AN EVALUATION OF SHREDDED WASTE POLYETHYLENE TEREPHTHALATE BOTTLES LIGHTWEIGHT SORGHUM HUSK ASH BASED CONCRETE COMPOSITE

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DANIYA, Noel Sheabyimuilo

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DEPARTMENT OF BUILDING
FEDERAL UNIVERSITY OF TECHNOLOGY MINNA

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ABSTRACT

Concrete is the most common material for human beings to use in construction in this research thesis, the use of shredded waste Poly-ethylene Terephthalate (PET) bottle flakes as a lightweight coarse aggregate in concrete was examined. Study was carried out on two groups of concrete samples, one made with only granite as coarse aggregate (control) and second made with a combination of PET and granite aggregate. The PET replaced the granite aggregate at varying percentage of 0%, 5%, 10%, 15% and 20%. Additionally, Sorghum Husk Ash (SHA) was also used as the replacement of cement on mass basis at the replacement ratio of 10% to reduce the amount of cement used and provide savings. The water–binder (w/b) ratio used in the mixtures was 0.55. It was observed that 5% PET was the optimum PET replacement for coarse aggregate that gave strength properties that is close to the control concrete. A compressive strength of 34.11 N/mm^2 was achieved at 56 days, and a tensile strength of 3.94 N/mm^2 was achieved also achieved at 56 days for concrete 5% PET concrete containing SHA. The results of the laboratory study and testing carried out showed that concrete comprising PET and SHA as cement replacement can be categorized into structural lightweight concrete in terms of unit weight and strength properties. Therefore, it was concluded that there is a potential for the use of shredded waste PET as aggregate in the production of structural lightweight concrete. The use of shredded waste PET due to its low unit weight reduces the unit weight of concrete which results in a reduction in the self-weight of a structural concrete member of a building. Reduction in the dead weight of a building will help to reduce the seismic risk of the building since the earthquake forces linearly dependent on the dead-weight. Furthermore, it was also concluded that the use of industrial and agricultural wastes such as PET flakes and SHA in concrete provides some advantages, that is, reduction in the use of natural resources, disposal of wastes, prevention of environmental pollution, and energy saving.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Concrete is the most widely used construction material in the world. There is a concern to more understanding and to improve its properties. Using waste and recycled materials in concrete mixes becoming increasingly important to manage and treat both the solid waste generated by industry and municipal waste. Plastic is one of the most significant innovations of 20th century material. The amount of plastic consumed annually has been growing steadily and becomes a serious environmental problem. For solving the disposal of large amount of recycled plastic material, use of plastic in concrete industry is considered as feasible application. Amidst the major constituent materials of concrete, aggregate takes about 65-–80% of concrete bulk. Hence, aggregate plays a substantial role in influencing concrete properties such as workability of fresh concrete, strength development, dimensional stability, and durability. Therefore, the use of waste materials as aggregates in concrete production can immensely influence the amount of waste material recycling, reduction and reused (Ismail & Al-Hashmi, 2008).

Lightweight aggregate is an important material in reducing the unit weight of concrete. Previous studies have shown that the use of plastic waste (Polyethylene Terephthalate-PET) bottle as Lightweight aggregates in concrete production is technically and environmentally viable (Choi *et al.,* 2005; Siddique *et al.,* 2008). Information on using plastic as light weight aggregate in concrete were provided only for concrete without pozzolanic content as partial replacement for cement. Studies on using plastic as either fine or coarse light weight aggregate in agriculturally based pozzolanic concrete to the best of the researcher's knowledge is limited or none, thus, the need for the study (Akçaözoglu *et al.*, 2010; Saikia & Brito, 2014).

Lightweight aggregate is an imperative material in plummeting the density or unit weight of concrete to produce earthquake resilient constructions since the earth tremor forces are linearly reliant on the mass of the structure (Jafari & Mahini, 2017; Semiha *et al.,* 2010). The use of Lightweight aggregates is largely meant for the reduction of the unit weight of concrete through substituting the conventional aggregates. Currently, there are numerous lightweight concrete submissions made with natural or artificial lightweight aggregates in the literature (Saikia *et al*., 2014; Islam *et al.,* 2016; Madandoust *et al*., 2019; Ashrafian *et al*., 2020; Záleská *et al*., 2018). Though, the cost of non-natural lightweight aggregate production is high owed to necessity of high burning temperature or thermal treatment (Semiha *et al*., 2010). Consequently, unlike other common materials, using waste plastic pellets as lightweight aggregate in the manufacture of lightweight concrete has engrossed considerable interest and keen devotion from the researchers. This method offers both recycling of the plastic waste and manufacture of a lightweight concrete in a cost-effective manner (Hilal *et al.,* 2021; Koide *et al.,* 2002).

Poly-ethylene (PE) is some of the plastic wastes used in lightweight concrete. The PET bottles are ahead of the wastes with its high growing speed of consumption. PET excels by its inherent values like strength, safety, cost-effectiveness and being lightweight, unbreakable and recyclable. Today, the food and beverages industry is increasingly using PET (polyethylene terephthalate) to replace glass and other materials. In Nigeria, the usage of PET started in a noticeable way only very recently. It is projected that the demand will grow appreciably, especially for packaging soft drinks and water. Research indicates that the main driver of growth for PET (polyethylene terephthalate) bottles in Nigeria has been the food and beverage sector with water industry accounting for about sixty-five percent (65%) of PET (polyethylene terephthalate) usage in Nigeria (Tuleun & Jimoh, 2018).

As a result of wild increase in the usage of PET bottles in our environment, solid waste problem is upstretched and over a hundred of years is required to degrade the waste PET bottles naturally (Ioakeimidis *et al.,* 2016; Pol, 2010). Hence, one of the realistic approaches for disposal of PET wastes, which causes environmental pollution, is using these wastes in the other manufacturing expanses, thus recycling the PET for beneficial, ecological and economic purpose. Several experimental studies have been carried out on using waste PET bottles as resin in polymer concrete and as fibre in fibrous concrete in recent years (Asdollah-Tabar *et al.,* 2021; Patil *et al.,* 2020; Batista *et al.,* 2021; de Luna *et al.,* 2020; Alani *et al*, 2020). Nevertheless, the utmost cost-effective use of waste PET bottles in concrete as being described by researcher to be shredded waste PET bottles used directly as aggregate in concrete fabrication. Thus, the use of PET wastes as aggregate in concrete will afford benefit in the disposal of wastes and reduce the environmental damages owed to the use of natural mineral aggregates resources (Semiha *et al.,* 2010). Limited study on concrete fabricated with waste PET flakes as coarse aggregate is reported in literature (Islam *et al*. 2016; Saikia & de Brito, 2014; Silva *et al.,* 2013; Ghaly & Gill, 2004). Though, beside waste PET, other plastic wastes such as HDPE, PE and PS have been used as aggregates in preparing various concrete composites (Naik *et al.,* 1996). Plastic bottles shredded into PET flakes and pellets may be used successfully as substitution for coarse aggregates in cementitious concrete composites and be used for structural concrete member.

In addition, SHA was used as a replacement of cement in concrete in previous studies. It is reported in many investigations that, the use of SHA in concrete as a cement replacement has positive influence on the properties of the fresh and hardened concrete (Ndububa & Nurudeen, 2015; Tuleun & Jimoh, 2018). In addition, it also provides economic benefits (Tuleun & Jimoh, 2018). It improves strength, reduces permeability and porosity, reduces alkali-silica expansion of hardened concretes (Ogork & Danja, 2018; Tijani *et al.,* 2019a; Tijani *et al.,* 2019b). 10% SHA replacement level was reported as the optimum quantity for achieving a competitive value for compressive strength of resulting concrete (Ndububa & Nurudeen, 2015). The usage of SHA in concrete affords ecological advantages apart from the energy savings and contribution to the properties of strength and durability of concrete (Tuleun & Jimoh, 2018).

1.2 Statement of the Research Problem

Rapidity of population, urbanisation and economic growths has increased solid waste generation rates and material composition (Harir, *et al.,* 2015a). Finding sustainable option of solid waste disposal remains a major challenge to waste management industry (Farrell & Jones, 2009). Thus, in Nigeria and most developing countries, authorities are facing the challenges to determine the appropriate option among alternative policies for sustainable solid waste management in cities (Harir, *et al.,* 2015b). Solid waste management continues to be seen as an important issue because the areas for landfill disposal of waste are limited. In the twenty-first century, the consumption of plastics has been increasing rapidly (Tamang *et al.,* 2017) and the generation of plastic waste has also become alarming (Raghatate, 2012). In 2018, the total plastic production reached a quantum of 359 million metric tons, where 1.5 million metric tons of production were reported in the 1950s (Harir, *et al.,* 2015b).

Despite the undeniable economic gain due to the emergence of plastic science, the concurrent environmental problem occurring is also becoming a challenge to many parts of the world. According to d'Ambrières (2019), nearly half of all plastic produced since 1950 has ended up either in landfills or open dumped, and nine percent of the plastics have been recycled globally. Moreover, about 4 to 12 million metric tons of plastic waste ends up in the ocean. Different countries have different contributions to this phenomenon depending on the population size and status of the waste management system the nation state possess. In the absence of well-organized waste management infrastructure, the quantity of plastic waste entering into the fluvial system is predicted to increase. Developing countries, in particular, would face a significant challenge concerning waste management due to the rapid population growth; increased urbanization and inconsistent consumption patter which particularly worsen the issue of plastic wastes (Godfrey, 2019). There are several research and technological development efforts to avert or minimize the problem happening due to waste plastic. Among this recycling of plastic into different valuable materials is one stage in the integrated waste management principle. In recent years there are various scientific reports in using waste plastics such as PET in the construction sector as a sole construction material and as an aggregate (fine and coarse). The finding presented that the increase in the ratio of the plastic aggregate fraction lead to a corresponding decrease in the compressive and tensile strength, though a decrease in unit weight is achieved (Koide *et al.,* 2002; Ismail & Al-Hashmi, 2008; Saikia & Brito, 2013; Sojobi & Owamah, 2014; Chen *et al*. 2015; Arivalagan, 2016). Therefore, a possible introduction of admixture such an agricultural by-product pozzolan like Soghum Husk Ash (SHA) could enhance the strength properties of the light weight plastic base concrete.

SHA has the potential to act as an admixture, which increases the strength, workability and pozzolanic properties of concrete. Also, Ogunbode *et al* (2021) described the effect of SHA on strength properties of concrete to be significant. The outcome of their investigation shows that compressive strength of blended concrete with 10% SHA produced a valuable strength without adversely affecting the concrete strength.

Almost all reported papers in this arena used are plastic concrete (PET) mix without pozzolan admixtures. Conclusively, most of the research undertakings ignored the use of

SHA as a potential Supplementary Cementitious Material (SCM) in the production of PET concrete to determine the workable range in real practice. Therefore, this study aims to evaluate the technical feasibility of waste plastic bottles (PET) using SHA as an admixture to produce Light Weight Concrete Composite (LWCC).

1.3 Aim and Objectives of the Study

The aim of this research is to evaluate the effect of SHA on shredded waste poly-ethylene terephthalate (PET) bottles as coarse aggregate in light-weight concrete composite with a view to determining the suitability of PET and SHA for the production of light weight concrete.

The objectives of the research work are to:

i. Study the physiochemical properties of the constituent materials of the concrete composite.

ii. Establish the appropriate mix proportion of PET light weight SHA based concrete composite.

iii. Evaluate the fresh properties of PET light weight SHA based concrete composite.

iv. Determine the optimum PET coarse aggregate to natural coarse aggregate replacement ratio, which produces the best SHA based concrete strength properties

1.4. Scope of the Study

The research was principally experimental towards determining the potentials of PET as coarse aggregate in SHA based light weight concrete. Material characterisation based on determination of physical and chemical properties of the constituent materials was carried out. The fresh and hardened properties of LWCC mixtures containing varied proportion of PET in SHA based LWCC was examined. The strength properties test conducted was compressive strength test and splitting tensile strength test.

1.5. Justification for the Study

This study outcome presents the methodical reports on the potentials of plastic aggregate in SHA based LWCC using crushed waste water bottle (PET). The SHA used in this research is locally available SCM used as substitutes to the conventional cement for achieving an enhanced concrete mixture.

The research is of significance as it also bared the properties of light weight waste plastics aggregates (PET bottles) for adoption as plastic aggregate in light weight concrete composite production towards addressing the problem of disposal of wastes and reduces environmental damages caused through use of natural mineral aggregates resources. Also, it enhances the mechanical properties of the LWCC. Data generated from this study gives insight on appropriate use of waste PET bottles as coarse aggregate in SHA base LWCC.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Plastics

Plastics are polymers, an exceptionally enormous atom comprised of more modest units assembled monomers which are participated in a chain by a cycle called polymerization. The polymers by and large contain carbon and hydrogen with, some of the time, different components like oxygen, nitrogen, chlorine or fluorine (UNEP, 2009). Plastics have become an essential piece of our lives. The measure of plastics burned-through yearly has been developing consistently. Its low thickness, strength, easy to understand plans, creation abilities, long life, lightweight, and minimal expense are the variables behind such sensational development. Plastics have been utilized in bundling, auto and modern applications, clinical conveyance frameworks, counterfeit inserts, other medical care applications, water desalination, land/soil protection, flood avoidance, conservation and appropriation of food, lodging, correspondence materials, security frameworks, and different employments. With such enormous and fluctuating applications, plastics add to an always expanding volume in the strong waste stream. The world's yearly utilization of plastic materials has expanded from around 5 million tons during the 1950s to nearly100 million tons in 2001 (Siddique *et al.,* 2008).

Amounts of waste plastic have been rising quickly during the new a long time because of the great expansion in industrialization and the extensive improvement in the ways of life, however lamentably, most of these waste amounts are not being reused but instead deserted causing certain major issues like the misuse of normal assets and ecological contamination (Godfrey, 2019; d'Ambrières, 2019),

2.2 Types and Uses of Plastic

Plastic are ordered by the premise of the polymer, from which they are made.

The sorts of plastics that are most regularly reprocessed are polyethylene terephthalate (PET), polyethylene (PE), polypropylene (PP), polystyrene (PS), and polyvinyl chloride (PVC). Table 2.1 subtleties the sorts and employments of plastic and reused plastic.

Table 2.1: Types and uses of plastics and recycled plastics

Type of plastic	Description	Some uses for virgin plastic	Some uses for recycled plastic
Polyethylene terephthalate (PET)	Clear tough plastic, may be used as a fibre	Soft drink and mineral water bottles	clear film for packaging, carpet fibres, fleecy jackets
Low density polyethylene (LDPE)	Soft, flexible plastic, milky white, unless a	Lids of ice-cream containers,	Film for builders, industry, packaging and plant nurseries
High density polyethylene (HDPE)	Very common plastic, usually white or coloured	Crinkly shopping bags, freezer bags, and milk	Compost bins, detergent bottles, crates, and mobile
Unplasticised Polyvinyl chloride (UPVC)	Hard rigid plastic, may be clear	Clear cordial and juice bottles, plumbing pipes and fittings	Detergent bottles, tiles, and plumbing pipe fittings
Plasticized Polyvinyl chloride (PPVC)	Flexible, clear, elastic Plastic	Garden hose, shoe soles, blood bags and tubing	Hose inner core, and industrial flooring
Polypropylene (PP)	Hard, but flexible plastic	Ice-cream containers, potato crisp bags,	Compost bins, kerb side recycling crates and worm factories
Polystyrene (PS)	Rigid, brittle plastic. May be clear, glassy	cheap, transparent kitchen ware, light fittings, bottles, toys, and food containers	Clothes pegs, coat hangers, and video/CD boxes
Polyester (EPS)	Foamed, lightweight, energy absorbing, and thermal insulation	Hot drink cups, and takeaway food containers	spools, rulers, and video/CD boxes
Polyamides (PA)	Nylons	fibres, tooth brush bristles, and fishing lines	

Source: Siddique *et al.* (2008); UNEP (2009)

3.3 Sorghum Husk Ash

Sorghum husk ash is a loss in agriculture produced by processing guinea corn husks. The worldwide creation of guinea corn husks is assessed to be around 10 million tons each year. As per Akinloye *et al.*, (2014), guinea corn of 1.5 million is brought every year up in Nigeria alone. Be that as it may, debris acquired from the total consuming of guinea corn husk has been delegated Pozzolana containing basically 70% silica, alumina, and iron oxide the silica being generally in undefined structure, which can respond with $Ca(OH)_2$. (Medega *et al.*, 2014).

Table 2.2 Sorghum husk ash chemical composition

Chemical Composition	SiO_2	Fe_2O_3	Al_2O_3	MgO	SO_3	CaO	K_2O	Ph	LOI	SiO_2 $+Al_2O_3$ $+Fe_2O_3$
SHA	51.2	12.5	9.35	0.49	2.1	10.1	9.46	8.3	9.0	73.05

Source: (Ogunbode *et al.*, 2013)

3.4 Pozzolanic Materials

According to ASTM C125/C125M (2015), a siliceous or siliceous and aluminous material is alluded to as a pozzolan. This has almost no cementitious potential in itself except for can artificially respond with calcium hydroxide in finely isolated structure and within the sight of dampness at standard temperatures to shape compounds with cementitious properties. Pozzolan should be finely isolated and really at that time would silica be able to blend in with calcium hydroxide (fabricated by Portland concrete hydration) with water present to frame strong calcium silicates with cementitious properties (Wilson & Ding, 2007; Neville, 2012). As per a report by Neville (2012), the silica should be shapeless, or sparkling, since translucent silica has an exceptionally low reactivity. As indicated by a report by Duggal (2008), the name pozzolana was gotten from Pozzuoli, a town in a European city, Italy close to Mount Vesuvious on the Sound of Naples. At the point when sand (volcanic residue) from the space was joined with hydrated lime, cementitious properties were found. Pozzolan was blended in with lime to deliver concrete before the appearance of concrete, yet it is as yet used to substitute an extent of concrete in concrete. Moreover, following Edmeades and Hewlett (2006), pozzolana has two particular implications. The primary alludes to pyroclastic rocks that are essentially shiny and regularly zeolitized that can be found around Pozzuoli (the antiquated Puteoli of Roman occasions) or around Rome. Genuine and counterfeit pozzolanas are additionally high in silica and alumina, with simply a slight measure of soluble bases (Duggal, 2008). Volcanic magma, pumice, opalineshales, roasted dirt, and fly debris are instances of pozzolanic items. To be responsive, the silica in a pozzolana should be polished or indistinct. Volcanic debris is difficult to the touch, it very well may be red, orange, or dark in shading, and should not break up in water, profoundly rough, marginally destructive, and conducts power when it comes into contact with water. Pozzolanic materials can be ordered into two gatherings:

i. Artificial pozzolanas

ii Natural pozzolanas

i. Artificial pozzolans are for the most part results of warmth treatment of normal materials, and they are likewise materials with low pozzolanic movement that need extra medicines to accomplish pozzolanic action; they get from substance or underlying modifications of materials that initially had nearly nothing or just gentle pozzolanic properties; they are materials with low pozzolanic action that need extra medicines to accomplish pozzolanic action. (Ramezanianpour, 2014). Fly powder, Impact heater slag, Silica Smoke, Rice Husk debris, Guinea corn husk debris and Metakaolin are instances of Artificial pozzolans, as indicated by Shetty (2009).

ii. Natural pozzolanas has beginning in volcanic, with volcanic ash filling in as the genuine Pozzolan, as indicated by Neville (2012). Natural pozzolans as indicated by

Parhizkar *et al.* (2010), are regular materials containing responsive alumina or silica that have practically no limiting property all alone at the same time, when joined with Portland concrete and as lime is presented to daylight, it sets and solidifies like concrete. Regular pozzolans are partitioned into four gatherings relying upon the presence of the fundamental lime receptive constituent (Ramezanianpour, 2014). Volcanic tuff and pumice, unaltered volcanic glass, calcined earth or shale, and crude or calcinedopaline silica are the materials being referred to.

2.4.1 Standard specifications and test of pozzolans

According to (ASTM C 618, 2012), pozzolans are divided into different categories;

i. Class N: Regular pozzolans, calcined or crude, that meet the pertinent standards for the class as expressed here, which incorporates certain diatomaceous earths; shales and opalinecherts; calcined or uncalcined tuffs and pumicites or volcanic remains; and different materials, for example, muds and shales, expecting calcination to actuate good properties

ii. Class F: Fly ash shaped by the ignition of bitumious or anthacite coal that consents to the important rules for this class as presented thus. Pozzolanic properties are found in this sort of fly debris.

iii. Class C: The fly ash shaped normally from sub-bituminous or lignite coal that fulfills the important guidelines for this class as presented thus. This type of fly debris has pozzolanic and notwithstanding pozzolanic properties, cementitious properties exist.

To be delegated pozzolanic, a substance should meet the ASTM C618 (2012) physical and compound details referenced in Tables 2.3 and 2.4.

Tables 2.3 ASTM C618 (2012) Standard Chemical Requirement

Material contents	Mineral Admixture Class		
	N	F	C
$\Sigma SiO_2 + Al_2O_3 + Fe_2O_3$ min, %	70.0	70.0	50.0
SO_3 max, %	4.0	5.0	5.0
Moisture content	3.0	3.0	3.0
Loss on ignition, max, %	6.0	6.0	6.0

Source: ASTM C 618 (2012)

Tables 2.4 ASTM C618 (2012) Standard Physical Requirements

Material contents	Mineral Admixture Class		
	N	**F**	**C**
Fineness: Amount retained when wet-sieved on 45 µm (No. 325) sieve, max, %	34	34	34
Strength activity index: With Portland cement, at 7 days, min, percent of control	75C	75C	75C
With Portland cement, at 28 days, min, percent of control	75C	75C	75C
Water requirement, max, percent of control	115	105	105
Soundness: Autoclave expansion or contraction, max, %	0.8	0.8	0.8
Uniformity requirements: The density and fineness of individual samples shall not vary from the average established by the ten preceding tests, or by all preceding tests if the number is less than ten, by more than: Density, max variation from average, %	5	5	5
Percent retained on 45-µm (No. 325), max variation, percentage points from average	5	5	5

Source: ASTM C618 (2012)

2.4.2 Pozzolanic activity

As indicated by a report by Duggal (2008), when pozzolans are joined with common Portland concrete, the free lime consolidates with silica in the pozzolan created during concrete hydration, coming about in pozzolanic activity. The presence of finely partitioned shiny silica and lime causes pozzolanic activity, which brings about the arrangement of calcium silicate hydrate near that shaped during the hydration of Portland concrete. The silica in the pozzolan responds with the lime framed during Portland concrete hydration, adding to strength development. More hydrated calcium silicate is framed over the long run, which goes about as a folio and fills in the holes, giving impermeability, strength, and always expanding power.

The hydration of Portland cement can be expressed as follows:

$$C_3S + H_2O \longrightarrow \underset{\text{(Calcium silicate hydrate)}}{C\text{-}S\text{-}H} + \underset{\text{(Lime)}}{Ca(OH)_2} \tag{2.1}$$

Equation (2.1) shows how lime from equation (2.1) reacts with silica from pozzolana to form calcium silicate hydrate.

$$Ca(OH)_2 + \underset{\text{(Silica)}}{SiO_2} \longrightarrow \underset{\text{(Calcium silicate hydrate)}}{C\text{-}S\text{-}H} \tag{2.2}$$

The differentiation between dynamic pozzolanas and items with indistinguishable compound piece that have less pozzolanic activity is that formless silica responds with lime more promptly than translucent silica. Since pozzolanic action may just happen within the sight of water, adequate dampness should be made accessible for a lengthy timeframe to finish pozzolanic activity. While it is by and large accepted that the lime-silica response is the essential or one in particular that happens, new proof recommends that alumina and iron, if present, likewise take an interest in the substance response. (Dwivedi *et al.*, 2006; Duggal, 2008).

According to Massaza (2005), there is wide spread consensus on the following factors that influence the volume of combined lime:

• The essence of active phases

• In the pozzolan, their content

• The pozzolan's SiO_2 material

• The mixture's lime-to-pozzolan ratio, as well as

• The amount of time it takes to cure

• The rate of lime combination is also determined by;

• The pozzolan's specific surface area

• The water-to-solid percentage in the mixture

3.5 Sustainability and Environmental Benefits

Carbon dioxide (CO_2) discharges from OPC creation went from 5% to 10% of all out ozone depleting substance (GHG) outflows in the environment (Obada *et al.*, 2008). Subsequently, the World Business Chamber for Supportable Turn of events (WBCSD) proposed in 2002 that CO_2 outflows from concrete assembling tasks be decreased by 30% by 2020 and 60% by 2050. Concrete creation is plainly unreasonable at these measures of CO_2 contamination. These contamination issues are genuine; for each huge load of Portland concrete made, 1 to 1.25 huge loads of CO_2 is radiated into the environment by consuming carbon. Therefore, lessening OPC request diminishes CO_2 contamination into the air from concrete handling. Therefore, bringing down the OPC in concrete blends would bring about critical decreases in (GHG) discharges. Due to the huge measure of cement utilized every day all throughout the planet, the maintainability hypothesis for the utilization of Strengthening Cementitious Materials (SCMs, for example, pumice is that regardless of whether there is a slight decrease in OPC in concrete utilizations per ton of cement made, the subsequent ecological advantages are high (Altwair & Kabir, 2010). Accordingly, supplanting some measure of OPC brings CO_2 outflows down to the climate straightforwardly. Because of the use of SCMs, the weight of green gas outflows from cement calcinations can be decreased.

2.6 Findings on Studies Related to Using Recycled Plastic as Aggregate

Table 2.1 presents an outline of past investigations identified with utilizing reused plastic as aggregate in earlier years. It was seen that most investigation completed identified with utilizing reused plastic as aggregate is finished utilizing PET plastics as fine aggregate and in the creation of mortar. Not many investigations have been done on utilizing PET as coarse aggregate in substantial creation. From the accessible writing, it is by and by obvious that no particular elaborate examination on plastic total Valuable Cementitious Materials (SCC) substantial exists. Accordingly, it is exceptionally important to explore conceivable capability of utilizing PET as coarse total underway of cement containing agriculturally based pozzolan material. This is a fundamental need since the investigation is yet to be set up.

Table 2.5: Findings on studies related to using recycled plastic as aggregate

Author(s)/Date	Research Title	Objective(s)	Method	Findings	Remarks
Al-Manaseer and Dalal, (1997)	Concrete containing plastic aggregates	Determine the effect of plastic aggregates on the bulk density of concrete.	For this purpose, they made 12 concrete mixes with different w/c containing varying percentages (0%, 10%, 30%, and 50%) of plastic aggregates. Angular post-consumer plastic aggregates having a maximum size of 13 mm were used.	(i) bulk density of concrete decreased with the increase in plastic aggregates content; (ii) reduction in bulk density was directly proportional to the plastic aggregates content; and (iii) density of concrete was reduced by 2.5%, 6%, and 13% for concrete containing 10%, 30%, and 50% plastic aggregates, respectively. Reduction in density was attributed to the lower unit weight of the plastics.	Concrete density study
Kou *et al.* (2009)	Properties of lightweight aggregate concrete prepared with PVC granules derived from scraped PVC pipes	Investigate the fresh and hardened properties of lightweight aggregate concretes that are prepared with the use of recycled plastic waste sourced from scraped PVC pipes to replace river sand as fine aggregates.	Concrete mixes were tested, in which river sand was partially replaced by PVC plastic waste granules in percentages of 0%, 5%, 15%, 30% and 45% by volume.	Splitting tensile strength, 28-day values are 3.06, 2.89, 2.82, 2.58 and 1.83 MPa, respectively.	Used as fine aggregate
Rahmani et al. (2013)	On the mechanical properties of concrete containing waste PET	Investigated the effects of replacing 5%, 10% and 15% substitution		According to the authors, the flexural strength has an increasing trend at first when the amount of PET	15% of sand volume with

	particles	of sand with PET processed particles. To determine the effect of the percentage of sand replacement with PET on concrete flexural strength, some beam specimens with dimensions of 50 × 10 × 10 cm^3 were casted.		particles increases, but it reduces after a while. For example, the 5% replacement of sand volume with PET particles with w/c ratios of 0.42 and 0.54 shows 6.71% and 8.02% increase in flexural strength, respectively. However, 15% substitution of PET particles with w/c ratio of 0.42 and 0.54 yielded 14.7% and 6.25% reduction in the flexural strength, respectively. Also the study observed the effects of PET particles on tensile strength. By replacing	PET particles, the reduction occurred in tensile strength were 15.9% and 18.06%, respectively.
Marzouk *et al.* (2007)	Valorisation of post-consumer plastic waste in cementitious concrete composites	Reported the bulk density of cement mortar mixes prepared by replacing 0–100% in volume of sand by two different sizes of PET aggregates.	Reduction of bulk density remained small when the volume occupied by aggregates varies between 0% and 30%, regardless of their size. However, when this volume exceeded 50%, the composite bulk densities started to decrease until reaching a		

			value 1000 kg/ m^3.		
Ismail and Al-Hashmi, (2008)	Use of waste plastic in concrete mixture as aggregate replacement	Presented the possibility of using various plastic wastes, containing approximately 80% polyethylene and 20% polystyrene, as fine aggregates, up to 4.75 mm in concrete.	By increasing the plastic waste content, the compressive tests showed the tendency for compressive strength values of plastic waste concrete to decrease below the reference concrete at each curing age.	The concrete with 10% of plastic waste displayed the lowest compressive strength at 28 days curing age, about 30% lower than that of the reference concrete mixture. Also, the study found 5%, 7%, and 8.7% lower densities of concrete mix containing 10%, 15%, and 20% plastic aggregates respectively.	
Hannawi *et al.*,(2010)	Physical and mechanical properties of mortars containing PET and waste aggregates	Investigated the effect of using Non-biodegradable plastic aggregates made of polycarbonate (PC) and polyethylene terephthalate (PET) waste as partial replacement of natural aggregates in mortar.	Various volume fractions of sand 3%, 10%, 20% and 50% are replaced by the same volume of plastic.	According to authors the reduce in compressive strengths due to the addition of plastic aggregates can be attributed mainly to the poor bond between the matrix and plastic aggregates. The study presented the variations in the flexural strength of different mixtures as a function of the mixtures containing up to 10% of PET-aggregates and up to 20% of polycarbonate (PC) aggregates.	The study was on mortar. PET was used as fine aggregate
Akçaözoglu *et al.* (2010)	Physical and mechanical	carried out a study of using	Investigation was carried out on two	The authors found average values of flexural	The study was on mortar.

	properties of mortars containing PET and waste aggregates	shredded waste PET bottles as aggregate in lightweight concrete	groups of mortar samples, one made with only PET aggregates and, second made with PET and sand aggregates together.	strength similar to those of normal weight mortar.	
Frigione (2010)	Recycling of PET bottles as fine aggregate in concrete	Recycling of PET bottles as fine aggregate in concrete	By replacing 5% by weight of fine aggregate (natural sand) with an equal weight of PET aggregates manufactured from the waste un-washed PET bottles.	Specimens with different cement content and water/cement ratio were manufactured.	
Saikia and Brito, (2014)	Mechanical properties and abrasion behaviour of concrete containing shredded PET bottle waste as a partial substitution of natural aggregate"	Evaluate the effects of size and shape of recycled polyethylene terephthalate (PET) aggregate on the fresh and hardened properties. Three types of PET aggregate, collected from a plastic recycling plant, two were shredded and separated fractions of similar types of PET bottles and	Test results showed that density of fresh concrete decreased as the content of plastic aggregate increased. Differences in the size and shape of PET-aggregates affect the slump of fresh concrete mixes, which	The study also observed a reduction in the compressive strength of concrete due to the addition of PET-aggregates to replace natural aggregates. For 5% replacement the 28-day compressive is more than 75% of the compressive strength of reference concrete. For concrete with 10% and 15% plastic aggregate are respectively 71% and 59%. According to the authors, natural	PET is used a coarse aggregate

		one was a heat-treated product of the same PET bottles with sieve size from 0.5-11.2mm. 5%, 10% and 15% in volume of natural aggregate in the concrete mixes were replaced by an equal volume of three differently shaped and sized PET aggregates with deferent W/C ratios.	ultimately change the mechanical behavior.	aggregates and PET-aggregate cannot interact with cement paste and therefore the interfacial transition zone in concrete containing PET-aggregate is weaker than that in the reference concrete, which lowers the resulting compressive strength.	
Choi *et al.*,(2005)	Effects of waste PET bottles aggregate on the properties of concrete	Studied the effects of polyethylene terephthalate (PET) bottles lightweight aggregate (WPLA) on the density of concrete. Mixture proportions of concrete were planned so that the water/cement ratios were 45%, 49%, and 53%, and the replacement ratios of WPLA were 0%, 25%, 50%, and 75% by volume of	Splitting tensile strength of concrete mixtures decreased by 19%, 31%, and 54% with the increase in PET aggregates by 25%, 50%, and 75% respectively; and (ii) for a particular PET aggregate content, splitting tensile strength increased with the reduction in	The study presented the abrasion behaviour of concrete specimens (depth of wear and weight loss) containing various types and contents of PET-aggregate, and the reference concrete. In this paper, 5%, 10% and 15% in volume of natural aggregate in the concrete mixes were replaced by an equal volume of three differently shaped and sized PET-aggregates. According to the authors, the abrasion resistance of the concrete mixes with the various types of PET-aggregate is better than that of	The PET was used as fine aggregate

		fine aggregate. Density of concrete mixtures decreased with the increase in WPLA content.	w/cm ratio. Also the study investigated the effect of polyethylene terephthalate (PET) bottles lightweight aggregate (WPLA) on the modulus of elasticity of concrete. According to the authors, modulus of elasticity of concrete mixtures decreased with the increase in PET aggregates.	the normal concrete, also they found that the behaviour of the abrasion resistance of concrete arising from the incorporation of various types and contents of PET-aggregate suggests that this property depends on the compressive strength of concrete as well as on the properties of plastics.	

3.7 Concluding Remarks

The previous studies showed that lot of efforts have been done for investigating the effect of using waste/recycled plastic materials as a component in the concrete mix, but all of them are trying to confirm the situation and the relevant specifications in their local areas. Also, most studies are limited to using the conventional cement alone as the matrix. This research aims to implement a similar task but with applying the available locally used materials specially using PET plastic bottles as a coarse aggregate replacement and the use of SHA as cement replacement in achieving a light weight concrete.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

The materials used in the test programme included cement (CEM 1), natural coarse aggregate, river sand, water and recycled plastic (PET). The properties of this concrete constituent material are as follows:

3.1.1 Cement

Portland Cement type CEM II/A-LL, 42.5 N from Dangote Cement Company conforming to BS EN 197-1 (2011) and NIS 444-1 (2003) was used as main binder (PC) throughout the investigation. The cement was obtained from local cement merchant in Minna and effort was made to ensure that the supply is acquired from the most recent stock and kept in dry position.

3.1.2 Sorghum husk ash (SHA)

Sorghum Husk Ash (SHA) obtained from Sorghum husk used in this study was gotten from a farm waste dump in Wukara Village of Kyami District, FCT-Abuja, Nigeria. At first, the collected Sorghum Husk was treated by drying and screening to eliminate unwanted leaves and straw constituents. The treated Sorghum Husk were afterward burned in open air using a locally fabricated incinerator described in the literature (Abalaka & Okoli, 2013). The resulting Sorghum Husk Ash (SHA) was sieved to remove irrelevant and unburned carbon materials. Afterward, the ensuing SHA particles were ground to sizes below 150 µm using a local milling device. Finally, the pulverized ash was sieved to 75 µm particles to obtain the SHA used for the subsequent experiments. The SHA powder was white in colour, which was an indication of complete burning of all carbon and impurities within the husk.

The PC and SHA were then analysed under the X-Ray Florescence (XRF) analysis machine to determine their oxide composition.

3.1.3 Plastic (PET) Aggregate

In this research, shredded waste Polyethylene terephthalate (PET) bottles used was collected from Sarz Gen Enterprise, a waste plastic recycled plant, in Free Trade Zone, Sharada, Kano State, Nigeria. It was got by picking-up waste PET bottles and washing, then crushing into flakes by machines. The average maximum size of PET aggregate was 12.5 mm. The same standard procedure like natural aggregate was applied to conduct the properties of plastic aggregates according to the ASTM specifications such as specific gravity, unit weight, absorption, and sieve analysis. Figure 3.1 illustrates samples of PET waste after shredding.

Plate I: Shredded PET waste

3.1.4 Coarse aggregate

Locally available crushed granite stone was used in this study. The maximum nominal size of the coarse aggregate was 12.5 mm. The crushed granite was used at saturated surface dry conditions. Figure 3.2 shows samples of coarse natural aggregates that constitute the concrete mixes used throughout the experimental testing program for this research study.

Plate II: Crushed granite stone as coarse aggregate

3.1.5 Fine aggregate

River sand with maximum size of 4.75 mm was used in this study. The sand was used at saturated surface dry conditions. The grading of sand was measured according to ASTM C 33 (2019).

Plate III: River sand as fine aggregate

3.1.6 Super plasticizer

Master Rheobuild plasticizer is a polycarboxylic ether (PCE) polymer based Super plasticizer supplied by BASF Nigeria Limited. Master Rheobuild plasticizer was used as a high range water reducer and administered at constant concentration of 1.0% by weight of binder (bwob).

3.1.7 Water

Potable water available within the Concrete Laboratory of Department of Building, School of Environmental Technology, Federal University of Technology, Minna was used for mixing. The water is in conformity with BS EN 1008 (2015).

3.2 Methods

The work is mainly experimental and the approach adopted for the study are discussed under the following sub-heads; experimental plan, material analysis (physical and chemical) and mechanical properties.

3.2.1 Experimental plan

The study implemented the following experimental procedure in actualizing the study objectives as outlined in section 1.3 and thus fits into work plans with the details provided in the following subsections:

3.2.1.1 Work plan one

This is in line with objective one (1), which is concerned with studying the physiochemical properties of SHA, PC and other concrete constituent materials. This is the materials characterization stage (section 3.2.2.1) of the study. Procedure for determining the physical properties of the fine and coarse aggregates used were also discussed.

3.2.1.2 Work plan two

This is in line with objective two (2) which is mainly concerned with mix proportioning and fresh properties of SHA based light weight concrete with PET as partial replacement of coarse aggregate. Section 3.2.2 provides the procedure involved in this stage of study.

This involved making the requisite combination of the materials (PET and natural coarse aggregate) at the various proportion. The PET is varied in 4 stages (5%, 10%, 15% and 20%) while the cementitious material was included in two phases of 0% and 10%. The PC (CEM II 42.5 N) was used as control.

3.2.1.3 Work plan three

This involved determination of the optimum PET coarse aggregate to natural coarse aggregate replacement ratio, which produces the best SHA based light weight concrete strength properties (compression and splitting tensile). The procedure involve here is further discussed in Section 3.2.2.

i. Compressive strength test

ii. Splitting tensile strength test.

3.2.2 Experimental procedure

The work plans as outlined in Section 3.2.2 were handled with the following procedural stages adopted.

3.2.2.1 Material characterization

The material characterizations involved examination of both the chemical and physical properties of the constituent materials. The physical analysis done on the SHA is Particle Size Distribution analysis (PSD). The chemical analysis conducted on PC and SHA samples was done in the laboratory for Xray Fluorescent (XRF) analysis for determination of oxide composition in accordance to ASTM C618 (2015) using XRF analyzer connected to a computer system for data acquisition.

The physical properties of all the constituent materials were determined in the Building Laboratory of Federal University of Technology, Minna. The properties examined are the PSD by the sieve method for aggregates (both fine and coarse), the tests on cement (constituency, setting time and soundness) conducted on the binder combination. The procedure used for various physical properties are discussed in the subheads that follows:

a. Grading of particle size distribution (PSD)

This test operates on dividing a sample of aggregate into various fractions each consisting of particle of the same size. It was conducted to determine the PSD in a sample and was done mechanically with the sieve shaker and continued till such time that almost no particle size passes through in conformance with BS EN 933-1 (2012). PSD is the grading of aggregate into fractions with each containing particles of the same size (Neville, 2012)

b. Specific gravity test of binder and the aggregate used

The specific gravity of a material is the ratio of the weight of given volume of that material to the weight of an equal volume of water displaced. The apparatus that was used for the test include; pycnometer, trays, scoops, drying cloth, electrical weighing balance and measuring cylinder. The test was conducted in accordance to BS EN 1097-6 (2013). The calculated values of specific gravity of fine and coarse aggregates, alternative binders and cement are shown in Table 4.1. The data presented in an average of three results.

The formula implies:

$$G = \frac{M_2 - M_1}{(M_2 - M_1) - (M_3 - M_4)} \tag{3.1}$$

Where M_1 =mass of empty pycnometer,

M_2= mass of the pycnometer with dry sample

M_3= mass of the pycnometer and sample and water

M_4 = mass of pycnometer filled with water only.

G =Specific gravity of the sample.

c. Total moisture content determination

The test procedure for the evaluation of total moisture content is covered by ASTM C 566 (2013) called “total moisture of aggregate by drying” or otherwise called frying pan method.

$$\text{Moisture content } (\rho) = \frac{\text{initial weight of sample - dry weight of sample}}{\text{Dry weight of sample}} \times 100\% \qquad (3.2)$$

Where ρ = moisture content of sample, (%)

W= weight of original sample in stockpile condition. (g)

D= weight of oven-dry sample

d. Setting time of cement

The significance of this test is determination of the time setting of the hydraulic cement by vicat apparatus. The knowledge of the setting time of the cement is always helpful in deciding duration of mix, transport, place and compact the concrete effectively. We always prefer a high initial setting time so that we can mix, transport and place the concrete easily in accordance to ASTM C 191 (2013). The code specifies initial setting time of PC not to be less than 45 minutes but an initial setting time not less than 90 minutes is always preferred on the field. A smaller value of the final setting time is always preferred in order to avoid large expenditures in the formwork. According to most specifications, the final setting time is recommended not to be greater than 10hrs and bellow (90 + 1.3 X (initial setting time)) mins (Aggarwal & Pandey, 2018) as presented in Equation (3.3).

$$(90+1.2x \text{ (Initial setting time)) min} < \text{final setting time} < 10\text{hrs} \qquad (3.3)$$

In the setting process, very little chemical reaction takes place. It only includes the shape acquisition due to evaporation of water. During the setting process the cement remains in the fluid or the semi-fluid state and there is very little or no gain in strength. The finer the cement particles, the better the hydration and therefore it will lead to quick setting (Aïtcin, 2004)

Initial setting time of cement past is the time elapsed between the initial contact of cement and water and the time when 1mm² cross section needle gives a reading between 4-7 mm from the bottom in a standard Vicat apparatus.

The final setting time on the other hand is the time elapsed between the initial contact of cement and water and the time the time when the smaller needle (1mm² cross sections and 0.5 mm deep) completely penetrates into the paste and the outer metal attachment of 5mm diameter does not leave an impression on the cement paste.

e. Soundness of binder

Soundness test is the measure of the quality of binder with respect to expansion effect in conformance to BS EN 196 (2016). This was done within the temperature and humidity range of 27 ± 2°C and ± 5% respectively using the Le-Chatelier mould. It was done after the constituency test (ρ) was conducted to obtained water demanded to give a standard paste. The paste was prepared adding 0.78 ρ). The Le-Chatelier mould was oiled, place on an oiled glass sheet, filled with prepare binder paste and cover with another oiled glass sheet. The whole assembly was submerged in water at temperature range of 27 ± 2°C and kept for 24hours. The whole assembly was removed from water bath shown in plate 2 of appendix II and the distance separating indicator points measured to the nearest 0.5mm (L_1). The whole assembly was again submerged in water bath and the temperature of water bathe to boiling temperature in 25 to 30 minutes. It was kept at boiling temperature for a period of 3 hours.

After completion of 3 hours, the temperature is of the water bath was allow to cool down to room temperature and the whole assembly removed from the water bath. Distance between the two indicator points was measured to the nearest 0.5mm (L_2) with the results presented in Table 4.3.

The soundness of the cement paste was thereby calculated as follows:

Soundness (i.e expansion) of concrete paste = L_2- L_1

Where L_1 is measurement taken after 24 hours of immersion in water at 27 ± 2°C

L_2 = measurement taken after 3 hours of immersion in water at boiling temperature.

The means for duplicate sample calculated to the nearest 0.5mm gives the soundness value.

3.2.2.2 Mix proportions, sample preparation and testing methods

Normal concrete mix design with water binder ratio of 0.55 was adopted in conformance to requirement for mix proportioning for typical light weight concrete. CEM II with 10% of SHA content was used throughout as the control binder for concrete production. Light weight PET aggregate contents of 5%, 10%, 15% and 20% by volume of by weight of coarse aggregates (bwoac). The specimen prepared were 100 mm x 100 mm x 100 mm concrete cube for compressive strength, and 100 mm Ø x 200 mm high concrete cylinders for splitting tensile strength test. Triplicate samples were cast and cured in water bath for the varied curing age (7, 28 and 56 days) respectively before testing. M (1-5) signifies mixture without SHA content, while S (1-5) mixture is the concrete produces with 10% blended cement mix. The proportions of concrete mixtures are given in Table 4.7.

Table 3.1: The proportions of concrete mixtures by weight (%).

Mix ID	SHA (%)	PET (%)	SHA (kg/m^3)	CEM 1 (kg/m^3)	PET (kg/m^3)	Coarse Aggregate (kg/m^3)	Fine Aggregate (kg/m^3)	Water (kg/m^3)	SP (1%)
M1		0	0	404.26	0.00	1189.54	578.01	215.72	4.04
M2		5	0	404.26	59.48	1130.06	578.01	215.72	4.04
M3	0	10	0	404.26	118.95	1070.60	578.01	215.72	4.04
M4		15	0	404.26	178.43	1011.11	578.01	215.72	4.04
M5		20	0	404.26	237.91	951.63	578.01	215.72	4.04
S1		0	40.43	363.83	0.00	1189.54	578.01	215.72	4.04
S2		5	40.43	363.83	59.48	1130.06	578.01	215.72	4.04
S3	10	10	40.43	363.83	118.95	1070.60	578.01	215.72	4.04
S4		15	40.43	363.83	178.43	1011.11	578.01	215.72	4.04
S5		20	40.43	363.83	237.91	951.63	578.01	215.72	4.04

Cubical and cylindrical specimens with 100 x 100 x 100 mm and 100 x 200 mm dimensions respectively were prepared from fresh concrete mixtures. They were afterwards demoulded after 24 hours and immediately cured in water at 22 ± 2^{o}C for 7, 28 and 56 days (ASTM C192/C192M, 2007). The samples were tested for compressive strength and tensile strength. In addition, slump test and the fresh unit weights test was conducted on the fresh concrete mix in accordance with the British Standards (BS EN 12350-2 (2009). While the dry unit weights test, was conducted on the hardened specimen. The compressive and tensile strength values of concrete specimens were measured by using the test methods according to (BS EN 12390-3, 2009; ASTM C496/C496M, 2011). All testing measurements were obtained from three samples, and the average of three samples was presented and discussed in the study.

3.2.2.3 Specimen testing and data collation

The various test specimens were removed from curing tank and tested for density, compressive and splitting tensile strength in accordance with the respective codes (BS EN 12390-3, 2019) using the compressive testing machine (model No.JYS-2000A Class 1) available in the Concrete Laboratory of the Department of Building, Federal University of Technology, Minna. The records taken of force failure were thereby tabulated and presented.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Materials Characterisation

The characterization of the materials used in this study is discussed as physical and chemical properties in the following sub-sections.

4.1.1 Physical properties of constituent materials

4.1.1.1 Particle size distribution of SHA

Figure 4.1 presents the particle distribution of the SHA used in this study. This test is established in order to examine the fineness of the pulverized SHA used as a substitute to the PC. The SHA are categorized as fine pozzolan. The ash is described in terms of the fineness and particle size distribution curve of the pozolan, as shown in Figure 4.1. The distribution portrayed that the pozzolan examined in this study contained well-graded fine. More than 90% particle of ash passed through 150 µm sieve. This shows that the ash is suitable for use as an SCM.

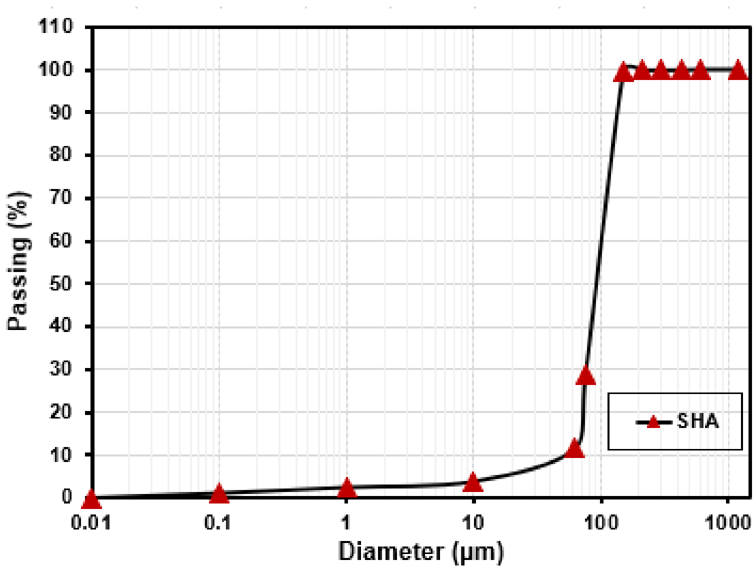

Figure 4.1 Particle distribution curve of the SHA

4.1.1.2 Chemical composition of SHA and PC

The result of the chemical analysis showing the chemical composition of SHA and Portland cement is presented in Table 4.1. The total combined content of silica, alumina and ferric oxides is 80.374%. ASTM C618 (2015) specifies that any pozzolana that will be used as a cement blender in concrete requires a minimum 70% of combined silica, alumina and ferric oxides. Hence SHA is very suitable as a pozzolana. Also, the very low SO_3 content of 1.02% is far from the maximum acceptable content of 5% specified in the same ASTM C618 (2015). The SiO_2 per cent composition of 60.25 is a high value. This quality has the potential of giving up the SHA as a better pozollana for concrete. It however exhibited that quality optimally at 10% replacement. PC on the other hand is majorly calcium oxide (CaO-65.0%). This agrees with oxides composition for CEM II Portland cement found in literature (Neville, 2012; Mehta & Monteiro, 2014).

Table 4.1: Chemical composition of Portland Cement (CEM 1) and Sorghum Husk Ash (SHA).

Oxides (%)	**NaO**	**MgO**	**Al_2O_3**	**SiO_2**	**P_2O_3**	**K_2O**	**CaO**	**TiO_2**	**MnO**	**Fe_2O_3**	**SO_3**	**LOI**
CEM 1	0.10	1.24	6.12	21.3	0.05	0.23	65.0	0.25	0.01	3.47	1.02	0.80
SHA	0.45	2.05	20.10	60.25	0.15	2.45	0.76	1.16	0.30	10.89	2.38	5.76

4.1.1.3 Results on physical properties of fine and coarse aggregates

Tables 4.2 and 4.3 summarize the physical properties of fine and coarse aggregates respectively.

Table 4.2: Physical Properties of Fine Aggregate

Properties	Fine aggregate	Maximum allowable value	Relevant reference
Material finer than 75µm	0.4%	3%	ASTM C33
Bulk density (unit weight)	1611kg/m^3	1600-1700kg/m^3	Kosmatka *et al.*, 2002
Void content	33.8%	40-50%	Kosmatka *et al.*, 2002
Specific gravity on Saturated Surface Dry (SSD)	2.64	2.40-3.00	Neville, 2011
Total evaporated moisture content	1.0%	0.05-0.80%	Neville, 2011

Table 4.2 shows that the fine aggregate used in this study complies with the appropriate requirements, as determined by ASTM C33 (2019), and other related review articles.

Fine aggregate had a nominal overall size of 4.75 mm and a fineness modulus of 2.40, respectively. The fineness modulus of fine aggregate is usually between 2.4 and 3.2. Fine aggregate's fineness modulus indicates that it is ideal for concrete work. This is because aggregate that meets the ASTM C33 (2019) grading limit normally produces concrete that is strong and durable. A well-graded aggregate reduces the need for water and superplasticizer, resulting in improved concrete strength and workability.

The oven dry bulk density was 1635 kg/m^3 for compacted and 1392 kg/m^3 for uncompacted bulk density. This is in line with the findings of the survey (Kosmatka *et al.,* 2002). According to Kosmatka *et al.,* (2002), coarse aggregate bulk density ranges from 1200 to 1750 kg/m^3. On an oven dry basis bulk density basis, the void volume of coarse aggregate foundation was 40%. As a consequence, the measured void content is an average approximation of the void percentage between rodded aggregates.

Table 4.3: Physical Properties of Coarse Aggregate

Property	Test value	Maximum allowable value (%)	Relevant Reference
Material finer than 75µm	0.8%	1%	ASTM C33
Bulk density (Unit weight)	1635kg/m^3	1200-1750kg/m^3	Kosmatka, *et al.*, 2002
Void Content		30-45%	Kosmatka, *et al.*, 2002
Specific Gravity on saturated surface dry(SSD)	2.67	2.40-2.90	Neville, 2011
Total evaporated moisture content	0.65%	0.5-4.50%	Neville, 2011

The void content of coarse aggregate varies from 30 to 45 per cent, and the specific gravity on a saturated dry basis was 2.61, which was considered acceptable since most natural aggregates have a specific gravity of 2.4 to 2.9. Table 4.3 shows that the coarse aggregate used in this analysis satisfies the normal criteria and is thus suitable for use.

4.1.1.4 Results on physical properties of PET coarse aggregates

The experimental results of the PET plastic coarse aggregate properties are presented in Table 4.4.

Table 4.4: Properties of PET coarse aggregate

Physical property	Value
Specific gravity	1.221
Absorption %	0.01
Unit weight (kg/m^3)	592

The sieve analysis of plastic PET coarse aggregate was carried out by using a series of sieves. As natural aggregate, ASTM C136 procedure was used to determine the sieve analysis of coarse plastic PET aggregate. Table 4.5 illustrated the sieve grading of the plastic aggregate.

Table 4.5: Sieve analysis of PET Aggregate

Sieve Size (mm)	% Passing
25	100
19	100
12.5	96.43
9.5	72.69
4.75	68.65
2.36	24.92

4.2 Fresh Properties of the Binders and Light Weight Concrete Composite (LWCC)

The fresh properties result on binder and the LWCC specimen (Table 4.6) are discussed in this section. The water demanded for consistent paste of the binder (containing 10% SHA) was found to be 95 ml at 48 mm depth of penetration while the initial and final setting times are 115 mins and 230mins respectively. The soundness of the binder paste gave a 3.50 mm expansion which also is well below the 10 mm maximum stipulated by BS EN 206-1 (2015).

Table 4.6: Fresh Properties of the Binders

Test	Consistency			Setting Time		Soundness		
Trial Mix	Wt. of Binder (g)	Vol. of water (ml)	Depth of penetration (mm)	Initial (mins)	Final (mins)	Before Boiling (L1) (mm)	After Boiling (L2) (mm)	Expansion (L2-L1) (mm)
1	300	90	21	90	244	10.00	13.50	3.50
2	300	93	33	105	240	10.50	13.00	2.50
3	300	95	48	115	230	Av. Soundness		3.00

4.2.1 Slump and wet unit weight

The fresh unit weights of M1-M5 and S1-S5 where M1 is mix without SHA and PET and S1 is mix containing 10% SHA and 0% PET which are the control samples. The mix proportions were presented in Table 4.7.

The relationship between the workability (slump) and the percentage replacement of the PET aggregate is displayed in Table 4.7. The slump value of both PET concrete containing 10% SHA by weight of cement and without SHA declines as the percentage replacement of the PET aggregate rises, as revealed in Table 4.7. The declining ratios of workability indicate 89.5%, and 94.7% in comparison with that of normal concrete at the percentage cement replacement ratio of 0%, and 10%, respectively. This may be attributed to not only the smooth shape of the PET but also to the absorption and hydrophilic property of SHA. The workability reduction experienced by the light weight concrete is due to the large surface area of the ash and the smooth surface of the PET. PET and SHA is capable of reducing the unit water content and the water-reducing agent content. It is expected that the reduction of the unit water content could compensate for the strength reduction of the PET/SHA concrete in the case of manufacturing the concrete with the same slump.

Table 4.7: Fresh Unit weight and Slump (mm) of concrete produced.

Mix ID	SHA (%)	PET (%)	Fresh Unit weight (kg/m^3)	Slump (mm)
M1		0	2383.98	95
M2		5	1915.72	60
M3	0	10	1884.19	50
M4		15	1855.44	35
M5		20	1821.28	10
S1		0	2316.23	80
S2		5	1896.84	55
S3	10	10	1853.39	45
S4		15	1818.22	25
S5		20	1781.74	5

4.3 Hardened Properties of PET-LWCC containing SHA

4.3.1 Dry unit weight

Measured dry unit weights of concrete specimens at 7, 28 and 56 days are presented in Table 4.8. The dry unit weights of all specimens decreased in course of time due to the evaporation of free water and as the due to the increase in percentage of the PET in concrete due to the increase of the pore structure. The dry unit weight at 28 days hydration period values of PET concrete without SHA (M1-M5) and (S1-S2) containing 10% SHA were between 1138 m^3 and 2243 kg/m^3. The unit weight of S1-S2 is lower than the unit weight of M1-M5. Since the specific gravity of SHA was lower than CEM 1 cement as the binder, the dry unit weights of the PET concrete made with SHA (S1-S5) were lower than the concrete without SHA (M1-M5) serving as the control sample. ACI Committee also opined that the air-dry unit weight of a structural lightweight concrete should be lower than 1850 kg/m^3 (ACI Committee 213R, 1987). The air-dry unit weights of the PET concrete containing SHA presented in Table 4.8 was lower than 1850 kg/m^3; in other words, they complied with the above definition in terms of unit weight.

Table 4.8: Dry Unit weight (kg/m^3) of concrete produced

Mix ID	SHA (%)	PET (%)	Dry Unit weight (kg/m^3)		
			7	28	56
M1	0	0	2254	2243	2201
M2		5	2085	1831	1839
M3		10	1965	1810	1847
M4		15	1792	1744	1656
M5		20	1557	1503	1453
S1	10	0	2174	2115	2046
S2		5	1847	1808	1745
S3		10	1802	1766	1662
S4		15	1744	1482	1384
S5		20	1254	1138	1058

4.3.2 Compressive strength

Structural lightweight concrete is defined by ACI Committee, as the concrete with compressive strength of 28 days, which is higher than 15–17 N/mm^2. The compressive strength values of concrete measured in the laboratory are presented in Table 4.9. Table 4.9 shows that the compressive strength values at 28 days of the concrete specimens were quite higher than 17 N/mm^2. When the unit weight and compressive strength values are considered together, M1-M5 and S1-S5 mixtures can be classified as a structural lightweight concrete

The 28 days compressive strength values of the mixtures containing only PET aggregates (M2-M5) were 33.28, 29.55, 26.27 and 23.40 N/mm^2. These values reached 36.76, 32.22, 30.48, 25.91 N/mm^2 at 56 days, respectively (Table 4.9). The compressive strengths of S2-S5 mixtures (including PET and SHA together) were 32.90, 26.50, 25.98 and 21.33 N/mm^2 at 28 days. At 56 days, their levels raised to 37.93, 34.11, 31.87 and 27.11 N/mm^2, respectively (Table 4.10). It was seen from these results that, the compressive strengths of the mixtures containing 10% SHA and varying percentage replacement of PET together were higher than the mixtures containing varying percentage replacement of PET without SHA at 56-day hydration period. This was an expected result. Nonetheless, the compressive strength values of PET aggregates with SHA blends (S2–S5) were found to be suitable. The compressive strength values of typical control normal weight concrete mixture (M1) which is set for evaluation purposes were 18.43, 32.54 and 34.35 N/mm^2 at 7, 28 and 56 days, respectively (Table 4.9).

Table 4.9: Compressive strength (N/mm^2) of concrete produced

Mix ID	SHA (%)	PET (%)	Compressive Strength (N/mm^2)		
			7	28	56
M1		0	18.43	32.54	34.35
M2		5	16.84	33.28	36.76
M3	0	10	14.65	29.55	32.22
M4		15	12.91	26.27	30.48
M5		20	10.44	23.40	25.91
S1		0	14.44	31.20	34.96
S2		5	13.22	32.90	37.93
S3	10	10	11,39	26.50	34.11
S4		15	10.16	25.98	31.87
S5		20	8.49	21.33	27.11

It can be seen from Table 4.9 that the compressive strengths of concrete produced in this investigation developed rapidly at an early age up to 28 days, however, after 28 days the speed of compressive strength developments slowed down in long term (56 days). This result was found to be similar to the strength development of normal weight mortar. It can be observed from Table 4.9 that, in general, the compressive strength of the concrete modified with SHA as cement replacement corresponding in pattern with the compressive strength of the cement concrete at 7 and 28 days. After that, they passed the compressive strength of concrete made with only cement as the binder. Replacement of cement with SHA increased the compressive strength of concrete when compared to strength of concrete made with cement only especially at 56 days. This could be seen from Table 4.10 that strengths development of S2 to S5 was better than the strength developments of M2 to M5 for concrete with age 56 days. It was explained in the literature that, the strength of concrete modified with Supplementary Cementitious Materials (SCMs) as cement replacement was lower than the strength of CEM II concrete at early ages (Semiha *et al.,* 2010). However, when it was cured adequately, its strength could be equivalent or higher than the control concrete in long term (Fernandez & Malhotra, 1990; Yeau & Kim, 2005; Bilim, 2006; Yazici *et al.,* 2006; Oner & Akyuz, 2007). The result observed in this study for SHA concrete was found to be in-agreement with the literature.

4.3.3 Splitting tensile strength

The effect of substituting granite aggregate with waste PET bottle flakes at varying percentage in CEM II concrete and SHA based concrete is presented in Table 4.10.

Table 4.10: Tensile Strength (N/mm^2) of concrete produced

Mix ID	**SHA (%)**	**PET (%)**	**Tensile Strength (N/mm^2)**		
			7	**28**	**56**
M1		0	2.05	3.85	3.98
M2		5	1.46	3.73	3.88
M3	0	10	1.36	3.34	3.57
M4		15	1.12	2.91	3.37
M5		20	0.73	2.39	3.13
S1		0	1.69	3.70	4.18
S2		5	1.25	3.56	3.94
S3	10	10	1.12	3.38	3.74
S4		15	0.71	3.22	3.62
S5		20	0.34	3.04	3.44

As illustrated in Table 4.10, the general trend of tensile strength is decreasing when the amount of PET particles increases. For instance, both concrete mix without SHA (M2-M5) and concrete mix with 10% SHA, reduction occurred in tensile strength. This can be attributed to the negative effect of the smooth surface texture of the PET flakes on the bond strength between the PET, matrix and the aggregates. The increase surface area of PET particles compare to granite coarse aggregate is also a factor to consider. In addition, as the PET ratio increases, the reduction in splitting tensile strength is more significant. The observed behavior is in consonance with a similar study by Adela *et al*. (2020).

CHAPTER FIVE

CONCLUSION AND RECOMEDATIONS

5.1 Conclusion

Concrete containing only PET aggregate and concrete modified with SHA as cement replacement produced in this study fall into structural lightweight concrete category. The use of SHA reduced the slump and both wet and dry unit weight of the specimens. It also increased the compressive and tensile strength of the samples at later ages (56 days). The compressive and tensile strength values of the concrete containing PET and SHA together were higher than the concrete containing only PET aggregates. Based on the experimental study, the use of shredded waste PET flakes in concrete has a potential to reduce the dead weight of concrete, thus, can reduce the earthquake risk of a building, and it could be helpful in the design of an earthquake resistant building. The usage of industrial and agricultural wastes such as shredded waste PET flakes and SHA in concrete production would be helpful and resourceful in solving a part of the world present day environmental concern, in reduction and recycling plastic waste which has become a menace to the environment and also for achieving a cleaner environment and reduce the depletion of the ozone layer and energy saving.

5.2 Recommendations

Based on the finding in this research work, the following is recommended;

1. The recycled PET can be used in concrete mixes as aggregate with 5% PET aggregate ratio without large reduction in compressive strength.
2. Despite the percent replacement of PET to coarse aggregate is low, utilizing waste plastics in the concrete mix would help countries with the weak waste management system.

3. PET aggregate concrete containing SHA is recommended for Light Weight Concrete production.

5.3 Area for further study

1. The influences of the addition of super plasticizers on the mechanical property of PET aggregate concrete mixes containing SHA need to be studied in detail.
2. The effect of different W/C ratios on the mechanical property of concrete with recycled plastic aggregate need to further research.
3. Other studies are encouraged to obtain the effect of using different percent of PET plastic bottles in nonstructural elements.

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APPENDICES

Plate 1: PET

Plate 2: Blending PET and fine aggregate

Plate 3: Plastic PET concrete mix

Plate 4: Superplasticizer

Plate 5: Coarse aggregate

Plate 6: PVC cylinder mould

Plate 7: Superplasticizer

Plate 8: Superplasticizer

Plate 9: Plain concrete cube under compression machine

Plate 10: 5% PET concrete cube under compression machine

Plate 11: Failure mode of concrete cube under compression machine

Plate 12: Operational procedure of splitting tensile test

Plate 13: Failure mode of 5% PET concrete cylinder specimen

Plate 14: Failure mode of PET concrete cylinder specimen

Plate 15: Plain and PET concrete cylinder specimen

Plate 16: Plain and PET concrete cube specimen

Plate 17: Initial and final setting time test

Plate 18: Soundness test in progress

Plate 19: fresh concrete in cube formwork

Plate 20: fresh concrete in cylinder mould

Plate 21: Concrete testing in progress

Plate 22: Demoulding of concrete samples from mould