Malaysian Journal Of
Civil Engineering

THE FIRE RESISTANCE OF CONCRETE MADE WITH RECYCLED PLASTIC AS PARTIAL REPLACEMENT FOR COARSE AGGREGATE

Article history
Received
14 February 2022
Received in revised form
24 May 2022
Accepted
26 May 2022
Published online
30 July 2022

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Abstract

This research is aimed to investigate the fire resistance of recycled discarded plastic when used as partial replacement for normal granite coarse aggregate in concrete when exposed to elevated temperatures. Discarded Polyethylene Terephthalate (PET) bottles were cut into a maximum size of 20mm to produce Recycled Plastic Aggregate (RPA). The replacement of normal aggregates with RPA were in proportion of 0%, 5%, 10%, 15%, 20%, 25% and 30% by weight of normal coarse aggregate. The compressive performance of the concrete made with RPA were studied by casting three 100 mm cubes for each of the percentage replacements and tested at 7, 14 and 28 days of curing age. A set of three (3) concrete cubes for each percentage replacement was cured for 28 days and subjected to a temperature of 718°C for a duration of 15 minutes in a furnace. Results of slump tests on fresh concrete showed that workability decreased with increase in RPA. Densities and compressive strengths for normal cube samples not subjected to elevated temperatures and the sample subjected to temperature of 718°C increased with increase in curing age and decreased with increase in percentage of RPA. The result showed that the concrete specimen with 10% replacement of RPA was optimum for good thermal stability.

Keywords: *Recycled Plastic Aggregate (RPA), Polyethylene Terephthalate (PET), Fire hazard, Coarse aggregate, Lightweight concrete.*

1.0 INTRODUCTION

Concrete is one of the commonest materials in the construction industry, and it can be shaped to match any structural form (Khaloo and Afshari, 2014). Due to many advantages like as high durability, strong mechanical qualities, and selected affordability, it has become a key building material in infrastructure and industrial growth today. (ACI, 2000). Concrete comprises cement, coarse aggregate, fine aggregate, water and sometimes admixtures. Apart from the major concrete constituents known, in an attempt to recycle wastes, certain agricultural wastes have been used as pozzolanas in their calcined form. For example, Wilson (2021a) have shown that 10% replacement of cement with white cowpea husk ash (WCHA) can adequately suffice for a design characteristic strength of 25 N/mm^2 at 28 days of curing amongst other findings. Coarse aggregate which is a fundamental constituent of concrete is mostly gotten from quarrying of natural occurring rocks. Quarrying activities immensely impacts negatively on the environment (Okafor, 2016). Residue from quarry destinations is a significant wellspring of air contamination, albeit, the seriousness will rely upon factors like the nearby microclimate conditions, the centralization of residue particles in the surrounding air, the size of residue particles and their chemistry. For instance, limestone quarries produce exceptionally alkaline dust. The air contamination is not just noxious as far as destruction on surfaces is concerned, but also has potential impact on wellbeing, specifically with respect to respiratory issues. It can likewise affect the surrounding plants, like hindering and harming their internal structures as well as causing abrasion of leaves and cuticles (Guach, 2010). One of the greatest adverse consequences of quarrying activities on the environment is the harm to biodiversity (Anand, 2016).

Seeking aggregates for concrete and a means of plastic waste disposal is of current interest. Presently, sustainability has got top emphasis in the construction industry. There are numerous recycling industries over the world, yet plastics lose their strength with the quantity of recycling. So, most of these plastics end up as landfills. In the present condition as opposed to recycling over and again, plastic is used to prepare aggregates for concrete; thus, being of advantage to the construction industry (Shubham et al., 2019).

The majority of concrete construction failures are caused by concrete failure as a consequence of crushing strength or aggregate value. Plastics that have low crushing values due to their low density and specific gravity will not be crushed as effectively as the coarse aggregates (Shubham *et al*., 2019). Since a total replacement for recycled waste plastic has not been found to be plausible, a partial replacement with various percentages of recycled waste plastic can be done. Most plastics are tough and degrade very gradually (or could be considered as near non-degradable), as their chemical structure renders them impervious to numerous natural processes of degradation (SPI, 2000).

Building fires have been a major concern throughout the globe in recent years. Concrete's quality is sometimes questioned since it loses a substantial amount of strength after being exposed to fire (Bamigboye *et al.,* 2019). Concrete's capacity to withstand fire or provide fire protection during a fire is determined by its compressive strength after exposure to a certain temperature at a specific time (Umasabor and Okovido, 2018). Wilson (2021b) in a study on the thermal resistance evaluation of raffia palm ash concrete showed that the use of 5% partial replacement of cement with raffia palm ash for concrete under an elevated temperature of 718^{o}C and 812^{o}C indicated a drop in strength of about 6% as compared to the control, but with fewer flakes produced even at a higher temperatures

2.0 METHODOLOGY

2.1 Materials

The concrete comprised cement, fine aggregate, coarse aggregate, water and recycled plastic aggregate as partial replacement for coarse aggregate in percentages (5%, 10%, 15%, 20%, 25% and 30%,).

2.2 Preparation of Recycled Plastic Aggregate (RPA)

The aggregates were produced from waste Polyethylene Terephthalate (PET) bottles. The plastic bottles were sourced from different households. The bottles were crushed and cut into smaller pieces of different sizes, within the range of 12-20mm. The plastic aggregates were soaked and washed properly to make them clean and to ensure the absence of deleterious materials. The plastic aggregates were drained and air-dried to get a moisture-free aggregate. Samples of the waste plastic bottles are shown in Plate 1.

Plate 1: Samples of Waste Plastic Bottles as Coarse Aggregates

2.3 Cement

The cement was obtained from the open market. The cement is a grade 42.5R ordinary limestone cement produced by Dangote Cement which conforms to NIS 444-1:2003.

2.4 Fine Aggregate

The fine aggregate was sourced from a local distributor of fine aggregate in Kawo, Kaduna State. The fine aggregate that passed through sieve 4.75mm was used for this research work.

2.5 Coarse Aggregate

The coarse aggregate with a maximum size of 19mm was sourced from a local distributor of coarse aggregate in Mando, Kaduna State and used for the research work.

2.6 Water

Potable drinking water supplied by the Kaduna State water works was used for concrete preparation.

2.7 Physical Properties of Cement

The following tests were carried out on cement in accordance to BS EN 197-1 (2000); consistency, setting time and soundness in order to check its suitability for use in concrete production as required by code specifications. The test results are presented in Table 1.

Table 1: Physical Properties of Cement

S/No.	Parameters Tested	Test Result	BS EN 197-1 (2000) Requirement
1	Standard Consistency (%)	30	26-33
2	Setting Time (min)		
	Initial Setting Time	76	≥ 45
	Final Setting Time	198	≤ 600
3	Soundness (mm)	0.1	≤ 10

From Table1, it could be seen that the cement satisfied the physical requirements provided by BS EN 197-1 (2000).

2.8 Properties of Aggregate

Aggregates affect the qualities of concrete in the plastic stage, such as water requirement, cohesiveness, and workability, as well as the strength, density, durability, and surface finish in the hardened stage. Specific gravity test was carried out on both fine and coarse aggregates while aggregate crushing value and aggregate impact value tests were carried out on coarse aggregates to ensure their suitability for concrete production. Table 2 shows the specific gravities of the aggregates used as well as the code requirements.

Table 2: Specific Gravity of Aggregates

S/No.	Aggregate Type	Test Result	Code Requirement	Code Used
1	Fine	2.55	≤ 2.65	BS 1881-3
2	Coarse	2.6	≤ 3.0	BS 1881-3
3	RPA	1.35	1.34 – 1.39	SPI 2000

According to BS1881-3, the specific gravity of fine aggregate should not exceed 2.65 and a maximum value of 3.0 for coarse aggregate. The mean specific gravity on fine and coarse aggregates obtained were 2.55 and 2.6 respectively which lie within the acceptable value specified by the standard.
According to Society of Plastics Industries (SPI) 2000, the specific gravity of polyethylene terephthalate (PET) is in the range of 1.34-1.39. The mean specific gravity of RPA obtained is 1.35, which lies within the range values specified by SPI 2000. The 1.35 mean specific gravity obtained for the RPA did not exceed maximum specific gravity value of 3.0 specified by BS18881-3 for coarse aggregates. Thus, the specific gravity of RPA is within the acceptable limits specified by SPI: 2000 and BS1881-3. Table 3 shows the crushing and impact values of the aggregates used.

The aggregate crushing value test and aggregate impact value test were carried out on the RPA but both tests did not have any effect on the RPA due to its malleability. According to BS 812: Part 3, the aggregate crushing value and aggregate impact value should not exceed 30% for the concrete used for structures. Both the ACV and AIV carried on the coarse aggregate incorporated with RPA conforms with BS 812: Part 3. The results obtained are 12.2% and 24.6% respectively. Thus, the aggregates are exceptionally strong. From the results obtained, it shows that plastic has low crushing and impact values.

2.9 Mix Design

A prescribed mix, 0.50/1:2:4 targeting a concrete strength of class C15 was adopted after some trial mix tests. RPA was added to concrete as partial replacement for coarse aggregate at 0%, 5%, 10%, 15%, 20%, 25% and 30% by weight of coarse aggregate and 100mm×100mm×100mm formworks for the cubes to be cast were adopted. Concrete matrix was prepared using prescribed mix method for a characteristic strength of 15N/mm^2. A total number of 84 cubes were cast, out of which 63 cubes were used as unfired concrete and 21 concrete cubes were fired in a furnace at a temperature of 718^{o}C for 15 minutes after curing. The concrete specimens were cured for 7, 14 and 28 days. The density and the compressive strengths of both fired and unfired concrete cubes were determined. The mix proportion is shown in Table 4.

Table 4: Weight of Materials for Unit Volume of Concrete

S/No.	Material	Weight (kg)
1	Cement	336
2	Fine Aggregate	724
3	Coarse Aggregate	1402

Table 3: Aggregate Crushing Value (ACV) and Aggregate Impact Value (AIV)

S/No.	Sample	ACV	AIV
1	0% RPA	24.6	12.2
2	5% RPA	24.6	12.0
3	10% RPA	24.5	12.2
4	15% RPA	24.6	12.2
5	20% RPA	24.6	12.0
6	25% RPA	24.6	12.0
7	30% RPA	24.5	12.2

2.1.0 Mixing, Casting and Curing

Manual mixing was done on a clean, hard non-absorbent surface. To avoid the balling and segregation, the dry materials that is, cement and the aggregates were mixed properly until homogeneity was achieved before water was added to the dry materials and the mixing continued for few minutes until a good blend of concrete was achieved. The slumps of the fresh concrete were taken immediately after mixing the concrete for respective percentage of replacement of coarse aggregate with RPA (0%, 5%, 10%, 15%, 20%, 25% and 30%). The test was carried out in accordance with BS EN 12350-2 (2009). After taking the slumps, the casting of cubes started immediately. The moulds were oiled before placing concrete in three layers for cube specimens. For compaction of the specimens, each layer was given 25 manual blows using a tamping rod, and then vibrated for 15 seconds on a vibrating table. The concrete was left in the moulds for 24 hours at room temperature before demolding. After demolding of the concrete cubes, the cubes were immersed in a curing tank containing clean water for curing ages of 7, 14 and 28 days. Plates 2 and 3 show the hand mixing of concrete and the cube curing process respectively.

Plate 2: Hand Mixing of Concrete

Plate 3: Plate 4: Curing of concrete Cubes

3.0 RESULTS AND DISCUSSION

The slump test was carried out on fresh concrete in accordance with BS EN 12350-2 (2009) to determine the workability of the concrete. Figure 1 shows the graphical representation of slump values obtained in comparison with percentage replacement of RPA. Plates 4 and 5 show the slump tests at 0% and 25% replacement of RPA.

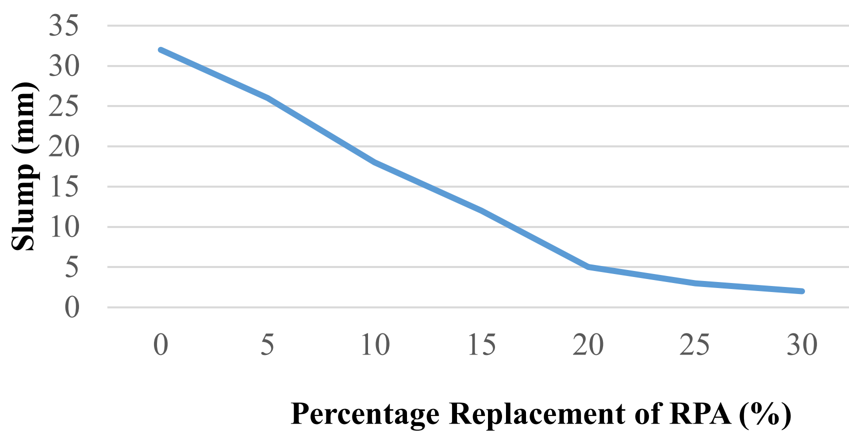

Figure 1: Slump of Fresh Concrete

Plate 4: Slump Test at 0% Replacement

Plate 5: Slump Test at 25% Replacement

3.1 Properties of Hardened Concrete

Density, fire resistance and compressive tests were carried out on the hardened concrete cubes. The test values obtained were within acceptable limits specified by relevant codes.

3.2 Density Test

The mean densities for both fired and unfired concrete cubes are presented in Figure 2 and Figure 3. The test was done in accordance with BS EN 12390-7(2009).

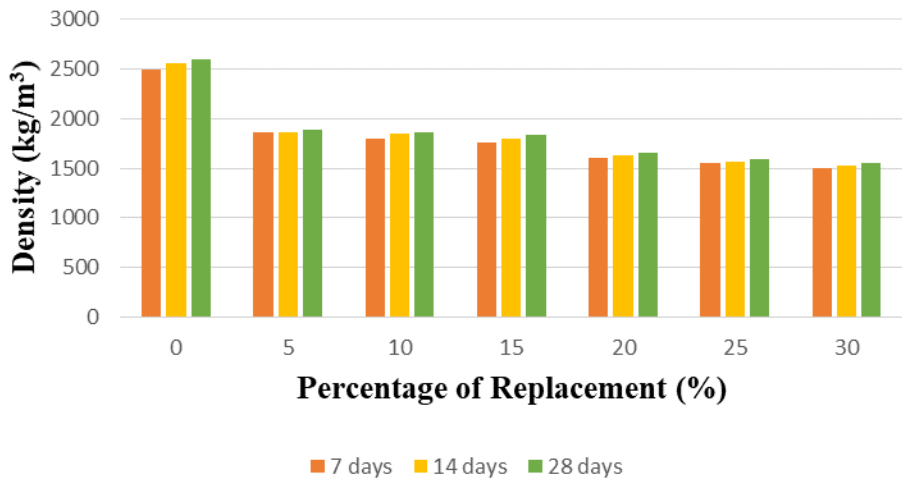

Figure 2. Density of Unfired Concrete Cubes Corresponding to Percentage of Replacement

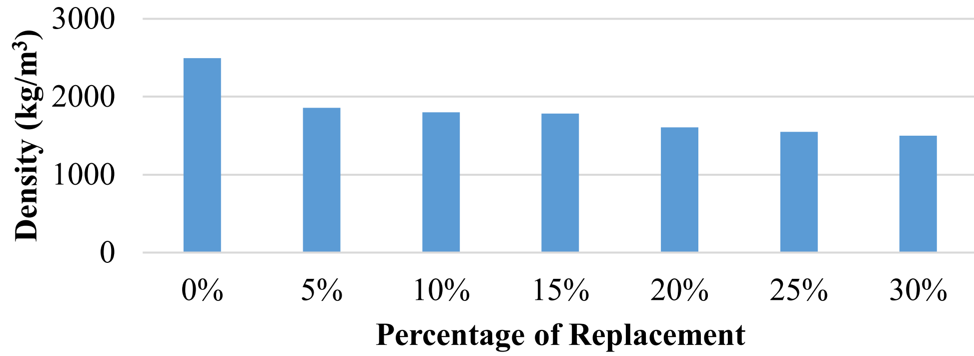

Figure 3: Density of Fired Concrete Cubes Corresponding to Percentage of Replacement

The results revealed that when the amount of recycled plastic aggregate (RPA) in the concrete cubes increased, the density of the concrete decreased for both fired and unfired concrete cubes. According to ACI 213 (2001), the density of a lightweight concrete is in the range of 800 kg/m^3 – 1920 kg/m^3. The unfired RPA concrete cubes have densities in the range of 1891-1536kg/m^3 at 28 days curing age while the fired RPA concrete cubes have densities in the range of 1880-1521 kg/m^3 at 28 days after firing. Thus, both fired and unfired RPA concrete cubes can be considered as lightweight concrete based on their densities.

3.3 Fire Resistance Test

The fire resistance test was carried out in accordance with ISO 834 (1999) on hardened concrete cubes. According to the code, concrete cracks, spall and become weak and friable at temperature 590-950^{o}C. The concrete cubes were fired at 718^{o}C which lies within the temperature specified by the code but there were no physical changes such as cracks and spalls on the surface of the concrete cubes.

According to ASTM E 119, concrete with lower densities have better fire resistance. Lightweight concrete is insulating and transmits heat more slowly than medium weight concrete of same thickness. Plate 6 shows the electric furnace used for the fire resistance test.

Plate 6: Electric Furnace used for Fire Resistance Test

3.4 Compressive Strength Test

The test was carried out in accordance with BS EN 12390-3: (2009). Figure 4 and Figure 5 below show the graphical presentation of compressive strengths with respect to curing age for unfired and fired concrete cubes respectively.

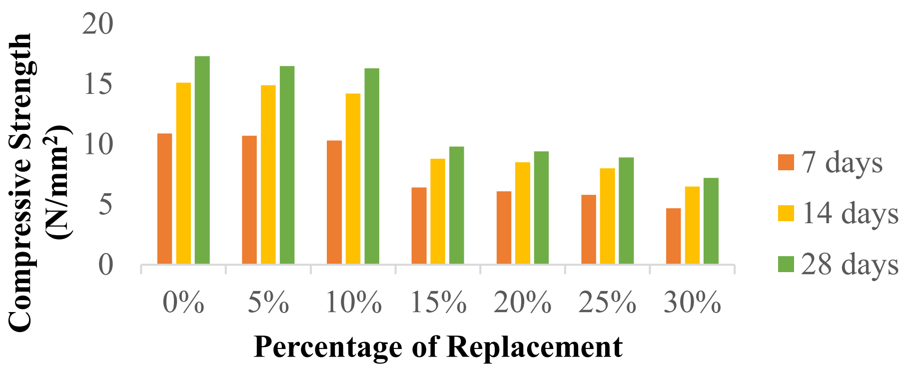

Figure 4: Compressive Strength of Concrete Cubes at Varying Percentage of Replacement

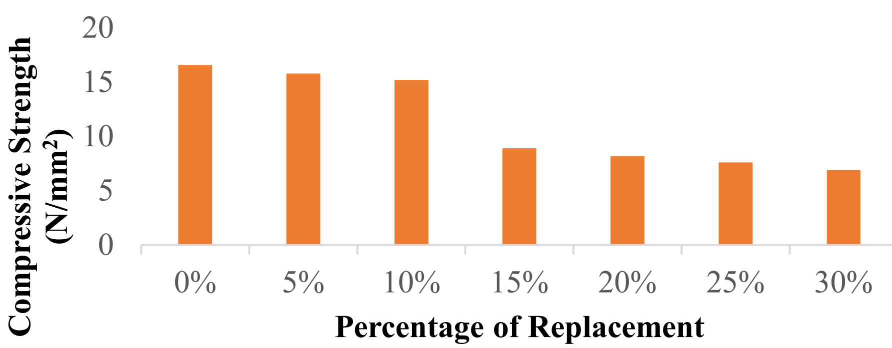

Figure 5: Compressive Strength of Fired Concrete Cubes Corresponding to 28 days Curing Age at Different RPA Percentage Replacement.

The compressive strength decreases with increase in RPA for both fired and unfired concrete cubes. There was 36% decrease in compressive strength for the unfired concrete cubes while 38% decrease in compressive strength for the fired concrete cubes.

Both 5% and 10% replacements have compressive strengths within the acceptable compressive strength specified in BS EN 12390-3: (2009) for C15 for both unfired and fired concrete cubes. The compressive strength of the fired concrete cubes is lower than the compressive strengths of the unfired concrete cubes because the compressive strength reduces when subjected to higher temperature.

3.5 Statistical Analysis

Two-way analysis of variance was used to assess the level of significance of the percentage replacement of RPA on the compressive strength of the concrete, as well as the level of significance of the impact of burning temperature/time on the compressive strength of the concrete.. The result is presented in Table 5

Table 5: Two-factor without Replication for Unfired Concrete Cubes

Summary	Count	Sum	Average	Variance
7 days curing	7	54.9	7.84286	7.11952
14 days curing	7	76	10.8571	13.7429
28 days curing	7	84.4	12.0571	16.9929
0%	3	40.3	13.4333	8.00333
5%	3	42.1	14.0333	8.97333
10%	3	42.8	14.2667	9.22333
15%	3	25	8.33333	3.05333
20%	3	24	8	2.91
25%	3	22.7	7.56667	2.54333
30%	3	18.4	6.13333	1.66333

3.6 ANOVA

Source of Variation	SS	DF	MS	Fcal	P-value	Fcrit
Rows	66.001	2	33.0005	58.7629	6.32341E-07	3.885293835
Columns	220.392	6	36.7321	65.4076	1.81433E-08	2.996120378

The result shows that the effect of curing age and RPA replacement on the compressive strength was statistically significant, with (FCAL = 58.763 > FCRIT = 3.885) for curing days while (FCAL = 65.408 > FCRIT = 2.996) for RPA replacement.

4.0 CONCLUSIONS

The following deductions can be drawn from the results of the study:

i. The values obtained for determination of physical properties of cement and aggregates were within acceptable limits specified by relevant codes. Thus, both cement and aggregates were suitable for use in concrete.
ii. the workability of the fresh concrete decreased with an increase in percentage of recycled plastic aggregate (RPA)
iii. the densities and compressive strengths of concrete cubes for both unfired and fired concrete cubes increased with increase in curing age and decreased with increase in percentage of RPA. The concrete cubes are classified as lightweight concrete based on their densities (between 1891-1536 kg/m^3).
iv. The compressive strength of the concrete at 28 days curing age at 5% and 10% replacements for both unfired and fired concrete cubes were all found to be above target mean strength of 15N/mm^2, while the compressive strength of 15%, 20%, 25% and 30% replacement fell below the target mean strength. The compressive strength of the concrete made with 10% replacement was found to give the optimum strength of replacement at 28 days. The compressive strength of fired concrete cubes decreased with increase in temperature. However, the reduction in compressive strength with temperature occurred both in Normal concrete (0%) and RPA concrete (5% - 30% Replacements).

Acknowledgement

We sincerely wish to express our deep and profound gratitude to the Department of Civil Engineering, Nigerian Defence Academy Kaduna, for making its laboratory available for the execution of this research. Also worthy of note is Mr OC Eze, a Chief Technologist who dedicated his time and efforts in the experimental procedures conducted. Thanks for all your guidance and support.

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