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ARTICLE

Effect of Partial Replacement of Coarse Aggregate with Electronic Waste Plastic in Light Weight Concrete

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ABSTRACT

This study assessed the usefulness of the replacement of coarse aggregate partially with electronic waste (e-waste) plastic in lightweight concrete since developing countries have been challenged with management of e-waste as well as high cost of coarse aggregates for concrete production. Coarse aggregates were replaced with e-waste plastic in concrete at 5%, 10%, 15%, and 20% for a concrete class of C20. The particle size distribution of the e-waste plastic aggregates was determined as well as the slump, compressive strength, water absorption and bulk density of the concrete. Generally, the slump decreased as the e-waste increased. The compressive strengths decreased for the 5% and 10% replacement of coarse aggregates with e-waste but increased for the 15% and 20% replacement of coarse aggregate with e-waste. 0% water absorption was obtained for the 15% and 20% e-waste content while the 10% e-waste concrete obtained 0.01% and the 5% e-waste obtaining of 0.013% after 28days of curing. The densities of 5%, 10%, 15% and 20% e-waste plastic content decreased as compared to the 0% e-waste plastic content. The values of compressive strength obtained showed that coarse aggregate replacements by e-waste plastic at 15% and 20% may be appropriate for lightweight concrete of class C20/25 since compressive strengths ranged between 16.09 Nmm^{-2} and 22.87 Nmm^{-2}. This implies that partial replacement of coarse aggregate with e-waste plastic may be useful for lightweight concrete as well as helping in eradicating the environment of the menace of e-waste plastic.

1. Introduction

Globally, management of the huge volumes of waste generated is a challenge. A component of the waste which has gained much attention due to its environmental degradation in recent times is electronic plastic waste (e-waste). Scavenging for valuable materials such as wires in waste has become a means of livelihood for many families in most developing countries. The objective to reap enormous gains through burning off plastic coatings on computer wires and refrigerator coils to recover prolific metals, turns out to bedevil humans, livestock and the entire

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ecosystem [1].

In 2019 an estimated amount of 53.6 million tons of e-waste was generated. With the increasing demand for electronic gadgets steered from the essence of technological advancement and innovation, this is estimated to exceed 74 million metric tons in 2030 [2]. Most of these waste electronic gadgets are shipped to the developing countries which have none or limited recycling facilities and are sufferers of poor waste disposal issues thereby serving as dumping grounds [3]. The government of Ghana in an attempt to curb the importation of Waste Electrical and Electronic gadgets, formulated the Hazardous and Electronic Waste Control and Management Act (Act 917) [4] as well as the Hazardous and Electronic Control and Management Regulation and Legal Instrument (LI) 2250 [5] which ensures that producers and importers register with the Environment Protection Agency by paying a pre-emptive eco tax for importing electronics to finance the enforcement of the legal framework for e-waste management and the formulation of the informal sectors accompanied with recent policy brief on sustainability of formalization in Ghana's e-waste sector [6]. In spite of all these efforts and precedence set by the enforcement of other legislations in the country, there is no doubt that if drastic measures are not taken, the curtailment of the detrimental effects of the unsafe disposal of e-waste plastic on humans and the environment may not be achieved.

Incineration of municipal solid waste has been accepted as an indispensable disposal method for waste in the twenty-first century. The heat content of e-waste plastic may be recovered through incineration and used as fuel as most of the resins have a heating value almost the same as coal [7]. The emission of some toxic fumes during incineration have met public resistance, but, technological advancements have made it possible to operate incinerators in a fashion that would adhere to Environmental Protection Regulations [7].

Apart from restricting importation of electronic gadgets and incineration, exploratory research [8] revealed that, use of e-waste plastic, was found to be of importance in its shredded form in concrete in which the compressive strength gradually decreased with increasing percentage of plastic waste with 0.2% plastic waste content obtaining a compressive strength of 22.76 MPa after 28 days as compared to the 0% electronic plastic waste with compressive strength of 24.68 MPa. Similarly, the shredded plastics used to partially replace sand in concrete was seen not to increase compressive strength of concrete though, but for a mix ratio of 1:1.67:2.5 and w/c ratio of 0.46 at 5% replacement of recycled plastic with sand in concrete, a compressive strength of 38.95 MPa at 28 days as compared to 66.6 MPa for 0% replacement of recycled plastic indicating a 16% deficit in compressive strength [3]. This reduction in compressive strength does not render the recycled plastics in the concrete useless but a compressive strength of 38.9 MPa is adequate to be targeted for concrete production for construction of structures in which characteristic strength may range between C30 and C40. This means that, the e-waste plastic concrete may be appropriate for structures which may be exposed occasionally to sea water spray or deicing salts either directly or indirectly as specified in Structural use of concrete-Part 1 [9].

Coarse aggregate replaced with e-waste plastic [10] in concrete with the intention of reducing cost of aggregates as well as providing a good strength for structures revealed that at 10% intervals of increasing e-waste content to manufacture C20 concrete with a mix ratio of 1:1.4:2.4 and w/c ratio of 0.5, compressive strength of e-waste plastic concrete decreased as compared to the reference concrete which increased at all curing stages. The decrease in the adhesive strength between the materials may have accounted for reduction in the compressive strength as the e-waste plastic content increased. Furthermore, due to poor water absorption properties of the e-waste plastic, the hydration process was inhibited ultimately, affecting the compressive strength of the hardened concrete. That notwithstanding, it was concluded that the e-waste plastic may be used to replace some of the aggregates at either 10%, 20% or 30% depending on the characteristic strength expected with the intention to reduce the unit weight of concrete thereby making use of the e-waste plastic concrete as non-load bearing light weight concrete such as concrete panels for facades [10].

As a result of e-waste plastic being lighter in weight as compared to natural aggregates where fuel consumption is reduced during transportation as well as its associated cost [11], it also has comparatively less production cost which provides benefits with respect to the impact of earth quake forces which mainly rely on self-weight of structures for the intensity of their impact which may be on e-waste concrete structures [12].

With the high housing deficit and the increasing demand for infrastructure accompanied with high cost of the constituents of concrete and other construction materials, it is extremely important that the cost of raw materials used as concrete constituents needs to be reduced to the minimum to enhance infrastructural development to be able to meet the sustainable development goals. Moreso, a drastic reduction in the piling up of used and discarded electronic, electrical and computer equipment is expected to be achieved through the conversion of electronic waste plastic into a useful and ecofriendly raw material with the help of affordable technology. In the long run, utilizing e-waste in concrete will result in the reduction of health hazards involved in burning the plastic coatings from computer, electronic and electrical devices. This study therefore seeks to add on to the on-going research works in recent years on the partial replacement of coarse aggregate with e-waste plastic in concrete production [13,14], with emphasis on the workability and mechanical properties of concrete containing e-waste plastic aggregates as partial replacement of coarse aggregates.

2. Materials and Methodology

Ordinary Portland Cement (OPC) which has a strength of 42.5R was used as binder with river sand as fine aggregates whiles granite and electronic plastic waste were used as coarse aggregates, together with portable water were used in the manufacture of the concrete specimens.

2.1 Source and Treatment of Materials

The e-waste plastic obtained from Agbogbloshie a suburb of Accra in the Greater Accra Region of Ghana and transported to the Civil Engineering Laboratory of Takoradi Technical University where it was washed, dried and crushed. Granite and sand used as coarse and fine aggregates respectively were obtained from Justmoh Construction Company Limited, Takoradi. The wet sand, granite and crushed e-waste plastic were dried for about 6hours at room temperature and sieved through 4.75 mm and 20 mm sieves.

2.2 Batching, Mixing and Preparation of Specimen

The British Department of Environment (DOE) mixing for a grade of 20 MPa target strength of 32.5 MPa and target slump ranging from 30 mm to 60 mm was adopted. OPC, fine aggregate (sand), coarse aggregates (granite & e-waste plastic) in 1:1.5:3 mix ratio and 0.62 w/c ratio in which the e-waste plastics were added in amounts of 0%, 5%, 10%, 15% and 20% by mass entailed the mix resulting in the manufacture of 60 cubes of sides 150 mm × 150 mm × 150 mm. The concrete constituents were batched by mass and prior to mixing, the moulds were assembled and lubricated adequately for easy disassemble of mould and easy removal of hardened concrete. Mixing of the constituents was done by turning severally with a shovel in a mixing metal tub until a uniform plastic mixture was obtained where the slump test followed to find the w/c ratio of mix after which prepared concrete was placed in the lubricated cast iron mould in three layers with each layer receiving about 25 blows from a tamping rod after which the surface was dressed with a hand trowel and the specimens allowed to set for 24 hours before demoulded and cured in water tanks by totally submerging to reduce heat of hydration. Cubes were removed from the curing tanks and allowed to attain dry surface state for about 3 hours on the day of testing in which concrete samples were weighed and crushed.

2.3 Physical Properties Tests on Aggregates

2.3.1 Particle Size Determination of Coarse Aggregates

In accordance with American Society for Test and Materials (2006) [15], grading test was conducted to find the particle size distribution of each of the aggregates as well as the e-waste plastics after which particles were allowed to pass through stack of sieves whose apertures are known. The setup was shaken for about 10 minutes using a mechanical test sieve shaker. When the sieves were removed, masses of samples retained on each sieve were recorded and the respective mass of each sieve was subtracted from the mass of sieve and content. The percentage passing was calculated by subtracting the cumulative percent retained from 100% after which a semi-logarithmic curve was plotted with ordinate axis being percentage passing and the sieve sizes being the abscissa (logarithmic scale).

2.3.2 Specific Gravity of Coarse Aggregates

In accordance with American Society for Test and Materials (2007) [16], specific gravity test was performed where specific gravity is given as:

$$S.G = X / (X - C) \tag{1}$$

where X = weight of oven dry sample in air
C = weight of saturated specimen in water.

2.3.3 Water Absorption Determination of Coarse Aggregates

The saturated surface dry test method according to ASTM-2007 [17] given as:

$$\%WaterAbsorbed = \frac{Y - X}{X} \times 100\% \tag{2}$$

It was used to determine the water absorption of the aggregates (granite and Sand) where X = mass of oven dry specimen in air and Y = mass of saturated surface dry specimen in air.

2.4 Slump, Compressive Strength and Density tests

In accordance with BSI, 12350-Part 2 [18], the slump test was performed to determine the workability of the concrete mix by pouring the concrete in the cone in three layers where each layer received compaction of 25 blows with a 16 mm tamping rod. The cone was lifted upwards after compaction in which the slump was determined as the difference between the highest points on the concrete to the bottom of masonry level on top of the cone. The concrete cubes were drained of excess water by sun drying after each curing period. The densities of the specimens were determined by dividing the mass of air-dried specimen by the volume.

A Universal Compression Testing machine of capacity 1000 kN was used to crush the concrete where the Compressive Strength was determined by dividing the crushing load of the specimen by the cross-sectional area as prescribed by the BSI, 12390-Part 3 [19].

3. Results and Discussion

3.1 Physical Properties of Fine Aggregates

The particle size distribution of the fine aggregates used is presented in Figure 1 which shows the variation of percentage passing with particle sizes of fine aggregates.

Figure 1 shows that the particle size of the fine aggregates ranges from 0.15 mm of sand to 5 mm of gravels with 10% of the fine aggregates being smaller 0.22 mm, 90% of the fine aggregates being smaller than 2 mm and 50% of the fine aggregates being smaller than 0.58 mm but larger than 0.075 mm representing a coarse-grained soil according to the Unified Soil Classification System.

3.2 Physical Properties of Coarse Aggregate

For the coarse aggregate, its particle size distribution curve shown in Figure 2 indicates that the particles range between 0.75 mm to 7.5 mm where 50% of the particles are less than 3.2 mm but larger than 0.075 mm and in accordance with the Unified Soil Classification System as a coarse aggregate and qualifies to be used for concrete production.

3.3 Physical Properties of E-waste Plastic Aggregates

For the e-waste particles, the particle size distribution curve in Figure 3 indicates that the e-waste particles range between 1 mm and 8 mm with more than 50% percent being larger than 0.075 mm in accordance with unified gravels classification system, as a coarse aggregate.

3.4 Specific Gravity, Fineness Modulus and Water Absorption of Aggregates

From the results obtained, the granite, sand and e-waste plastic attained a specific gravity of 2.6, 2.608 and 1.1 respectively, which fell within the range of 2.6 ~ 2.8 specified in BSI, Part 2-1999 [20] for aggregates to be recommended as normal aggregates except the e-waste plastic which has a low specific gravity as compared to the fine and coarse aggregate. The plastic nature of the e-waste and its inability to absorb water may have accounted for the low specific gravity. The fineness modulus of the sand, granite and e-waste plastic were found to be 6.5, 7.60 and 8.1 respectively and did not fall within the range of 2.3 ~ 3.1 as specified in ASTM 1999 [21] indicating that the e-waste plastic aggregates were coarser than the coarse aggregate. The granite, sand and e-waste plastic obtained water absorption values of 0.66%, 2.7% and 0% respectively indicating that the coarse aggregate absorbed more water than e-waste aggregates and fine aggregates.

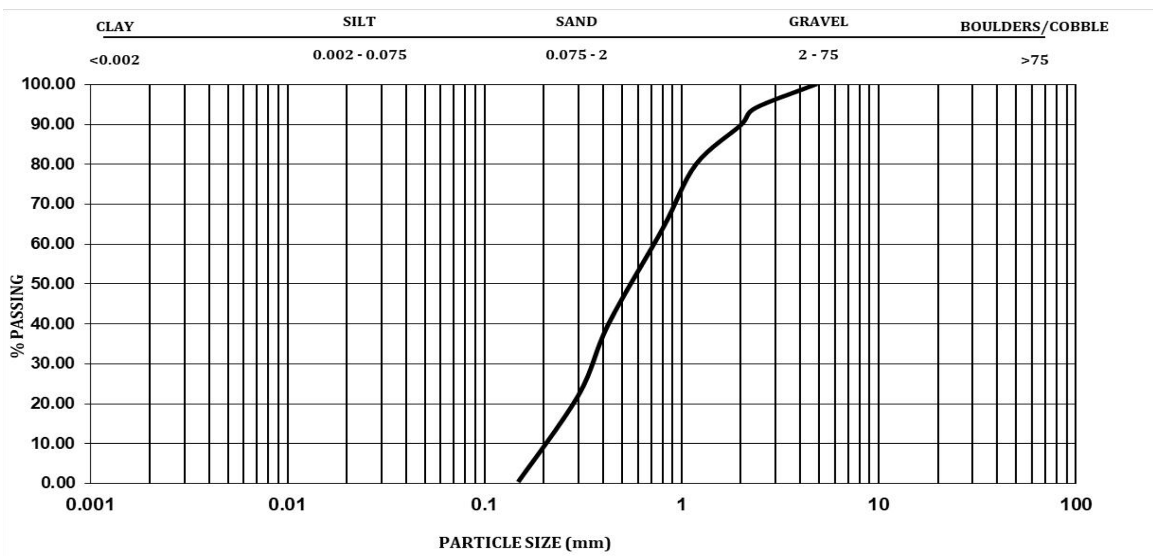

Figure 1. Variation of %Passing with sieve sizes for fine aggregate (sand)

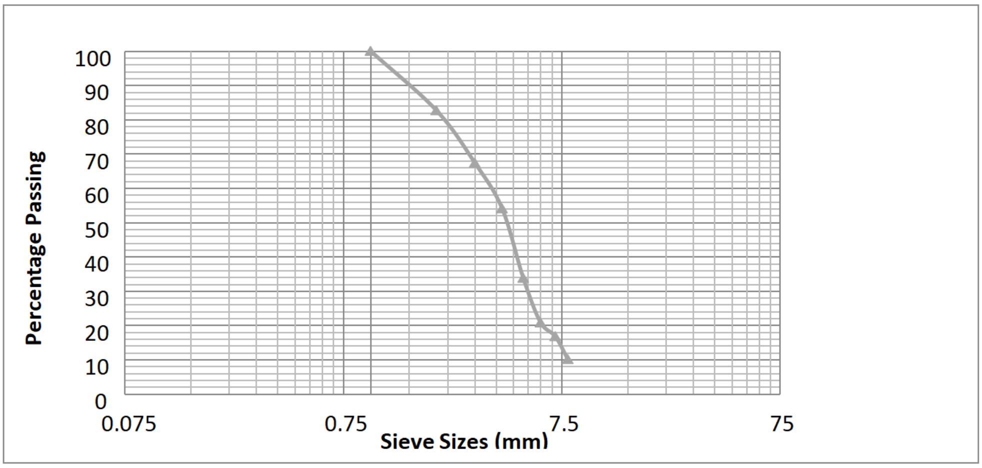

Figure 2. Variation of %Passing with sieve sizes for coarse aggregate

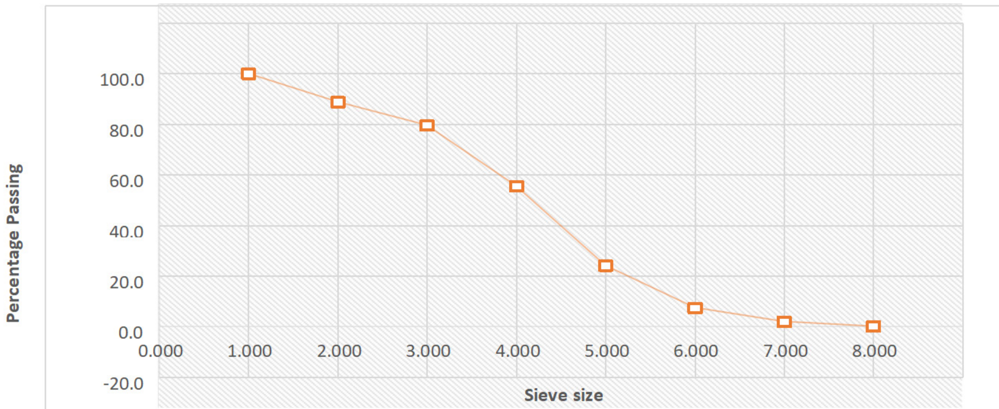

Figure 3. Variation of % Passing with sieve sizes for E-waste plastic

3.5 Slump Test

The results obtained from the slump cone test as shown in Figure 4 show that the concrete workability or ease of flow for the control concrete was 61mm whiles no slump was obtained for both 5% and 10% e-waste replacement. Generally, the slump decreased as the e-waste increased. At the 20% e-waste replacement, the slump measured reduced appreciably from 61mm of the control to 55mm but increased from the 15% e-waste content of 28 mm slump. Zero slumps were observed for the 5% and 10% e-waste replacement respectively which indicated difficulty of the concrete to flow. It therefore means that more water is required to make the concrete workable with 5% and 10% e-waste inclusion in the concrete.

3.6 Water Absorption of E-waste Concrete

Figure 5 shows the variation of water absorption of e-waste plastic concrete with e-waste content. The 0% water absorption was obtained for the 15% and 20% e-waste content while the 10% e-waste concrete obtained 0.01% and the 5% e-waste obtaining of 0.013% after 28 days of curing. It is an indication that, an increase in the replacement of coarse aggregates with e-waste plastic reduces the water absorption with respect to the duration of the curing. This may be as a result of the e-waste being able to seal all the voids in the concrete.

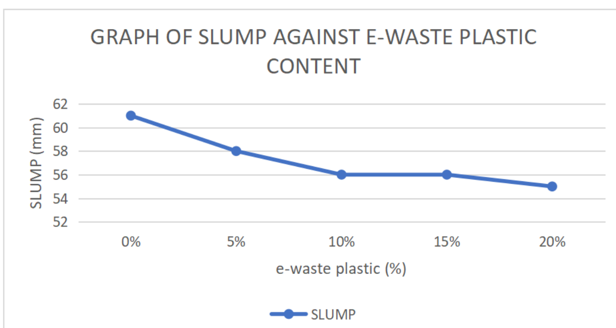

Figure 4. Variation of slump with E-waste content

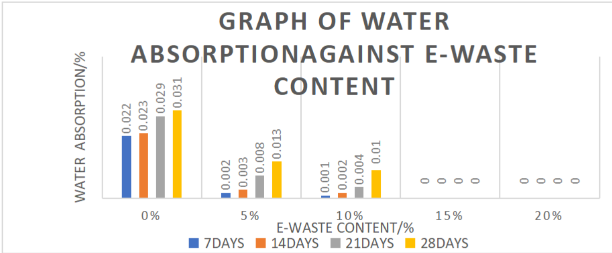

Figure 5. Variation of water absorption with E-waste content

3.7 Compressive Strength

Figure 6 indicates that the replacement of 5% and 10% e-waste reduced the compressive strength of the specimen by 5.0 N/mm^2 and 2.31 respectively after 28 days of curing as compared to the control concrete whiles the 15% and 20% percentage of the e-waste of the specimen increased the compressive strength by 0.8% and 5.2% respectively. The reduction in compressive strength for the 5% and 10% e-waste concrete specimens as compared to the 0% may be accounted for by the poor packing density of the specimen and the reduction in the adhesive strength between the materials whiles the increase in the compressive strength of the specimen after the 15% and 20% e-waste concrete specimens may be as a result of a good packing density despite [10] reporting of a significant reduction of about 52.9% at 20% coarse and fine aggregates replacement with e-waste particles in concrete.

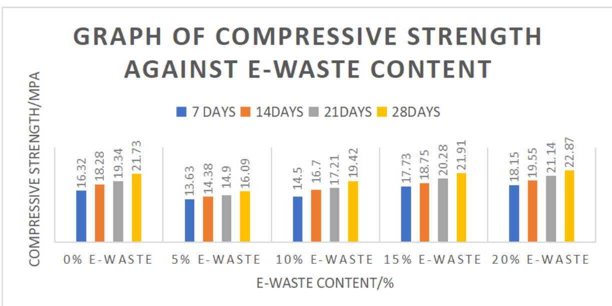

Figure 6. Variation of Compressive strength with E-waste content

3.8 Density

From Figure 7 it can clearly be seen that, initially zero e-waste specimen surfaces absorb more water resulting in a higher density than the 5%, 10%, 15% and 20% e-waste concrete surfaces after 28 days of wet curing. Hence, there was a decrease in densities of the e-waste specimen surfaces as the e-waste content increased in the mix. The density of the specimen decreased by 2.4% at the 5% replacement, 3.9% at the 10% replacement, 5.0% at the 15% replacement and 6.3% at the 20% replacement respectively. The densities of the e-waste cubes decreased due to the incremental difference in the content e-waste in the specimen as well as the low specific gravity of the e-waste plastic aggregates.

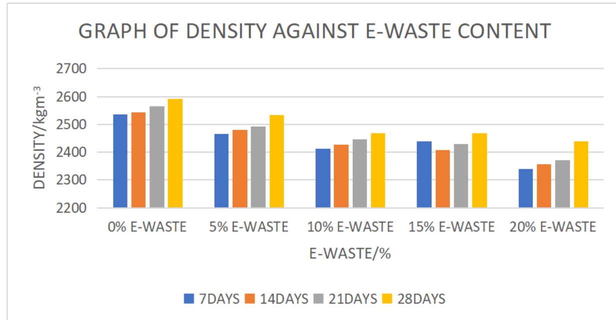

Figure 7. Variation of Density with E-waste content

4. Conclusions

The experimental results of the study revealed that e-waste plastic may be used as replacement of coarse aggregate partially in concrete production. Water absorption rate of the specimen decreased as the percentage of the E-waste plastic increased after 28days of curing. 0% water absorption was obtained for 15% and 20% e-waste content in the concrete.

Similarly, the density of the specimen reduced due to the increased content of the E-waste plastic in the mix. The density of the specimen decreased by 2.4%, 3.9%, 5.0% and 6.3% respectively as the percentages of the E-waste were increased after 28days of curing. The 5% and 10% E-waste plastic content reduced the compressive strength of the specimen after 28 days of curing because the packing density was poor but, the 15% and 20% of the E-waste plastic in the specimen increased the compressive strength by 0.8% and 5.2% respectively, indicating a significant influence on the compressive strength after 28days of curing due to the increase in the quantity of the E-waste plastic as well as the good packing density.

Applying e-waste plastic in concrete production showed a significant reduction of water absorption by concrete surface.

Recommendation

It is recommended that coarse aggregate may be replaced at 15% and 20% with e-waste plastic in concrete production whiles further research may be conducted to investigate e-waste plastic in concrete at 5% and 10%.

Conflict of Interest

There is no conflict of interest.

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