The Impact of Low Density Polyethylene (water sachets) on the Mechanical Property of Cement Mortar

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Abstract

Many building collapsed cases have been reported throughout the West African regions. It is recorded that during some of these subsidences, many lives are lost and the vast majority end up in hospitals and clinics with huge loss in investments also. This poses a major challenge to the health and wellbeing of the human race. Overwhelming facts of poor workmanship, engineering fault and poor maintenance have been highlighted as major factors. On the other hand, most research has shown that a huge accumulation of these problems is due to the fact that there is a bias in the mechanical properties of the type of concrete material used. Some focus on high strength, not toughness; others on high toughness not strength. In other instances, people produce low quality to minimize cost and maximize profit which result in these catastrophes. This current research explores incorporating low density polyethylene (LDPE) waste into cement mortar to improve its fracture toughness with balanced compressive strength. Furthermore, this will minimize some common environmental problems in the contemporary world associated with the disposal of these LDPE waste and alleviate issues posted due to its non-biodegradable nature. Different volume fractions (0, 5, 10, 15, 20, 30, and 40%) of the powdered LDPE were used to mix with the cement while the density, compressive strength, flexural strength, and the fracture toughness were observed under different testing conditions. All specimens were tested after curing of 7, 14, and 28 days. The results show that there is 6.12% increase in the fracture toughness at 5%, 6.88% increase at 10%, and 24% increase at 20%. Also, it was observed that the weight and compressive strength decreased with increasing volume fraction of the LDPE waste.

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DEDICATION

With love and passion,

This research work is particularly dedicated to God Almighty who kept me strong throughout and to my loving daughter Mosetta Keraline Bindu Flomo, my heart beat, ever-potent parent Mr. and Mrs. Nyanquoi Flomo and uncle, Brahama Kroma Siaffa for been the people I always look up to in times of difficulties.

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Chapter One

1.1 Background and Introduction

Building collapses have posted major challenges and threats to the health and wellbeing of the human race. Over time, major damages have been reported resulting in expansive loss of huge investments in housing, properties. Many people lose their lives during the incidence. In most cases, people have sleepless nights and state of unrest. The world is, however, relatively unstable as a result of the geometrical order of population growth, urban development in coastal areas, poor planning and housing developments in high risk areas of cities [1].

Furthermore, engineers throughout the West Africa have shown that building collapses occurs to a diversity of factors [2]. Some attribute these factors to the employment of incompetent artisans [3] and weak work supervision of workmen at building sites. Others also believe that the cause is due to endemic poor work ethics and non-enforcement of existing laws [2] [3]. Research done by Oluwunmi et al [4] showed that cases of building collapse are not restricted by climatology or level of urbanization as they cut across cultural and ethnical barriers**.** For instance, as part of the cases aside climatic condition, Folagbade and Chinwokwo [2] [5] enumerated forty-two (42) cases of building collapse as occurring in Nigeria between 1980 and 1999, while Makinde listed fifty-four (54) cases occurring between January 2000 and June 2007 alone [6]. Additionally, other main causes and major challenges have being attributed to non-compliance with specifications standards use of sub-standard building materials and equipment [2] [5]. In line with this non-compliance or use of sub-standard material, the quality of cement used in concrete construction plays major a role. Furthermore, concrete ability to withstand certain loads has significant impact on its durability. There is, therefore a need to investigate the quality of materials used in making the concrete for construction in the West African region [7].

If most undeveloped countries in West Africa should meet the standards of developing countries, then social, economic and infrastructural development play key roles. This vision is very important for governments that are investing in infrastructural development, such as local houses, storey buildings, sky scrapers, durable rail ways, bridges, etc. The key factor in achieving these objectives is to make sure that the structures are sustainable and robust, so that inhabitants' lives are secure and the investments are guaranteed. However, there are some concerns about the cost of concrete relative to earth-based building materials [8]. There is also a need to explore ways of recycling waste into building materials [9].

Thus, this thesis presents the result of an effort to recycle low density polyethylene sachet bags into building blocks for affordable housing. The blocks are produced by mixing polyethylene granules (produced by the processing of LDPE plastic bags) with cement and sand to produce cement/ polyethylene composites with attractive combinations of strength and fracture toughness.

1.2 Problem Statement and Scope of Research

Concrete forms the basis for most construction in our contemporary world. It is a major construction material that is commonly used in construction [7] work and constitutes at least about 40% of the total works [8]. Henceforth, concrete is considered to be the widely used materials in the construction industry which serve diversity of purpose.

Cement and aggregates, which are the most indispensable constituents used in concrete production are also vital materials that are needed by the construction industry [10].

However, the high cost of cement plays vital role in current poor construction practices, this leads to majority of the major challenges faced with buildings collapses. This high cost of cement has barricaded infrastructural development across most part of Africa. As a result, the overwhelming majority become victims of disasters. People rather live in huts, mud houses, etc. rather than in concrete buildings, since they cannot afford buying cement because of its high cost. Consequently, most regions across West Africa still remain underdeveloped infrastructural. Poor housing facilities, unequipped medical centers, discarded school buildings, poor road networks and sub-standard governmental buildings become normal under such circumstances. Furthermore, the cost of affording sustainable building materials has become a major hindrance to development. The unaffordability of such materials has made it more difficult for most people to afford sustainable housing For example; the price of Portland cement has become too expensive for an average person to afford buying to build a house.

Also, in recent years, engineers have become interested in replacing/ substituting concrete with waste materials [10]. These include: agricultural waste, [11] industrial waste such as furnace slags, [12] car tires [13] and other waste materials [14]

Such applications have been considered as alternative strategies for the management of waste materials in the developing world [15]. In the case of polyethylene, LDPE sachets bags are often used to package “pure” water, there is the potential to recycle them into building blocks that are used in alternative housing [7].

1.3 Scope of work

This will be explored in this study using LDPE powder produced by dissolving LDPE in a solvent prior to freezing in an ice bath. The resulting LDPE powders and granules will then be sieved and mixed with cement, sand and water to produce polyethylene-reinforced concrete mortar for building blocks. The strength and fracture toughness/resistance-curve behavior of the composites will then be studied using a combination of experiments and models. The implication of the rebuilding blocks will then be discussed for design of strong and tough cement composites for building blocks. The thesis is divided into 6 Sections. Following the introduction, the literature review will be presented in section 2. This will be followed by Section 3 in which the experimental methods will be described. The models for the prediction of strength and fracture toughness will be discussed in Section 4 before presenting the results and discussion in Section 5. Salient conclusions arising from the work will be presented in Section 6.

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Chapter Two

2.0 Literature Review

2.1 Introduction

There is global interest in the use of waste (particularly plastics) in building material **[1].** The commonly used of these waste plastic (low linear density polyethylene and low density polyethylene) has unique properties that makes it significant for construction purposes.

	LDPE	HDPE	LLDPE
World	23.3	25.5	7.4
Europe	6.7	5.1	1.1
US	3.5	6.5	2.8
Russia		Total 1.41	
Middle East	1.9		
China	3.5	1.4	1.6
Rest of Asia	4.3	6.4	1.8

Table 2. 1 Shows the annual production of poly (ethene) /million tons [1]

Data from: 1.Federal State Statistics Service: Russian Federation 2011

2.2.1 Properties of low density polyethylene

Low density polyethylene has quite interesting properties that can be merged with some other properties of concrete to achieve a desired design in construction. LDPE is the first of the polyolefin family [1]. Process of producing LDPE is under very high pressure (1000-3000 atm) at moderate temperatures (420-570 K) as may be predicted from the reaction equation:

$$nC_2H_4 \rightarrow [-CH_2 - CH_2 -]n \ \triangle H^P = -92kJmol^{-1} \rightarrow \text{Eqn 2.1}$$

This is a radical polymerization process and an initiator, such as a small amount of oxygen, and/or organic peroxide is used [2].

Properties of low density polyethylene	
Density	0.92 g/cm^3 (57 lb/ft^3)
Young modulus	0.3 GPa (0.04 x 10^6 psi)
Degree of crystallinity	50%
Hardness	SD55
Melt Temperature	120^{0}C
Tensile strength(UTS)	7 MPa (1.0 x 10^3 psi)
Shear Modulus	0.21 GPa (0.03 10^6 psi)
Specific Heat Capacity	2300 J/kg-K
Thermal Conductivity	0.36 W/m-K
Shear Modulus	0.21 GPa (0.03 10^6 psi)

Table 2. 2: Below Illustrates some of the Major Properties of LDPE

Additionally, there are about 20 branches per 1000 carbon atoms. The relative molecular mass, and the branching, influence the physical properties of LDPE. The branching affects the degree of crystallinity which in turn affects the density of the material. The branches prevent the molecules fitting closely together and so it has low density [2]. LDPE is generally amorphous, transparent and robust enough to be virtually unbreakable and at the same time quite flexible [2]. Chemically, LDPE is unreactive at room temperature, although it is slowly attacked by strong oxidizing agents and some solvents will cause softening or swelling. It may be used at temperatures up to 95° Celsius for short period and at 80° Celsius continuously.

2.2.2 Applications of LDPE in Construction

Scientists and engineers have developed great interest in waste recycling in this 21st century because of their negative impact on the environment [3]. Low density polyethylene has become the main recycled waste because of its unique material properties. LDPE was used in asphalt cement, to study its effect on the physical properties of the asphalt concrete [4]. The polymer was at to the binder at different percentage (0%, 1%, 2%, 3%, 4%, 5%, 6%, and 7%). The result shows that increasing the LDPE percentage increases the hardness of the asphaltic cement. However, reinforcement with (1%) LDPE reduce the hardness of the asphaltic cement. Also, Increasing the LDPE percentage decreases the susceptibility of asphalt cement temperature and at (1%) of LDPE, the asphaltic cement lower susceptibility; and increasing the LDPE percentage increase the stiffness binder of the asphalt cement except at (1%) the asphalt cement becomes lower in stiffness.

Similarly, reclaimed low density polyethylene (LDPE) from carry bags of goods was used for modification asphalt mixture performance as fatigue life, resilient modulus, resistance to moisture susceptibility, in addition to marshal characteristics [5]. Likewise, polyethylene used as an additive to achieve asphalt concrete of much higher stability and lower thermal susceptibility [6].The author concluded that by adding polyethylene "PE" in small percent reduce penetration, raised the softening point and increased the shear strength of asphalt joints.

Additionally, it was found that the additive of polyethylene and chlorinated polyethylene to asphalt binders does significantly increase their low temperature fracture toughness and fracture energy [7].Further to that, polymer was in cement to study its influence on hydration in SBR-modified cement pastes [8]. The results of DSC and XRD show that the $Ca(OH)_2$ content in wet-cured SBR-modified cement pastes increases with polymer–cement ratio (P/C) and reaches a maximum when P/C is 5%, 10% and 10% for the pastes hydrated for 3 days, 7 days and 28 days, respectively. These results show that polyethylene has served the construction industry in different ways.

2.2.3 Impact of LDPE on Mechanical Properties of Concrete

Several authors have also reported on the strengths of plastic concrete. Research has shown that increase in plastic aggregate content reduces the strengths of plastic concrete [9]. The author mentioned that the incorporation of ground plastic in concrete had effect on its compressive strength. The compressive strength was reduced by about 23%, 35%, 50%, and 71% when fine aggregates of 5%, 10%, 15%, and 20%, respectively, were substituted with plastic.

In addition to this, the effect of post-consumer waste plastic in concrete as a soft filer was scrutinized [10]. The test results showed that lowering the compressive strengths of the mix made with plastic than the reference mixture without plastic. Furthermore, some researchers also noticed a reduction in both compressive strength and splitting tensile strength [11]. The compressive strength was lowered by 33% when compared to that of normal concrete. For the splitting tensile strength, increased in plastic content resulted in its reduction, regardless of the water cement ratio used. Further report displayed a reduction of compressive strength in plastic concrete when the sand was replaced by plastic [12]. Again, Al Manasser and Dalai [13] observed that the splitting tensile strength decreased as the plastic content increased**.** Batayneh and others also reported that the splitting tensile strength and the flexural strength of concrete mix reduced as the plastic content went up [9]. The splitting tensile strength was lowered by about 56% when 20% of the aggregate content was replaced by plastic. The flexural strength was also decreased by about 40% when 15% of the aggregate was substituted with plastic.

Additionally, the impact of waste on concrete was also investigated and the result explained that the compressive, split and flexural strength of concrete containing the waste plastic LDPE shows increasing indication [14]. Kandasamy and Murugesan added 0.5% by volume of polythene (domestic waste polythene bags) fibre to concrete and the cube compressive strength, increased by 5.12%, 3.84% and 1.63% respectively [15]. Ismail and Al-Hashmi [16] observed that the mixture of iron filings and plastic waste materials could be used successfully as partial substitutes for sand in concrete composites.

Moreover, the effect of the irregular surface of the crushed concrete on the properties of the concrete mixes was studied by Wilson [17].

2.2.4 Some Fracture Mechanics and Toughening Approach of Concrete

Despite the fact that concrete or mortar materials are brittle and fail under certain loading conditions, lots of research has been made to find out how their britility can be improved.

J.D. BRESSAN et al (2010) used ash solid waste as fly ash from the coal powder combustion in thermoelectric power plant in the mixture of structural concrete for enhanced mechanical properties. From the experimental results showed that about the replacement of 10% in mass of cement with fly ash in concrete: the compression strength was 46.0 MPa and the flexural strength was 5.2 MPa, indicating a high strength concrete. Fracture toughness was 1.25 $MPa.m^{1/2}$. Thus, it was possible to add class F fly ash to concrete [18].

Additionally, in the literature, various authors [19] have reported that in fact, the effect of sand partial replacement with fly ash is to increase the mechanical properties of concrete. Siddique

[18] has shown that the substitution of 10%, 20%, 30% and 50% of sand by class F fly ash from a thermoelectric has raised the compressive and flexural strengths of concrete in all test ages. The increase in compressive strength was linear with the fly ash content. At all ages, the maximum strength value occurred with 50% fly ash content. Compressive and flexural strengths have increased respectively from 26.4 MPa and 3.7 MPa for zero fly ash content up to 40 MPa and 4.3 MPa at age 28 days.

Alam R. et al (2010) experimentally and numerically determined the fracture toughness of plain concrete specimens made with industry-burnt brick aggregates [20]. The result showed that the variation of fracture toughness with respect to pre-crack depths, starting at 30% of beam depth and extending to 50 % of beam depth, was not found to be significant in both experimental and numerical studies. Fracture toughness values were found to lie between 0.451 to 0.658 MPa.m1/2 (mean value 0.540 ± 0.051 MPa.m1/2) for plain concrete specimens made with brick aggregates and 0.70 MPa.m1/2 to 0.93 MPa.m1/2 (mean value 0.807 ± 0.083 MPa.m1/2) for plain concrete specimens made with stone aggregates. Fracture toughness values obtained from FE analysis of the same specimens were found to be very close to the experimental results. Maximum variation in fracture toughness values between experimental and numerical studies was found to be less than 4.0%.

Furthermore, Rafat (2008) [21] The test results indicated that the replacement of cement with fly ash decreased the compressive strength and fracture toughness, and had no significant effect on the impact strength of plain (control) concrete. Addition of san fibers did not affect significantly the compressive strength, increased the fracture toughness and impact strength of high-volume fly ash concrete as the percentage of fibers increased.

However, there have been few studies designed to provide fundamental insights into the strengthening and toughening mechanisms in polyethylene-reinforced concrete. This will be studied in the work using recycled LDPE powder-reinforced cement for mortars. The implication of the work will also be discussed for design of affordable housing.

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Chapter 3

3.0 Materials and Experimental Method

3.1 Introduction

This section describes a general overview of materials used and the experimental processes of this research; beginning from how the powder that partially replaced certain percentage of the sand component was formed, the different mix ratio of the cement, sand, water and the linear density polyethylene powder. It furthers described the different standard used for the mixing.

3.2.1 Production of Cement Mortar

Since this work laid major emphasis on how to produce mechanically stable cement mortar for sustainable building application, fundamental and standard procedures were used to produce the powder for the mixing, the appropriate quantities of all materials for the various specimens.

All the fundamental steps are discussed in the next sub sections below presented in this chapter.

3.2.2 Materials for the Powder Production

The materials used to produce the powder from the waste water sachet were as follows: kerosene, acetone, waste water sachet, hot plate, ice block, mortar and pencil, sieve of size 2mm, beaker.

Figure 3. 1 Samples of the Materials used to produce the Powder for the Concrete Mortar

3.2.3 Materials/equipment used for the production of cement mortar

The basic materials used for the production of the cement mortar include: Dangote 3X cement, sand, and water, powder from water sachet, mortar machines, and stopwatch, mold. Figure 3.2 below shows sample of the materials used.

Figure 3. 2 Samples of Materials for Cement Mortar

Analysis	**Types of aggregate**	
	Sand	**powder**
Specific gravity	**2.66**	**1.04**
Density(kg/m^3)	**1080**	**640**
Water absorption	**1.0%**	**0.00**
Moisture content	**1%**	**0.00**

Table 3. 1 Properties of Sand

3.2.4 Standard Laboratory Equipment used to make the Mortar

The volumetric flask was used to measure the volume of the cement, sand, powder, and water at different mix ratio and a weighing balance was used to weigh all the samples to check the weight loss. The molds were used to prepare the specimen for testing while the crushing machine for cement was used to measure the compressive strength of the cement mortar. It was set at a revolution of about 50N/s.

Figure 3. 3 Some of the Materials used to Prepare Sample

3.2.5 Standard laboratory equipment for testing samples

Samples (mortar) prepared were tested using series of laboratory equipment. The crushing machine was used to measure the compressive and flexural strengths of all the samples at a loading rate of 50N/s. The fracture toughness was measured using the Instron machine with maximum load of 200mm. The loading span was set at 80mm.

Figure 3. 4 Some Testing Equipment

3.2.6 Properties of Dangote 3X Cement

According to the standard Organization of Nigeria, the Dangote 3X cement also known as extra life, extra life and extra yield is the latest version of cement produced by the Dangote cement company in few countries across West Africa to rid the cement market of low quality cement by ensuring a high quality 42.5 grade [1]. It was labelled DM. According to Oare Ojeikre, Group Chief Marketing Officer of the Dangote group, this 42.5R grade cement coupled with the unveiling of a new product (42.5 3X), with the recent maelstrom surrounding the ban of the 32.5 grade cement because of its low grade[1].

Moreover, this new cement has unique mechanical properties that slightly distinguish it from other cement. For example, unlike other cement (32.5, Portland), the Dangote 3X provides extra strength and rapid drying property which makes the product the first choice for builders and contractors. Furthermore, a bag of the new Dangote 3X Cement - 42.5R variety is observed as equivalent to one and half bag of the regular cement bag. Accordingly, whereas the number 32.5 (as found in other cement brands) refers to their strength, measured in Megapascals (MPA), which the cement achieves in 28 days of setting time, the 42.5 cement from Dangote achieves 42.5 MPA strength in 28 days setting time.

In terms of Xtra Life, it is speculated that 42.5 is ground finer than 32.5, giving a finer finish to concrete work, adding that the mixed cement has fewer air-pockets and therefore, adheres better and has longer life. Because of its higher strength characteristics, it is believed that 42.5 grade cement gives users higher yield than 32.5 in situations where strength is not a crucial factor, for ordinary applications, cement users could mix more sand into the same quantity of 42.5 cement, thus increasing the volume and making more blocks. Its setting characteristics is said to be rapid

(R) as against others that are normal (N). This 42.5R cement is has a tendency to set more rapidly than 42.5N cement. For example, if 'N' reaches a strength level of 10MPA in two days, 'R' would reach 20MPA in the same time.

Elemental composition		Structural Formula	
Magnesium	0.0039	Oxide	Weight
Aluminum	0.2055	CaO	54
Silicon	0.2171	SiO_2	16
Phosphorus	0.2315	$Al2O_3$	1
Sulfur	0.8676	MgO	1
Potassium	0.0515		
Calcium	53.4070		
Iron	2.9137		

Table 3. 2 Chemical composition of Dangote 3X cement

3.2.7 Powder, sand, Water

The powder formed from water sachet used conformed to zone I as per IS: 383 – 1970. It corresponds to the sieve size of 2mm. Ordinary River sand and CEN sand were used during the experiment. The sand was taken from a nearby river and dried in the sun to remove moisture content. Also, CEN standard sand was used; EN196-1[2] has silica content of at least 98%. Table 3.3 below shows the particle size distribution of CEN Reference sand:

Square mesh size(mm)	Cumulative sieve residue (%)
200	0
160	7 ±5
100	33±5
0.50	67±5
0.16	87±5
0.08	99±1

Table 3. 3 Showing Particle Size Distribution of the CEN Reference Sand

Normal drinking water was used for the experiment.

3.2.8 Production of Powder from Water Sachet

Waste water sachets made of low linear density polyethylene found littering everywhere were collected in huge quantity from streets, market place, dumpsite, etc. Detergents were used to remove microbes and other dirty substances. The plastics were then dried in the sun for about two hours to remove moisture. A hot plate was plugged to provide heat. Kerosene was placed on the hot plate. It was heated for about one hour thirty minutes until it reached 120^0C- the melting temperature of the polymer [3]. The plastics were then melted in the kerosene until they completely dissolved and formed a viscous liquid. The polymer’s long chains were broken down upon heating at its melting temperature. The viscous liquid was rapidly quenched/ cooled in a block of ice at a temperature of between -6^0C and -8^0C. After it was rapidly cooled, the plastic turned into smaller powder form. Acetone was used to watch the kerosene from the powder. The powder particles were dried in the sun for 24 hours. After that, it was sieved into different sizes using specific standards. The bigger sizes that couldn’t pass through the sieve and the ones that didn't quench properly were grounded using mortar and pencil and later passed through the sieve.

3.3 Experimental Procedures

3.3.1 Volume fraction mix of sand with polymer and cement

During the preparation of the cement mortar, two different types of samples were prepared- the one without the polymer which was labelled DM/0.00 and the one with the polymer which was labelled DM/c where c represented the percentage of polymer that partially replaced certain percentage of sand. The percentages of polymer used were 0%, 5%, 10%, 15%, 20%, 30% and 40%. The mix ratio was 2:1:6 as described by [2]. Mixing of concrete and compaction of the blocks was done mechanically. The prepared mortars were packed on boards for 24 hours before curing started.

Sample	Water(grams)	Cement(kilograms)	Sand(kilograms)	Polymer(kilograms)
DM	225	450	1350	0
DM/0.05	225	450	1282.5	67.50
DM/0.10	225	450	1215.00	135.00
DM/0.15	225	450	1147.5	202.5
DM/0.20	225	450	1080.00	270.00
DM/0.30	225	450	945.00	405.00
DM/0.40	225	45	810.00	540.00

Table 3. 4 Below is a Representation of the samples and Their Volume Fraction

3.3.2 Sample testing

Various tests were conducted for the fracture toughness, weight, and compressive strength, flexural strength with the polymer and without the polymer. A crushing machine was used to test for the compressive and flexural strength using the BS 6717 – Part 1 [4]; a weighing balance was also used to find the different weights using BS 1881 – Part 114 [4]. An Instron machine was used to measure the maximum load at failure by 150 mm (BSI, 2001) [5], which were then used to calculate the fracture toughness.

The flexural strength was calculated using the formula;

$\sigma = 3/2\ (LF / BD^2)$………..Eqn 1.2, where σ is the flexural strength (N/mm2), L is the loading span mm), F is the maximum applied load (N), B is the average width of the specimen (mm), and D is the average thickness (mm) [6].

For each of the specimen, where σ is the applied stress, f (a/w) is a function of the crack length, a, and W is the width of the specimen/component, the fracture toughness is given by;

$\mathrm{Kic} = \mathrm{F}(\frac{a}{w})\sigma\sqrt{\pi a c}$…………eqn 1.3 [6]

The values of the compressive strength of the mortar were compared to that of the European standard for the requirement of compressive strength for various curing time given in the table below [7].

Strength class	**Compressive strength(MPa)**				**Initial setting time(min)**	**Soundness(expansion)mm**
	Early strength		**Standard strength**			
	2days	**7days**	**28days**			
32.5N	**-**	**≥16.0**	**≥32.5**	**≤52.5**	**≥75**	**≤10**
32.5R	**≥10.0**	**-**				
45.2N	**≥10.0**	**-**	**42.5**	**≤62.5**	**≥60**	
45.2R	**≥20.0**	**-**				
52.5N	**≥20.0**	**-**	**52.5**	**-**	**≥40**	
52.5R	**≥30.0**	**-**				

Table 3. 5 European standard for compressive strength (EN97 -1)

3.4 References

[1] Dangote 3X oct. 5, http://www.vanguardngr.com/2014/03/son-stakeholders-approve-dangote-3x-cement/

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[3] Melting temp. Oct.5 http://www.essentialchemicalindustry.org/polymers/polyethene.html

[4] British Standard Institution (1983), “Method for Determination of Density of Hardened Concrete”, BS 1881, Part 114, BSI London

[5] British Standard Institution (2001), “Precast Concrete Paving Blocks”, BS 6717, Part 1, BSI London

[6] Mechanical properties of engineered materials (2003), Wole Soboyejo Princeton University Princeton, New Jersey Marcel Dekker, Inc. New York • Basel, 510

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Chapter Four

4.0 Results and Discussions

A 40cmx40cmx160cm mold was used to prepare the samples for the test. Three (3) 0f each types of samples were tested and the averages were taken and recorded. The below tables and figures show the results for the compressive, flexural strength, weight, and fracture toughness.

	Average weight (kilograms) versus compressive strength((N/mm^2)					
Sample Id	**7Days**		**14Days**		**28Days**	
	Weights	Compressive strength	Weights	Compressive strengths	weights	Compressive strengths
DM/0.00	586.60	39.80	583.20	41.60	580.12	50.40
DM/0.05	559.00	20.40	534.50	37.66	532.56	46.22
DM/0.10	543.13	18.95	519.43	35.01	510.00	44.34
DM/0.15	531.15	18.33	506.58	34.35	504.00	43.03
DM/0.20	510.14	18.01	485.11	29.37	483.00	42.19
DM/0.30	496.67	17.12	471.01	20.28	469.00	30.23
DM/0.40	440.12	16.53	415.12	17.21	413.09	26.33

Table 4. 1 Average weights for three of each sample tested

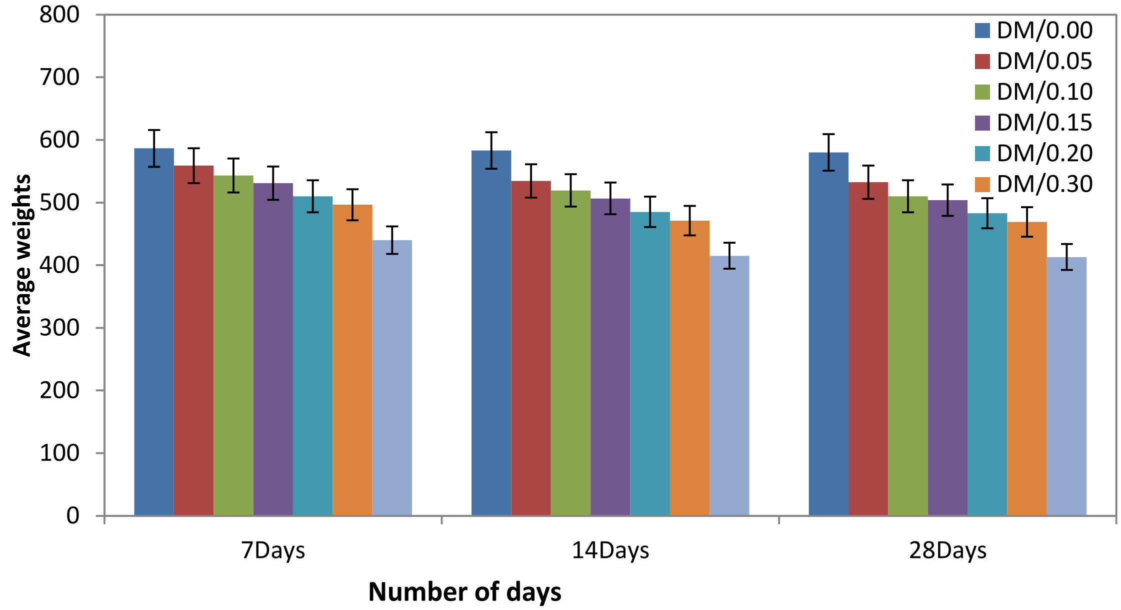

Figure 4. 1 Graph Showing Change in Weight

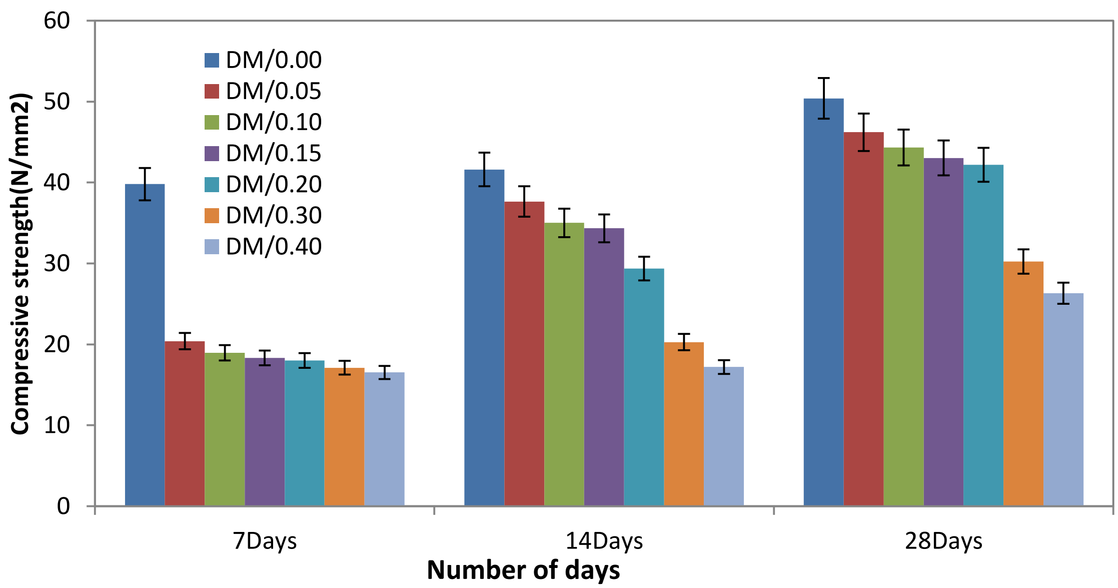

Figure 4. 2 Trend of Decrease in Compressive Strengths

4.1.1 Change in Weight:

From the above Table (**4.1**), the results showed that the weight of the mortar decreased with increasing percentage of polymer. This decrease is shown in Fig **4.1.** The percent change in weight of the material at different percentages of the polymer is calculated at 28days, which is the curing time at which the mortar gained its standard strength. At 28days, the weight of 0% polymer was 580.12g, at 5% it was 532.56g and at 10%, it was 510.00g up to 40%, where it dropped to 413.09g. The percent reduction in weight is 8.20% at 5%; 12.09% at 10%, and 28.79% at 40% volume fraction of the polymer. Also, as the curing time increased, the weight was found to decrease. The percent decrease in weight from 7 to 28days was calculated. It was found to be 1% at 0% polymer, 4.83% at 5%, 6.1% at 10%, and 6.14% at 40%. The results showed weight decreased with increasing curing time and also with increasing percent of polymer. The decrease in weight can be attributed to the low density of the polymer as compared to that of the sand as illustrated in **Table 3.1.** Partially replacing a percent by weight of the sand caused the weight of the entire mortar to decrease. The density of the material is directly proportional to its mass. The mass is related to the weight by multiplying by acceleration of gravity [1]; and thus, since the density of the polymer is lower than that of the sand, replacing a mass percent tend to impact its weight. Similarly, Choi et al. (2005) [2], Marzouk et al. (2007) [3] and Suganthy et al. (2013) [4] reported that density of plastic concrete decreased as the plastic content increased.

4.1.2 Impact of Polymer and Curing on Compressive Strength

The effects of the polymer and curing time on the compressive strength are displayed in Table 4.1. The result showed that the compressive strength decreases with increasing percentage of polymer and increases as the curing time increases. The percent decrease was calculated at

28days for different percentages. It was found to be 8.2% at 5% polymer, 12.04% at 10%, 14.62% at 15%, and 47.76% at 40% polymer. The reduction was as a result of poor adhesion between the cement paste and the polymer.

There was weak bonding between the cement paste and the mortar which lead to voids formation. The process of hydration plays key role in the formation of the mortar with great impact on its strength. It involves several reactions, which often occur simultaneously. During hydration, the major compounds in cement form chemical bonds with water molecules and become hydrates or hydration products. The hydration process gradually bond together the individual sand particles and other components of the concrete, to form a solid mass as the reactions proceed [5].

The following reaction occurs:

Cement chemist notation (CCN): $C_3S + H \rightarrow C\text{-}S\text{-}H + CH$

Standard notation: $Ca_3SiO5 + H_2O \rightarrow (CaO)\cdot(SiO_2)\cdot(H_2O)_{(gel)} + Ca(OH)_2$

Balanced: $2Ca_3SiO_5 + 7H_2O \rightarrow 3(CaO)\cdot 2(SiO_2)\cdot 4(H_2O)_{(gel)} + 3Ca(OH)_2$

For a good compressive strength, the above reaction needs to be satisfied. But from **Table 3.1**, it is observed that the polymer has poor water absorption capability. By replacing a volume fraction of the sand particles with polymer distorted the bonding requirement for good mortar formation and thus, weaken the adhesion forces which lead to the decrease in compressive strength. Similarly Ababio E. et al (2014) [6]

On the other hand, **Fig 4.2** also shows that as the curing time increased, the compressive strength also increased. The percent increases in compressive strength from 7 to 28days are 21.03% at 0%, 55.86% at 5%, and 37.22% at 40%. Even though the compressive strength decreased as the polymer increased, it is also observed that as the curing time increased, the hydration process seems to be favored to a certain level. The increased in strengths may be attributed to the hydration reactions [2] which gradually bonded the cement paste and increased the strengths of concrete as curing age increased.

4.1.3 Flexural Strength and Fracture Toughness

For the flexural strengths and fracture toughness, a portion of the mix was molded in a 2cmx2cmx 10cm mold. The sample curing was done for the same time. A center line with notch size of 0.3 was created on each sample while the INSTRON machine was used to calculate the load at which the materials fractured. The values of the maximum compressive loads recorded in the table below were used to compute the flexural strengths and fracture toughness.

Average maximum Compressive load strength(N)			
Sample	7Days	14Days	28Days
DM/0.00	209.03	281.05	335.80
DM/0.05	215.51	293.04	358.23
DM/0.10	229.01	330.01	400.20
DM/0.15	232.58	333.79	420.36
DM/0.20	235.58	337.23	422.5
DM/0.30	161.54	255.84	330.43
DM/0.40	154.52	242.05	320.58

Table 4. 2 Values of Maximum Compressive Load at Fracture

	Average flexural strength(N/mm^2) versus Fracture toughness($MPa\sqrt{m}$)					
Sample Id	**7Days**		**14Days**		**28Days**	
	Flexural strengths	Fracture toughness	Flexural strengths	Fracture toughness	Flexural strengths	Fracture toughness
DM/0.00	1.43	2.08	1.92	2.79	2.30	3.35
DM/0.05	1.47	2.14	2.01	2.92	2.45	3.57
DM/0.10	1.57	2.28	2.26	3.28	2.47	3.59
DM/0.15	1.59	2.31	2.29	3.33	2.88	4.19
DM/0.20	1.62	2.35	2.31	3.36	3.03	4.40
DM/0.30	1.11	1.61	1.75	2.54	2.27	3.30
DM/0.40	1.10	1.60	1.66	2.41	2.20	3.20

Table 4. 3 Flexural Strengths and Fracture Toughness for Average of Three of each Sample Tested

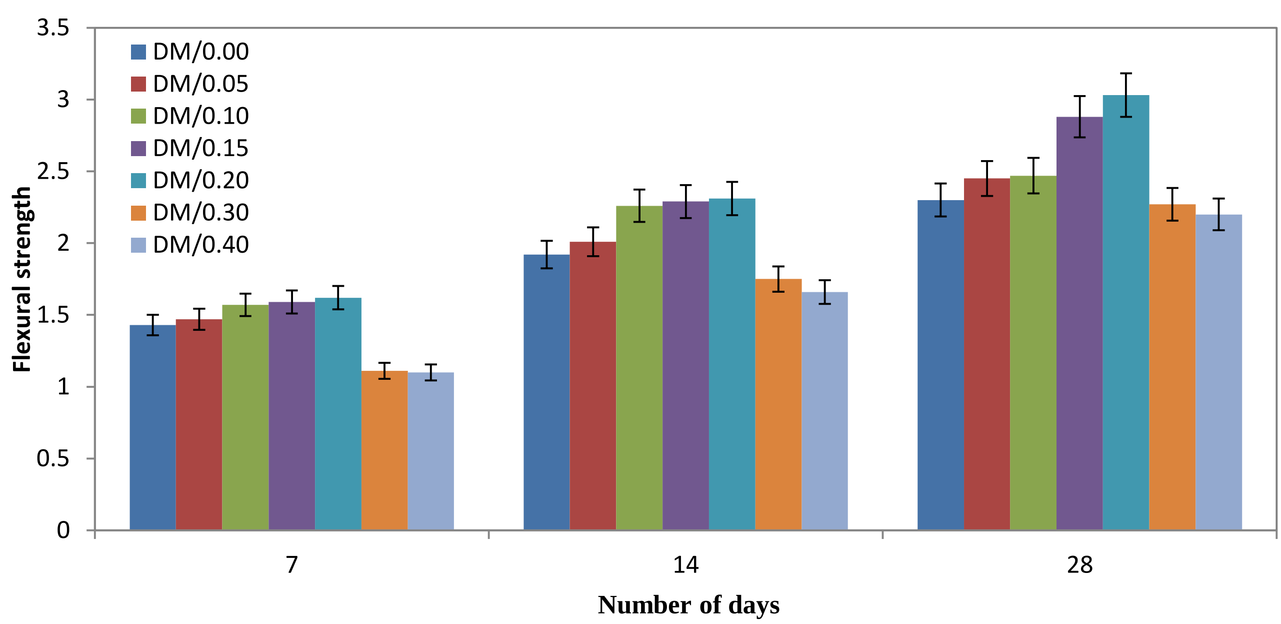

Figure 4. 3 Change in Flexural strength

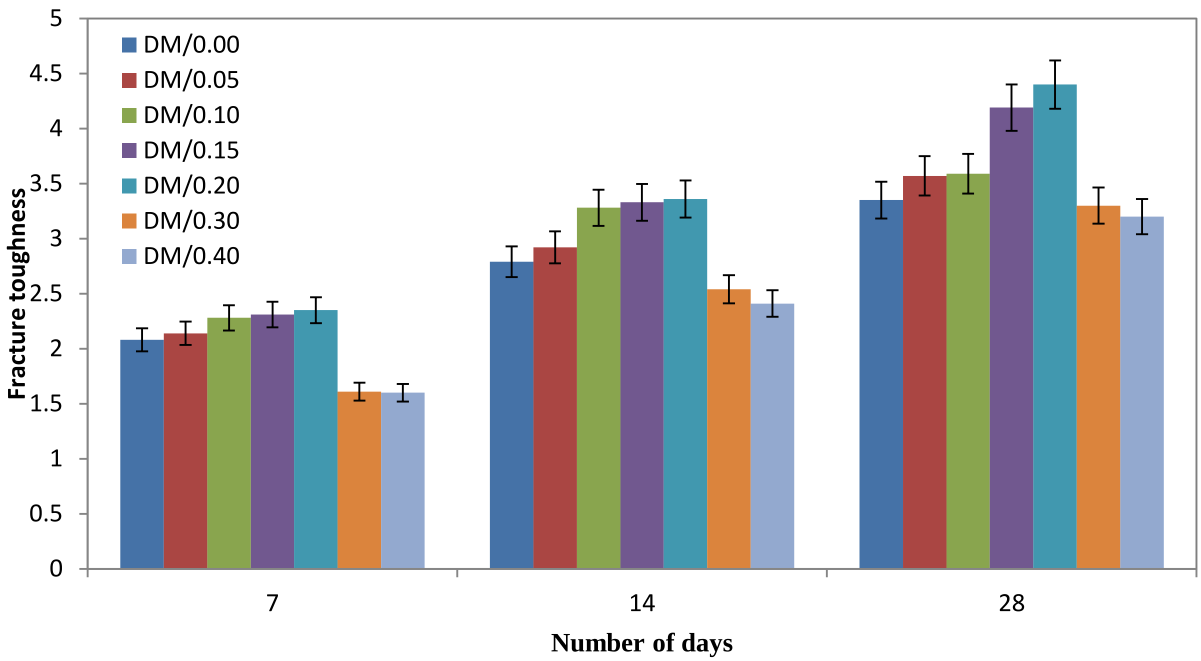

Figure 4. 4 Trend of Fracture Toughness

Flexural strength: Figure 4.3 and 4.4 display that the flexural strength and the fracture toughness of the mortar increased as the plastic content increased up to 20%. The percent change in flexural strength was calculated at 28 days. The percent increase was 6.12% at 5% polymer 6.88% at 10% polymer, and 24% at 20% polymer for both the flexural strength and the fracture toughness. Flexural strength is one measure of the tensile strength of concrete. It is a measure of an unreinforced concrete beam or slab to resist failure in bending [7] Cementitious materials are generally known to be strong in compression but poor in tension because the bonds formed cannot be stretched beyond their limits. The materials used to make the mortar are mostly brittle and fracture upon tensile loading. Flexural Strength of Concrete is about 10 to 20 percent of compressive strength depending on the type, size and volume of coarse aggregate used [7]. The polymer when deformed elastically can return to its normal shape. Therefore, the presence of the polymer in the mortar helped to improve its ductility. Furthermore, the flexural strength and fracture toughness increased up to 20% of the polymer before it started to decrease. This is also because the high tensile strength of the polymer in **Table 2.2** contributed to the increase in the flexural strength and fracture toughness of the mortar.

Fracture Toughness

Equation 1.3 shows that the flexural strength of the material is directly proportional to its fracture toughness. Thus, and increased in flexural strength will increase the fracture toughness of a material. From the calculated result in **Table 4.3** shows that the fracture toughness was also increasing with increasing percent polymer. When the crack was introduced in the mortar, it rate of propagation was fast in the 0% because the mortar was not tough enough to withstand the tension. Upon loading, the crack caused the mortar to fail catastrophically. This is due to the fact that brittle materials are not good in tension and deform elastically when a crack is formed and the material is loaded under that condition [8].

4.4.2 References

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[2] Choi, Y.W., Moon, D.J., Chung, J.S. & Cho, S.K. (2005), "Effects of Waste PET Bottles Aggregate on Properties of Concrete", Cement and Concrete Research 35(4), 776 – 781

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Chapter Five

5.0 Summary and Conclusion

This research presented a mechanistic approach of how to recycled waste into useful materials for building applications. This mechanism allows us to minimize environmental degradation and also its hazardous impacts (land pollution, health risks, etc.). According to this research, the use of such waste polyethylene materials in mortar helped to lower the weight of the material by 8.20% at 5%; 12.09% at 10%, and 28.79% at 40%. This means that these different decreased percentages at various increased in the PE can be used for applications as the designer may desire. Examples of such applications are slabs, designer column, beam, parapets, etc.

Additionally, the presence of the PE in the mortar decreased the compressive strength by 8.2% at 5% polymer, 12.04% at 10%, 14.62% at 15%, and 47.76% at 40% polymer because of poor adhesion between the cement paste and the polymer. However, 5%,10%,15% and 20% met the maximum compressive strength requirement for concrete/mortar after 28days. As the objective of the work was concerned, the flexural strengths, fracture toughness of the mortar increased as the volume percent of the PE increased and the percentages increased were 6.12% at 6.88% polymer, and 24% at 20% polymer. This implies that instances where the materials need to be strong and tough, these different percentages could help designers to make the right choice(s).

5.1 Recommendation

Despite the fact that this research has addressed several issues associated with building-how waste materials play key role in strengthening mechanisms, there are yet other key areas that are left undone.

There should be research done in improving the flexural strength and fracture toughness of concrete using waste polyethylene. Furthermore, the water- cement ratio plays key role in the strength of cementitious materials. Therefore, there is need for further research by varying the water-cement ratio to study the behavior of the materials. Finally, different grade of cement (Portland, Supa Elephant, etc.) should be use to see the difference in the strengths and toughness of the materials in comparison to the one(Dangote 3X) in this research.