Compressive Behaviour of Middle and High Strength Concretes Incorporating High Density Polyethylene at Elevated Temperatures

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Abstract

A rising interest has recently emerged for the use of post-consumer plastics as fillers to modify the properties of polymeric matrices. Little is however known about the mechanical behaviour of this new composites when subjected to elevated temperatures. This study investigated the compressive behaviour of superplasticised grades M25 and M50 concrete with (0, 0.25, 0.5, 0.75 and 1) percentages of pulverised high density polyethylene by weight of cement. Hydroplast-500 dosage in order of 1000litres/ 50kg by weight of cement was used throughout the study at constant water/cement ratio of 0.4 and 0.36 for requisite workability for grades 25 and grades 50 concretes respectively. After 28 days of curing in water, the150mm concrete cubes were subjected to elevated temperatures of 150, 300, 450 and 600 degrees for exposure duration of 1hour each. The results revealed that high density polyethylene admixture reduced explosive spalling of concrete up to 11.6% as a result of fibre bridging in the matrix and prevents spalling failure caused by high vapour pressure generated at high temperatures. It is therefore concluded that thermal stability could be achieved with pulverised high density polyethylene used as an admixture in concrete production.

Keywords: Concrete, Polyethylene, Elevated Temperatures, Compressive Behaviour

INTRODUCTION

Concrete as a universal material for housing and other construction activities has been continuously modified to perform better in many situations especially on exposition to elevated temperatures of fires (Nwankwo & Achuenu, 2014). Modifications to the matrix composition such as inclusion of plastic materials, injection of superplasticisers etcetera have not only resulted in striking improvements in many properties such as strength and ductility but have also made concrete economical and helped in reducing disposal problems (Siddique, Khatib, and Kaur, 2007).

The improvement in concrete properties is attributed to the light weight, high strength to density ratio, improved heat resistance and corrosion resistance, increased resistance to permeability and very low moisture absorption of the plastics used as admixtures (Dorigato, D’Amato & Peggoretti, 2012). The concrete matrix is modified with the injection of hydroplast-500 a superplasticiser to enhance workability and prevent the cement from clinging together and flocculating with the plastic particles when water is added to cement (Duggal, 2008). United Nations Environment Report (2018) estimated that only 9% of plastic waste ever produced has been recycled, 12% is been incinerated and the remaining 79% is accumulated in landfills, dumps or natural environment.

The plastic wastes generated blemish rural and urban scenery, causing damage to ground water, air and soil, flooding, choking of livestock and fish, entangle birds and threaten animals in general. They also block sewage pipes, turning them into safe haven for mosquitoes which causes malaria (Gowri and Rajkumar, 2011). Given the high volume of concrete produced annually for construction projects, concrete industry is unquestionably the ideal medium for the economic and safe use of millions of post-consumer plastics (Naik & Moriconi, 2004). As such, series of studies are tailored towards incorporating post-consumer plastics into various concrete applications to improve its performance (Parasivamurthy, 2007).

Neville (2000) defined elevated temperatures in concrete as the increase in temperatures above 250^{O}C which occurs when there is fire disaster. Concrete being a complex and heterogeneous material, its mechanical behaviour including compressive strength can remarkably change upon exposure to elevated temperatures (Nwankwo & Achuenu, 2014). The high strenghth concrete exposed to elavated temperature display a sudden catastrophic failure mechanism called explosive spalling. The addition of monofilament polypropylene was observed to dramatically reduce spalling without affecting strength (Khoury, 2000).

For normal strength concrete according to Kodour (2014), the compressive strength is marginally altered by a temperature of up to 400^{0}C . This is because normal strength concrete is permeable and allows easy diffusion of pore pressure as a result of water vapour. On the other hand, high strength concrete exhibit high variations in compressive strength due to the presence of a dense and superior microstructure makes it impermeable and under high temperature becomes detrimental as it does not allow moisture to escape resulting to build up of pore pressure and rapid development of micro cracks leading to faster deterioration and occurrence of spalling (Kodur, 2014).

Studies by Poon,Shui & Lam (2004) on high performance modified concrete subjected to high temperatures of 600^{0}C revealed that the concrete retained 45% of its strength. Nwankwo & Achuenu (2014) however recorded a 24% reduction in compressive strength of fibre reinforced ternary concrete at elavated temperature of 600^{0}C. This reduction was attributed to the chemical decomposition of the depleted calcium silicate hydrate (C-H-S) in the blend. Han, Hwang, Yang & Gowripalan (2005) reported results of residual compressive strenghth of concrete containing polypropylene fibres after heating the specimen to 850^{0}C for 40 minutes. Results showed that conventional concrete underwent severe spalling failure with no residual compressive strength whereas, plastic concrete containing 0.05 – 0.1% of polypropylen fibres experienced no spalling and retained 75% of its residual compressive strength.

The available literatures on the use of post-consumer plastics in concrete production are restricted to mechanical properties. The performance of concrete incorporating plastic materials at elevated temperatures is limited in literatures and needs investigation. Therefore this study is premised on investigating the effects of elevated temperatures on post-consumer high density polyethylene in superplasticised concrete in order to clarify the aspects that are unknown.

MATERIALS AND METHODS

Materials

The materials used in this research are: (a) The 'BUA' (42.5R grade) brand of Portland cement conforming to ASTM C 150(2004). (b) Pulverised high density polyethylene. High density polyethylene were sourced from landfills in Jimeta, Yola North local government Area of Adamawa State, Nigeria. The high density polyethylene (HDPE) were first sorted, cleaned and mechanically pulverized into smaller particles using local pulverising machine then sieved as shown in plate 1. (c) *Hydroplast - 500* conforming to ASTM C 494 (2005) was procured at Armosil West Africa Garki, Federal Capital Territory. (d) Good quality river sand sourced from Jere town in Kagarko Local Government Area of Kaduna State, passing 4.75mm sieve and falls within zone 1sand. The properties and suitability of the sand for the intended use were ascertained in the laboratory in accordance with the provisions of BS 812 (1997). (e) 20mm nominal sizes natural machined crushed rock which was sourced at Dutse Alhaji, Abuja, Federal Capital Territory, Abuja. (f) Potable water obtained from Nigerian Building and Road Research institute laboratory, supplied by the Federal Capital Territory water Board. This water was used throughout this research work both for mixing as well as curing of the concrete and in accordance with the provisions of BS EN 1008 (2002). The properties of the materials are presented in table 1.

Plate 1: Pulverised and sieved high density polyethylene

Table 1: Properties of Materials

Properties	Cement	HDPE	Fine Aggregate	Coarse Aggregate	Hydroplast-500
Specific Gravity	3.15	1.03	2.66	2.62	1.175
Standard Consistency	30%	-	-	-	-
Initial Setting Time (min)	60	-	-	-	-
Final Setting Time (min)	320	-	-	-	-
Bulk Density(Kg/m^3)	1440	-	-	-	-
Compressive Strength at 3 Days (N/mm^2)	11.3	-	-	-	-
Compressive Strength at 7 Days(N/mm^2)	25	-	-	-	-
Compressive Strength at 28 Days(N/mm^2)	46	-	-	-	-
Moisture Content (%)	-	0.55	0.13	0.2	-
Water Absorption (%)	-	0.067	0.38	0.29	-
Appearance	Grey	Ash-grey	-	-	Dark brown

Methods

The concrete specimens were prepared at the Materials and Concrete laboratory, Nigerian Building and Road Research Institute (NIBRRI) headquarters Abuja – FCT, Nigeria using 150 x 150 x 150 mm steel moulds. Concrete mixes were prepared using the "Design of Normal Concrete Mixes" by the Building Research Establishment (BRE) Ltd., London. Table 2 shows the quantity of materials required per cubic metre of concrete as computed by the mix design. Investigation was carried out on Grade 25 and grade 50 concretes representing medium strength concretes (grade 25) and high strengths (grade 50) concretes respectively.

The samples were prepared with pulverized HDPE of fine consistency, precisely those passing through 2.00μm BS sieve and added in percentages of (0, 0.25, 0.5, 0.75 and 1) by weight of cement. Dosages of *hydroplast-500* in order of 1000litres/ 50kg by weight of cement was used throughout the study as recommended by the manufacturers. A constant water/cement ratio of 0.4 and 0.36 for requisite workability was adopted for grades 25 and grades 50 concretes respectively after trial mixes. The fresh concrete was cast into the appropriate moulds and vibrated for at least 25 seconds in accordance with ASTM C 192 (1982) using an electrically operated small size poker vibrator. After 24 hours of casting, the concrete specimen were demoulded, weighed and completely cured in water tanks.

At the end of 28 days of curing in water, the concrete cubes were brought out of water and allowed to dry before subjecting them to elevated temperatures of 150, 300, 450 and 600 degrees respectively in an electrically operated furnace. These temperatures were adopted because temperature range between 400°C and 600°C are reported to be critical to strength loss (Anand & Arulraj, 2011; Gupta, 2012). The samples were exposed each for a duration of one hour for each elevated temperature range which is the minimum exposure period for 25mm concrete cover as provided by serviceability limit state design. After exposure to the required temperature, the furnace was switched off and the concrete specimens cooling at ambient temperature before crushing using the compressive strength testing machine.

The average failure loads was used in obtaining the compressive strength, using the relationship in equation (1).

$$f_{cu} = \frac{P_{max}}{A} \tag{1}$$

Where: f_{cu} = compressive strength (N/mm^2)
P_{max} = magnitude of the load at failure (N)
A = cross-sectional area of the cube specimen (mm^2)

Table 2: Quantity of Ingredients Required (kg) Per Cubic Metre of Concrete

		Concrete Grades	
Ingredient (Kg)		C25	C50
Cement		360	430
Fine Aggregate		630	570
Coarse Aggregate		1330	1330
Water		145	155
Hydroplast-500		7.2	8.6
Pulverized HDPE			
	0.0%	0	0
	0.25%	0.90	1.08
	0.50%	1.80	2.15
	0.75%	2.70	3.25
	1.0%	3.60	4.30

RESULTS AND DISCUSSION

Figures 1 and 2 show the relationship between varying elevated temperatures and compressive strength retained (percentage strength retained curves). Experimental results shows that for both grades of concrete investigated, there was an initial strength increase at 300^{0}C beyond which strength decreased generally with increased temperature. This increase recorded within this range of the melting point of HDPE (which is approximately 180^{0}C) could be attributed to relieve in vapour pressure when the temperature reaches this point. However, further reduction in compressive strength beyond 300^{0}C could be attributed to the chemical decomposition of calcium silicate hydrate (C-S-H) as observed by Nwankwo and Achuenu (2014). The trend in reduction of compressive strength was similar to that reported by Tao, Yuan and Taerwe (2010) and Han, Hwang, Yang and Gowripalan (2005) using propylene fibres as polymeric admixture in concrete. Further critical observation revealed that the addition of HDPE content reduced the probability of explosive spalling (see plate 2) which was in agreement with the findings of Tao et al. (2010) that propylene fibres reduced explosive spalling of concrete as a result of fibre bridging in the matrix and prevent spalling failure caused by high vapour pressure generated at high temperatures.

Generally, the range between 450°C and 600°C was observed to be critical to strength loss with the summary of the physical observations of the samples under elevated temperatures shown in Table 3. For grade M25 concrete, maximum percentage of strength retained at 450°C and 600°C was 79.52% and 74.75% both at 0.75% HDPE dosage representing loss of 20.48N/mm^2 and 25.25 N/mm^2 respectively, corresponding to 9.5% below control sample and 0.17% above control samples. Also maximum percentage of strength retained for grade M50 concretes at 450^{0}C and 600^{0}C was 78.95% and 87.75% respectively both at 0.75% HDPE dosage (which is loss of 12.25N/mm^2 and 21.05N/mm^2 representing 11.16% above control samples and 2% above control samples. The above findings are in agreement with Poon, Shui and Lam (2004) that high performance modified concrete subjected to high temperatures of 600°C retained over 45% of their strengths. The Values of percentage strength retained in all cases at 600°C were observed to be higher than those of control samples.

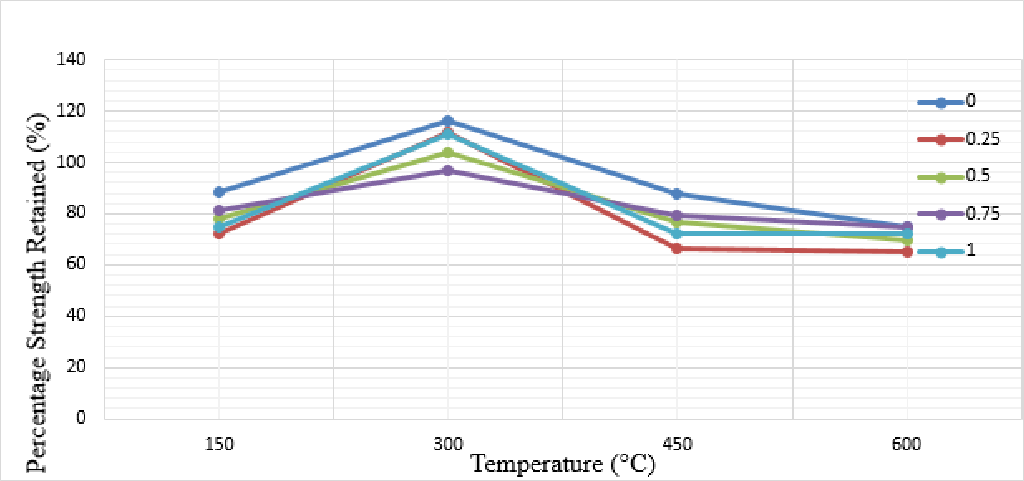

Figure 1: Percentage Strength Retained (N/mm^2) with temperature (°C) for M25 Concrete

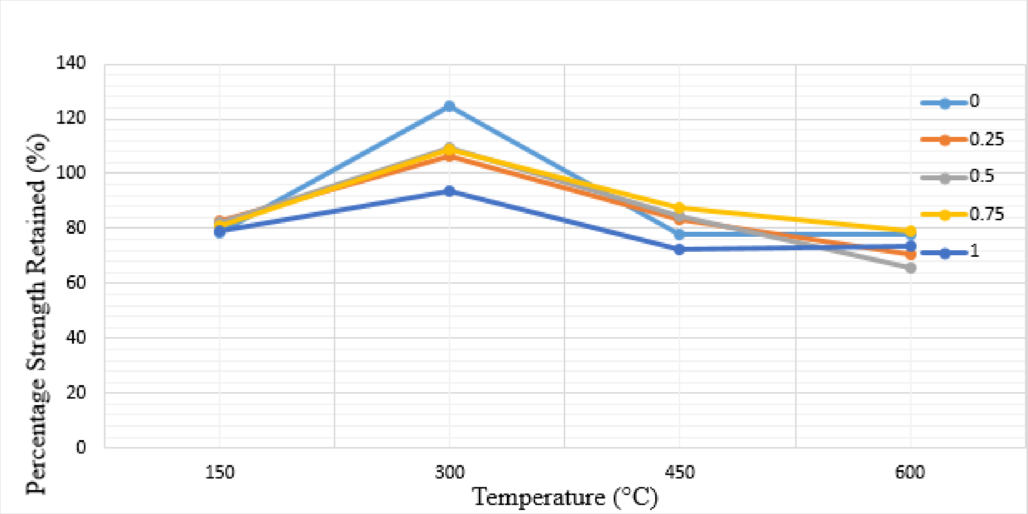

Figure 2: Percentage Strength Retained (N/mm^2) with temperature (°C) for M50 Concrete

Plate 2: Spalling Effect on control samples at 600°C compared to HDPE samples

CONCLUSIONS

The following conclusions have been drawn from the study; Concrete with HDPE admixtures exposed to elevated temperature of up to 600°C behaved differently from normal concrete, retaining a maximum of 11.16% strength above the normal concretes (control samples) with 0.75% dosage of HDPE. Furthermore, Grade M50 (high strength concretes) lost its mechanical strength in a similar pattern to grade M25 (Medium strength concrete) but compared to grade M25, grade M50 was found to possess higher compressive strength when exposed to high temperatures though more susceptible to spalling. This phenomenon could be as result of the more permeable nature of grade M25 concrete which allows easy diffusion of pore pressure as a result of water vapour. Similarly, Grade M50 (high strength concrete) possesses a dense and superior microstructure which makes it impermeable and under high temperatures does not allow moisture to escape resulting to build up of pore pressure and rapid micro cracks development leading to faster deterioration. It was also observed that the high density polyethylene admixture reduced explosive spalling of concrete as a result of fibre bridging in the matrix and prevents spalling failure caused by high vapour pressure generated at high temperatures. It is therefore safe to conclude that thermal stability could be achieved with pulverised high density polyethylene used as an admixture in concrete production.

Table 3: Observations on Concretes at Varying Elevated Temperatures

Temp. (°C)	Admixture dosage %	Colour/Colour change	Cracks	Remarks
0	0	Grey	Absent	No Spots Marked
	0.25	Grey	Absent	No Spots Marked
	0.5	Grey	Absent	No Spots Marked
	0.75	Grey	Absent	No Spots Marked
	1.0	Grey	Absent	No Spots Marked
150	0	Grey	Absent	No Spots Marked
	0.25	Light green	Absent	No Spots Marked
	0.5	Light green	Absent	No Spots Marked
	0.75	Light green	Absent	No Spots Marked
	1.0	Light green	Absent	No Spots Marked
300	0	Light green	Absent	Moderate Bonding
	0.25	Yellowish brown	Absent	Moderate Bonding
	0.5	Yellowish brown	Absent	Moderate Bonding
	0.75	Yellowish brown	Absent	Moderate Bonding
	1.0	Yellowish brown	Absent	Moderate Bonding
450	0	Faint Brown	Hair cracks	Moderate bonding & few dark spots
	0.25	Faint Brown	Absent	Moderate bonding & few dark spots
	0.5	Faint Brown	Absent	Moderate bonding & few dark spots
	0.75	Faint Brown	Absent	Moderate bonding & few dark spots
	1.0	Faint Brown	Absent	Moderate bonding & few dark spots
600	0	Faint Brown	present	Weak bonding/dark spots
	0.25	Dark Brown	Absent	Weak bonding/dark spots
	0.5	Dark Brown	Absent	Weak bonding/dark spots
	0.75	Dark Brown	Absent	Weak bonding/dark spots
	1.0	Dark Brown	Absent	Weak bonding/dark spots

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