the weight of the resultant concrete. The density at 30% and 40% replacement were satisfied the criteria for the classification of lightweight aggregate concrete.

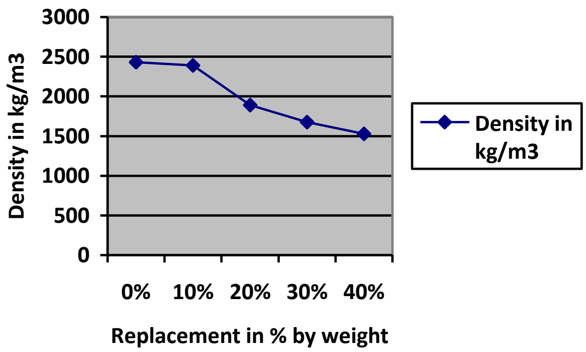

Fig. 3. Variation in Density of Concrete for Various Mix

V. CONCLUSIONS

Following are the conclusions can be made based upon the studied:

(1) Plastic can be used to replace some of the aggregates in a concrete mixture. This plastic aggregate can reduce the unit weight of the concrete. It may be possible to use for non-structural elements such as low rise building and where low strength are desirable.

(2) The specific gravity of plastic aggregate was less than conventional coarse aggregate and in the range of lightweight concrete aggregate category.

(3) The use of waste PET in concrete provides some advantages such as reduction in the use of conventional aggregate, disposal of waste and prevention of environmental pollution.

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