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Research Paper

EXPERIMENTAL INVESTIGATION ON RECYCLED PLASTICS AS AGGREGATE IN CONCRETE

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This paper reports on an investigation on the effects of partial and complete substitution of crushed granite with recycled plastic on the properties of concrete. A concrete mixture of ratio 1:2:4 by mass was used as control. Four additional mixes of concrete were produced using recycled plastic waste to replace 25%, 50%, 75% and 100% of the volume of crushed granite in the control concrete. The compacting factor test was used to assess the workability of the fresh concrete mixes. A 1500 kN Matest compression machine was used to determine the compressive strength of concrete specimens at 7, 14, 21, and 28 days of curing. The density and compressive strength of concrete reduced as the percentage of recycled plastic increased. However, the workabilities of recycled plastic concrete mixtures were not significantly different from the control concrete. Based on results obtained from the study, recycled plastic can partially replace conventional aggregates in the production of both lightweight and structural concrete.

Keywords: Compressive strength, Concrete, Density, Recycled plastics, Workability

INTRODUCTION

Despite being the world's most used construction material, the sustainability of concrete is a major concern confronting the global construction industry (Naik, 2008). The exploitation of aggregates for construction results in negative consequences such as noise pollution, air pollution and the destruction of the habitats of flora and fauna, damages to landscape, loss of land, reduction in water quality and displacement of inhabitants (Omosanya and Ajibade, 2011). To mitigate these and other negative impacts, research efforts have been directed towards alternative materials, especially those that can potentially contribute to the reduction of negative environment impacts. The advantages of replacing natural rock aggregates with materials which would otherwise impact negatively on the environment include reduction of the cost of construction, sustainability of concrete production and reduction of negative environmental impacts.

Plastics are widely used for domestic, industrial and commercial purposes throughout the world. Their advantages include

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durability, insulation properties; high strength to weight ratio, economy, etc. The major problem associated with the use of plastics is it their disposal. Plastics degrade at a very slow rate, so their disposal creates a lot of environmental problems leading to what can be referred to as the plastic menace. Recycling has been adopted as an effective solution to waste management problems associated with plastics.

Lakshmi and Nagan (2010) investigated the effects of e-plastic waste on the properties of concrete and found out that a significant decrease in strength occurred when the plastic content was more than 20%. They recommended that 20% of e-waste aggregate can be incorporated as replacement of coarse aggregate in concrete without any long term detrimental effects. Praveen *et al.* (2013) concluded that at a replacement of 20% of conventional coarse aggregates by recycled plastic, the compressive strength of concrete increased by about 27.4% compared to the control concrete, while at a temperature of 400°C, the compressive strengths of normal aggregate concrete and recycled plastics concrete reduced by 33% and 75% respectively. Elzafraney *et al.* (2006) established that the incorporation of recycled plastics into concrete provides higher levels of energy efficiency and comfort in buildings compared to concretes without plastics. Rahman *et al*. (2010) reported that the incorporation of expanded polystyrene in concrete decreased water absorption while the compressive strength decreased with increase in polymer content due to the lower strength of expanded polystyrene. Raghatate (2012) found out that 1% of plastic in concrete caused 20% reduction in compressive strength after 28 days of curing.

Sangita *et al.* (2011) studied the use of plastics in road construction and concluded that the binding properties of polymer improved the strength of bituminous mixes. Chavan (2013) reported that the incorporation of plastic waste in bituminous mixes increased strength and performance and reduced the need for bitumen by about 10%.

This study investigated the effects of recycled plastics on the compressive strength, workability and density of concrete.

MATERIALS AND METHODS

Materials

Super rapid hardening portland cement conforming to GS 22: 2004 was used as the binder in the production of concrete. Crushed granite aggregate of nominal size 20 mm was obtained from Sarobi quarry near Elmina in the Central Region of Ghana. Sand was obtained from local supplier. Pipe borne water which appeared free from visible impurities was used in producing concrete. Recycled plastics (Figure 1) with density of 370 kgm^{-3} were sourced from a plastic waste recycling factory in the Central Region of Ghana.

The results of sieve analysis of aggregates used in concrete are shown in Table 1.

Figure 1: Recycled Plastic Waste

Table 1: Summary of Sieve Analysis

BS Sieve Size	Percentage Passing		
	Sand	Crushed Granite	Recycled Plastic
37.5mm	100	100	100
20mm	100	71.9	100
14mm	100	12.1	100
10mm	100	0.1	98.5
9.5mm	99.8		95.5
6.3mm	97.6		41.1
5.0mm	95.8		21.8
4.75mm	95.2		17.3
2.36mm	86.2		2.1
2.00mm	83.0		1.3
1.18mm	64.3		0.2
425µm	10.6		
150µm	1.0		
75µm	0.4		

Sample Preparation

A concrete mixture of ratio 1:2:4 by mass with a water/cement ratio of 0.5 was used as control to which properties of other concrete mixtures were compared. Recycled plastic was used to replace 25%, 50%, 75% and 100% of crushed granite by volume to produce four additional mixtures. Volume replacement was adopted because in a previous study, Osei and Jackson (2012) established that replacement by volume produced concrete with better physical and mechanical properties than concrete produced by mass replacement. Concrete cubes (Figure 2) were produced in cast iron moulds of measuring 150 mm × 150 mm × 150 mm internally.

Figure 2: Concrete Cubes

Twelve concrete specimens of each mixture were produced for the determination of compressive strength and density. A total of sixty cubes were produced. The specimens were made in accordance with BS 1881: Part 108:1983. After casting, the moulds were covered with a plastic sheet to prevent water loss by evaporation. After 24 h, the specimens were removed from the moulds and immediately immersed in a curing tank (Figure 3).

Figure 3: Curing Tank

Effective curing of concrete increases the strength and other mechanical properties of hardened concrete.

Testing

The workability of fresh concrete was assessed using the compacting factor test;

carried out in accordance with BS 1881: Part 103:1993. The compressive strengths of concrete were determined using a 1500 kN Matest compression machine on the 7th, 14th, 21st and 28th day of curing. On each day of testing; the cubes were removed from the curing tank and placed in the open laboratory environment for about two hours prior to crushing. The densities of the cubes were determined before crushing by weighing and volume measurement. The cubes were then placed in the compression machine and compressed until they failed by crushing. The results presented are the average of three tests. All tests were conducted at the materials laboratory of the Department of Civil Engineering at Cape Coast Polytechnic.

RESULTS AND DISCUSSION

Workability

Table 2 shows the results obtained from the compacting factor test.

From the results shown in Table 2, it can be seen that there was no significant change in the workability as the percentage replacement of granite by recycled plastics increased. The workability of concrete is influenced by a lot of factors including water content, cement content, aggregate grading and properties.

According to the results of sieve analysis, the sizes of recycled plastic particles are smaller compared to crushed granite. As the recycled plastic content increased, the specific surface of coarse aggregates increased; therefore, more water was required to maintain the same level of workability as the control concrete. However, there were no significant changes in the workability of the various mixtures. This is because, as the quantity of crushed granite decreased and the quantity of recycled plastics increased, water was made available due to reduced absorption by decreasing quantity of crushed granite content and low water absorption by recycled plastics.

The interaction between the increasing water demand due to increasing specific surface and reduced water absorption by aggregates caused little change in workability.

Table 2: Results of Compacting Factor Test

Percentage Replacement (%)	0	25	50	75	100
Compacting Factor	0.87	0.84	0.84	0.81	0.84

Density

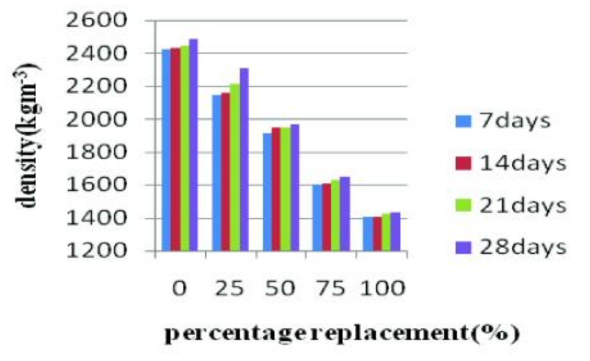
The results obtained from determination of density are shown in Table 3.

The 28-day density ranged from 1433 kgm^{-3} for concrete with only recycled plastic as coarse aggregate to 2483 kgm^{-3} for the control mixture. The variation of density of concrete with percentage replacement is shown in Figure 4.

Table 3: Density (kgm^{-3})

Percentage Replacement	Age(days)			
	7	14	21	28
0	2425	2433	2446	2483
25	2146	2158	2211	2307
50	1916	1947	1947	1972
75	1604	1609	1628	1653
100	1402	1408	1428	1433

Figure 4: Variation of Density with Replacement



As the percentage replacement of granite by recycled plastic increased, the density of concrete reduced. The crushed granite in the control mix was replaced by an equal volume of recycled plastic. This resulted in the reduction of the mass of the mixture since the density of crushed granite is higher than the density of recycled plastic. At higher percentage replacement, more reduction in mass of concrete was recorded. At 33% replacement, concrete attained a density of 2200 kgm^{-3}, the minimum for normal weight concrete. The range, (2200-2600 kgm^{-3}) is regarded as the density of normal weight concrete (Neville, 1996). Compared to the control concrete, the 28-day densities of concretes with recycled plastic contents of 25%, 50%, 75% and 100% reduced by 7%, 20.5%, 33.5% and 42.3% respectively

Compressive Strength

The results obtained from the compressive strength tests are shown in Table 4.

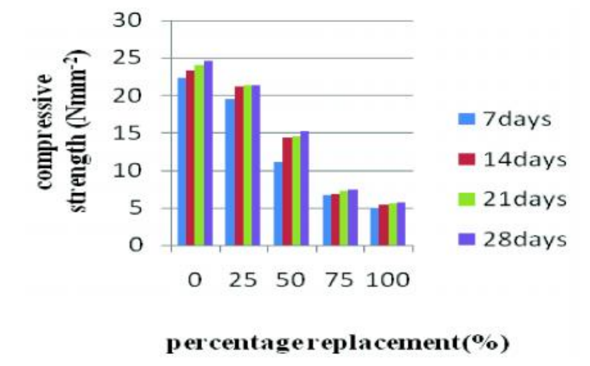
The variation of the compressive strength with the percentage replacement is shown in Figure 5.

At each percentage replacement, the compressive strength of concrete increased as the concrete aged. At all ages, the compressive strength of concrete reduced as the percentage replacement increased. Strength depends to a large extent on good bond between the cement paste and the aggregates. As recycled plastics content increased, the specific surface area increased. Therefore, more cement paste was required to form bond effective bond with the recycled plastics. Since the cement content remained the same, the bonding was inadequate to cater or the increased specific surface. The compressive strength therefore reduced as the recycled plastics content increased.

Table 4: Compressive Strength (Nmm^{-2})

Percentage Replacement	Age(days)			
	7	14	21	28
0	22.30	23.36	23.97	24.64
25	19.53	21.12	21.36	21.39
50	13.40	14.30	14.57	15.21
75	6.62	6.79	7.26	7.34
100	5.34	5.41	5.59	5.74

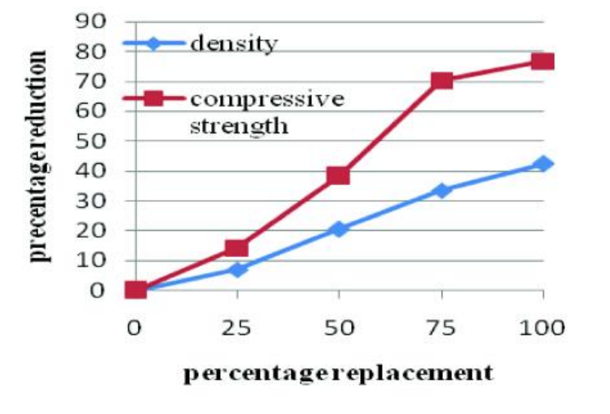
Figure 5: Variation of Compressive Strength with Replacement



The 28-day strengths of concrete with 50%, 75% and 100% replacement of crushed granite by recycled plastic were within the range 5-19.5 Nmm^{-2}, satisfying the criteria for classification as lightweight concrete (Chandra and Berntsson, 2002). The results suggest that concrete produced by replacing 37% to 100% of granite by recycled plastics can potentially be used in lightweight construction while replacement of less than 36% can be used in reinforced concrete construction according to the requirements of BS 8110 (1997). Compared to the control concrete, the 28-day compressive strengths of concretes with recycled plastic contents of 25%, 50%, 75% and 100% reduced by 14.2%, 38.3%, 70.2% and 76.7%, respectively.

From the results presented above, it is seen that the compressive strength and density of concrete reduced as the percentage replacement of crushed granite by recycled plastics increased. Figure 6 shows the variation of the percentage reductions in compressive strength and density with recycled plastics content.

Figure 6: Variation of Percentage Reductions in Density and Strength with Recycled Plastic Content



The magnitude of percentage reductions in strength and density increased as the recycled plastic content increased. However, at all percentage replacements, the magnitude of percentage reduction in compressive strength was higher than the percentage reduction in density.

CONCLUSION

At the end of the study, the following conclusions are drawn:

1. The compressive strength of concrete reduced as the percentage of recycled plastic increased but the workability of concrete did not change significantly with the increase in the recycled plastics content.
2. Less than 36% of crushed granite can potentially be replaced by recycled plastic waste in the production of reinforced concrete.
3. Concrete produced by complete replacement of crushed granite by recycled plastic waste is not suitable for structural concrete.
4. Recycled plastics can potentially be used as replacement of natural rock aggregates in concrete.
5. Based on the results of the study, a maximum of 33% replacement of granite by recycled plastics can be used in producing normal weight concrete.
6. The percentage reductions in compressive strength and density increased as the percentage replacement increased.
7. At all percentage replacements, the magnitude of percentage reduction in compressive strength was higher than the percentage reduction in density.

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