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Original Article

Influence of High-Density Polyethylene Admixtures on Water Sorptivity Behaviour of Medium and High Strength Concretes

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Abstract

The increasing research interest in the reuse of waste plastics have presented vast potentials for improving concrete properties and contributing to sustainable concrete production. This work studied the sorptivity behaviour of grades M25 and M50 concretes prepared using pulverised high density polyethylene (HDPE) immersed in 20% hydrogen peroxide as treatment. As an additive, the pulverised HDPE was added to the concrete at 0 %, 0.25 %, 0.5 %, 0.75 %, and 1 % based on cement weight. The concrete had been made with 150 mm^3 steel moulds using mix design method. A superplasticiser -Hydroplast-500, was used in the mixes. For the grades M25 and M50 concretes, respectively, 0.4 and 0.36 water/cement ratios had been selected to represent medium and high strengths concretes after 7, 28, and 90-day periods of water cure. After being taken from the water and dried, the concrete cubes underwent a sorptivity test. Results obtained indicated that incorporation of treated HDPE to the concrete reduced its sorptivity up to 59 % and 64.5 % respectively for grades M25 and M50 concretes due to the admixture's existence in the mix. The study recommends concrete prepared with 1 % HDPE by weight of cement for use in water retaining structures, drainage systems and constructions where damp is a challenge to existing infrastructure.

Keywords: Admixture; High Density Polyethylene; Modified Concrete; Pulverisation; Sorptivity; Treatment

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1. Introduction

Concrete, according to Tošić et al., is a relatively new construction material when compared to earth, stone, timber, and steel but is considered the most extensively utilised universal substance in order to construct [1]. According to Global Cement and Concrete Association [2], 140 billion cubic metres of concrete was used in the year 2020 alone. The increasing application of concrete for construction purposes is attributed to the growing human population requiring more infrastructure, its contribution to social and economic progress as well as environmental protection [3], [4]. According to Paul [5], additional benefits of using concrete for construction include its affordability and availability, ability to be formed into a variety of shapes, energy efficiency, excellent resistance to water and fire, environmental friendliness, and compatibility with steel. The aforementioned benefits of concrete calls for more than cursory understanding of its properties and how to improve its performance [6]. Concrete has demonstrated to be a practical disposal method for industrial byproducts like silica fume, powdered granulated blast furnace slag, fly ash as well as similar potentially harmful substances, according to Rutkowska et al. [7], with good promise of improving the properties of concrete and promoting sustainability. It is against this backdrop that research and development in construction materials which are environmentally friendly, structurally safe, with adequate durability and acceptable mechanical performance, becomes the focus of researchers in the 21st century [6]. By utilizing this technique, concrete can be made with a good possibility of reducing waste and pollution while also conserving energy and water [8]. One of three concrete durability index tests is the water sorptivity index (WSI) test and it gauges the speed at which a wetting front moves through concrete while being drawn up by capillaries [9]. Since the majority of deteriorations related with concrete are caused by water intrusion, the simplicity with which liquids and gases can get into and make their way through the concrete has a significant impact on its durability [10]. Similar to this, the effectiveness of concrete in hostile situations depends significantly on the pore system's ability to be penetrated, which is mostly managed by capillary absorption [11]. Plastic materials which are organic materials of high molecular weight made from resins, plasticisers and pigments are fast replacing other building materials such as glass, wood and ceramics because of their low cost and accessibility, low maintenance and weight, and the ease with which they can be shaped, especially in their plastic state [11], [12]. Interestingly, plastic waste accounted for approximately 275 million tons of solid trash out of a total of 2.5 billion metric tons created worldwide [13]. According to United Nations Environment Report [14], just 9 % of plastic trash is reclaimed, 12 % is burned, and the other 79 % ends up in dumping sites and surroundings. For instance, plastic usage in Nigeria, has steadily grown by 5 % per capital yearly in the past 10 years, rising to 6.5kg (2017) from 4.0 kg (2007) and being projected to be over 7kg by the year 2020 [13]. Such quick development has been credited to the acceleration of industrialisation and the quick rise in living standards [15]. Literature has shown evidence through previous studies by Naik et al. [16], Anum and Job [17] and Albano et al. [18] that post-consumer plastics could be used as admixtures in the various concrete applications to enhance its performance. Naik et al. [16] carried out a study on the effects of waste plastics in concrete and discovered that usage of plastics for concrete production have a propensity to reduce the stresses induced by loading deformation and hence improves the crack growth and propagation properties of the concrete. High density polyethylene (HDPE), a type of plastic having a density of higher than or equivalent to $0.941 g/cm^3$, consists of 46 % of the world's sum of production of polyethylene, and it has unique qualities like improved heat resistance, good impact resistance, and light weight that make it a preferred material for many engineering applications [19], [20]. HDPE that has been recycled and ground into smaller pieces to produce a novel substance with lower particulate sizes and increased surface area is known as pulverised HDPE [21]. Soliman and Elbialy have compared the thermal resistance of HDPE with other three materials as recycled materials mixed with cement and sand for producing cladding tiles to improve the thermal resistance of building envelops, the result of this experiment proved that the HDPE is the best materials in terms of thermal resistance [22]. Pulverised HDPE in concrete forms a mixture of materials made of a matrix made of cement and admixed with high-density polyethylene material in either ordered or random placement. A previous investigation carried out by Anum and Job [17], Albano et al. [23] have convincingly confirmed that pulverised and chemically treated high density polyethylene substantially improved some properties of the modified concrete such as its strengths and behaviour at elevated temperatures. A separate study by Drochytka et al. [24] suggested that water-proofing admixtures could be used to enhance the pore system and durability of concrete. This study is therefore an effort to examine the influence of water sorptivity on HDPE concrete. The study has potential for creating an environmentally safe and sustainable concrete for use in civil engineering and building projects.

2. Materials and Methods

2.1. Materials

2.1.1 *Binder Material*

"BUA" brand, ordinary Portland cement grade 42.5R with properties conforming to (American Society for Testing and Materials) ASTM C 150 [25] was used throughout this study. Preliminary tests were performed on the cement to ascertain its suitability for the experiment. Specific gravity was measured to be 3.15, consistency of the cement was measured to be 30 % and the bulk density of 1140 kg/m^3 was found. The compressive strength of 46 N/mm^2 was recorded at 28 days cure in water, the setting times were found to be 60 and 320 minutes, respectively for initial and final setting times.

2.1.2. *Aggregates*

Sand from river, belonging to zone one (1) and to pass a (British standard) BS 4.75mm sieve was utilized as the fine aggregate in this investigation. 20mm machined crushed rock was used as coarse aggregate. According to the guidelines of BS EN 12620 [26], the laboratory evaluation of the aggregates' appropriateness for the experiment was completed. It was determined that the river sand and crushed rock had specific gravities of 2.66 and 2.62, respectively.

2.1.3. *Admixtures*

The main admixture used for the experiment was pulverised high density polyethylene (HDPE) that came from Jimeta - Yola, Adamawa State of Nigeria. The pulverised HDPE was used in powder form. A superplasticiser (Hydrosplast -500) was also included to enhance the mix's workability and was compliant with ASTM C494/C494M [27]. The HDPE specific gravity was1.03, 0.55 % moisture level including water absorption of 0.067 %.

2.1.4. *Water*

Water used throughout the experiment for both mixing as well as sample curing was clean water that complies with the provisions of ASTM C1602/1602M [28].

2.2. Methods

2.2.1. *Specific Gravity Determination of HDPE*

According to the guidelines of BS EN 1097 [29], the substance's specific gravity was evaluated using a pycnometer process. Samples used were initially kept for 24 hours in the oven at 50°C. SPG (specific gravity bottle)/pycnometer was thoroughly dried before being weighed (M1). Unscrewing the cap, dried samples from the oven were added to it, and (M2) was used to measure weight. The SPG container with the samples was full of water until it reached the predetermined mark, and then it was weighed again after being cleaned with cotton towel (M3). Without the HDPE, SPG bottle was fully loaded with kerosene till it reached the position, then weighed (M4). Using the expression presented in equation (1), the specific gravity of the pulverized HDPE was calculated.

$$Specific\ gravity = \frac{M_2 - M_1}{(M_3 - M_2) - M_4 - M_1} \text{ x } 1 \qquad (1)$$

2.2.2. *Workability of the Modified Concrete*

According to guidelines set in BS EN 12350-2 [30] and BS EN 12350-4 [31], the compaction factor and slump tests were performed on the fresh mix of concrete to ascertain its workability. The findings obtained showed that the rise initially in HDPE content was typically identical to the control mixture up to a maximum of 0.5 % HDPE, then steadily fell both in slump/compaction factor as demonstrated by Anum et al. [23], and illustrated in Table 1. The aforementioned authors claimed that this pattern was caused by HDPE's closed cellular system, which has a limited capacity for absorbing water (about 0.067 %) and hence is unable to appreciably change the slump of new concrete. The irregular forms of the HDPE, which cause weak fluidity, were responsible for the further drop in slump beyond 0.5 % HDPE concentration.

2.2.3. *Density of Concrete*

The study's concrete sample had densities that ranged from 2390 to 2700 kg/m3. These values fall within the 2200–2600 kg/m3 density range that is designated as the density for regular weight concrete [32]. Further observation revealed that densities rose with curing age and fell with increasing HDPE content. This phenomenon could be interpreted that HDPE have a lesser density compared to aggregates, which causes the density of the concrete to decrease.

Table 1. Workability of the HDPE Concrete

Concrete Grade	Quantity of Admixture (%)	Value of Slump (mm)	Compacting Factor	Degree of workability
M_{25}	0	110	0.96	maximal
	0.25	110	0.95	Maximal
	0.5	100	0.94	Average
	0.75	100	0.93	Average
	1.0	85	0.92	Average
M_{50}	0	125	0.98	maximal
	0.25	125	0.96	Maximal
	0.5	120	0.95	Maximal
	0.75	120	0.95	Maximal
	1.0	115	0.95	Maximal

2.2.4. *Preparation and Treatment of HDPE*

After collection and sorting, the HDPE plastics were cleaned and mechanically reduced in size to pass the 2 mm BS sieve. The pulverised HDPE underwent chemical treatment by being submerged in saturated 20 % hydrogen peroxide solution for 30 minutes as reported by Anum and Job [17]. The treatment is expected to modify the surfaces of the plastics through improved surface energies, wettability and improved adhesion to cement paste, Naik et al. [16]. Following treatment on the admixture sample, test of sieve analysis was carried out on the ground-up HDPE powder as illustrated in Figure 1(a).

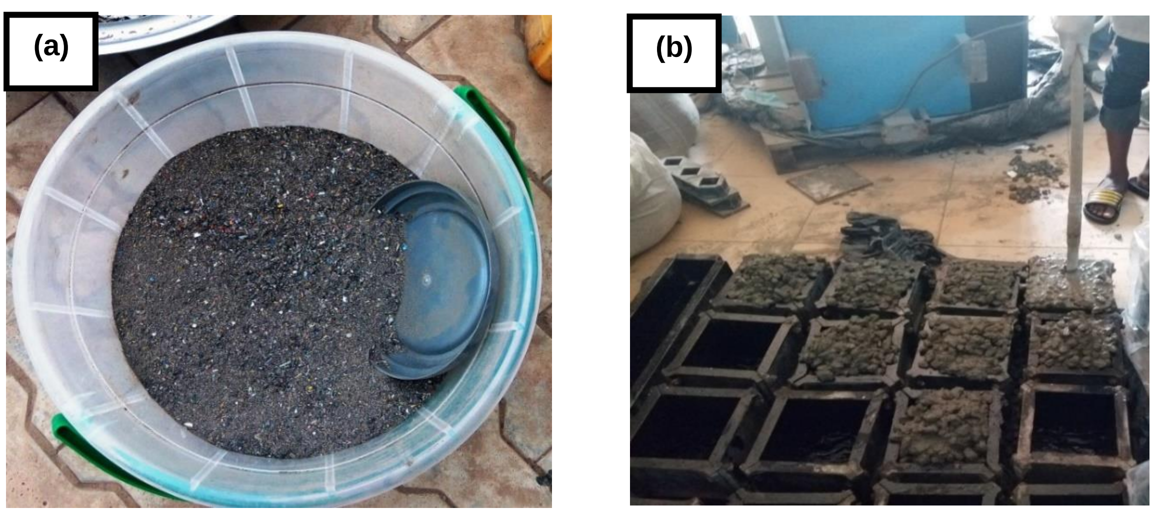

Figure 1. (a) HDPE Powder and **(b)** Casting and Vibration of Concrete Cubes using Hand Vibrator
Source: Laboratory experiment

2.2.5. *Specimen Preparation*

The concrete samples were produced using 150 mm3 steel moulds as depicted in Figure 1 (b), and the sample cubes were produced to the requirements of BS EN 12390-3 [33]. The experiment adopted the method of mix design for all mixes. The amount of materials utilized per cubic meter of concrete is displayed in Table 2 [17]. Grades 25 and 50 of concrete, which represent medium and high strengths, respectively, were the subjects of the investigation. HDPE that had been finely ground was added to the samples at 0 %, 0.25 %, 0.5 %, 0.75 %, and 1 % based on cement weight. Over the course of the experiment, dosages of hydroplast-500 in the range of 1000 ml per 50 kg by cement weight were used, as advised by the producers, to improve the workability of the mixture. For the required workability in the grades 25 and 50 concrete, the water/cement ratios were 0.4 and 0.36, respectively.

Table 2. Materials Utilized (Kg)/ M3 of Concrete

Concrete Grades	Material (Kg)					Pulverised HDPE				
	Cement	**Sand**	**Crushed rock**	**Water**	**Hydroplast-500**	***0.0 %***	***0.25 %***	***0.50 %***	***0.75 %***	***1.0 %***
M25	360	630	1330	145	7.2	0	0.90	1.8	2.7	3.60
M50	430	570	1330	155	8.6	0	1.08	2.15	3.25	4.30

2.2.6. *Sorptivity Test on Concrete Cubes*

The phenomenon by which porous materials absorbs/desorbs liquid (usually water) by capillarity is referred to as water sorptivity and the test technique of measuring the rate of absorbency is sorptivity test or sorptivity coefficient test [34]. The sorptivity test was performed on the concrete cubes according to the procedure reported by Abalaka and Okoli [35], Ganesan et al. [36] and Hall [37]. This was accomplished by timing the mass increase of the specimen with one surface in contact with water. The specimen was first heated to a steady mass at 50 °C in oven, the sides of the sample were covered using silicon sealant to a depth of 30mm as previously reported by Sugapriya and Ramkrishan [38] permitting water ingress from just a single surface as illustrated in Figure 2 (a). Consequently only a single side of the sample was immersed into 10mm depth of water as depicted in Figure 2 (b) and (c). The original mass of the cube was measured at time 0, 1minute, 2 minutes, 4minutes, 8 minutes, 10 minutes, 20 minutes, 30 minutes, 60 minutes, and 90 minutes [Figure 2 (c)], following that, samples were removed from the water and excess water was wiped away.

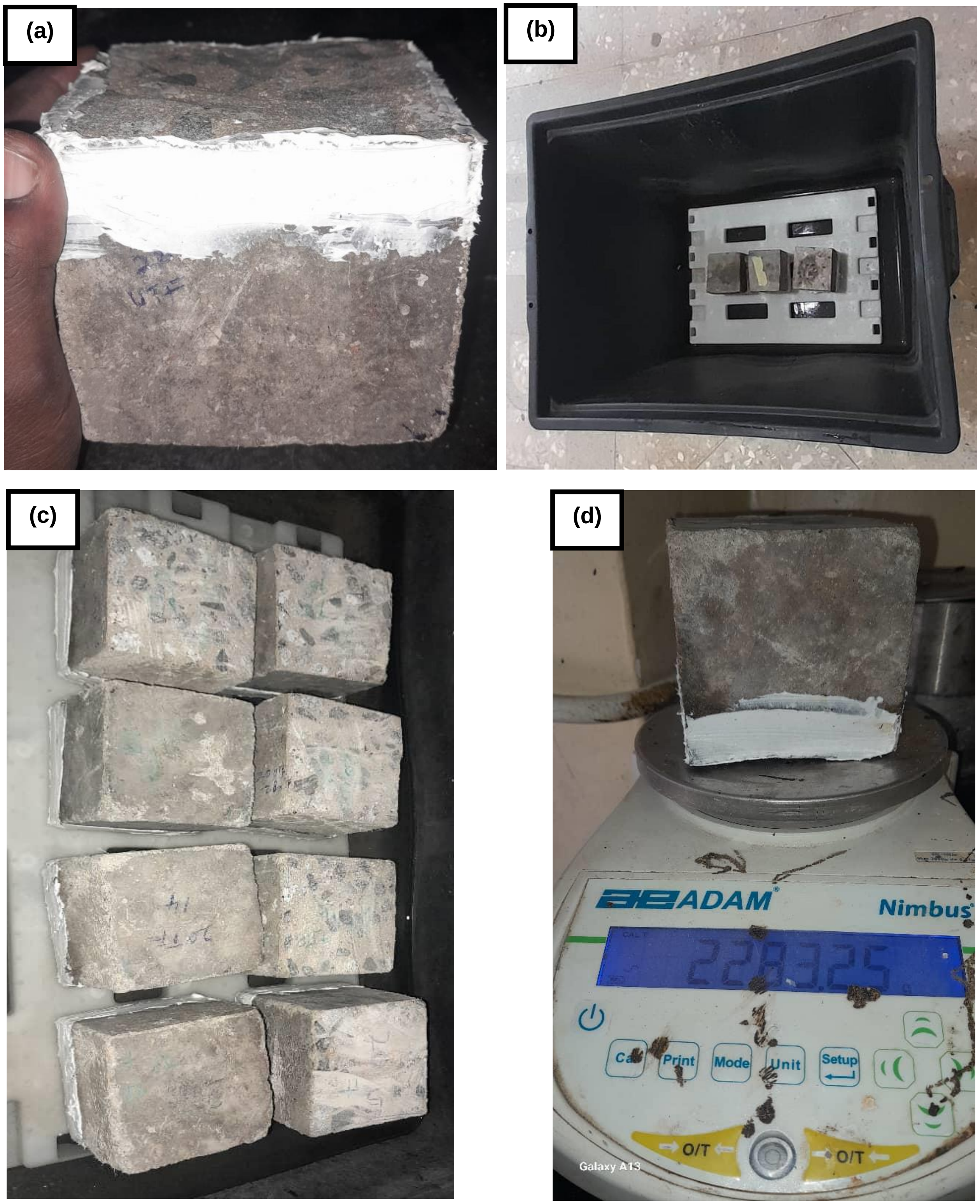

Figure 2. Coating with silicon sealant (a), Placement of cubes in basin (b) and (c) and weighing of samples (d)

The sorptivity, S [mm/sec1/2], was calculated using equation (2) and (3) Yang et al. [39]:

$$I = S.t^{\frac{1}{2}} \quad (2)$$

$$I = \frac{\Delta w}{Ad} \quad (3)$$

Where,

t = time (minutes)
Δw = weight change ($W_2 - W_1$)
W_1 = Dry weight (g)
W_2 = weight of sample after capillary suction
A = surface area (through which water penetrates)
d = water density (g/mm^3)

3. Results and Discussion

3.1. Sorptivity

Figures 3 and 4 show the relationship between water sorptivity values and curing period on the hardened concretes of M25 and M50 grades after 7-, 28- and 90-days water curing by immersion. Results indicated that in all concrete grades studied including that of control mixes, the sorptivity decreased with age of curing for the tested period. This pattern of sorptivity decrease with age of curing could be attributed to the increased calcium silicate hydrate gel production within the concrete during curing.

Results further revealed that for grades M25 concrete at 7days test, 1 % HDPE content gave the highest percentage reduction of 41 % in sorptivity compared to the control samples. Also, at 90days curing, the modified concrete had the highest percentage reduction of 59 % in sorptivity with the same 1% HDPE content against the control mixes. Similarly, for grades M50 concretes, at 7days, 1 % HDPE also gave the highest percentage reduction of 50 % in sorptivity compared to the control mixes while at 90days, a reduction of 64.5 % sorptivity compared to control samples was recorded with 1 % HDPE content.

It was generally observed that sorptivity decreased with increase in HPDE content in the mixes. This decrease in water sorptivity could be attributed to the improved performance in strengths of the concrete as a result of enhanced production of reactive hydroxyl (R-OH) and hydroperoxy (R-

COOH) functional sites on the HDPE surfaces by the oxidising hydrogen peroxide during HDPE treatment [17].

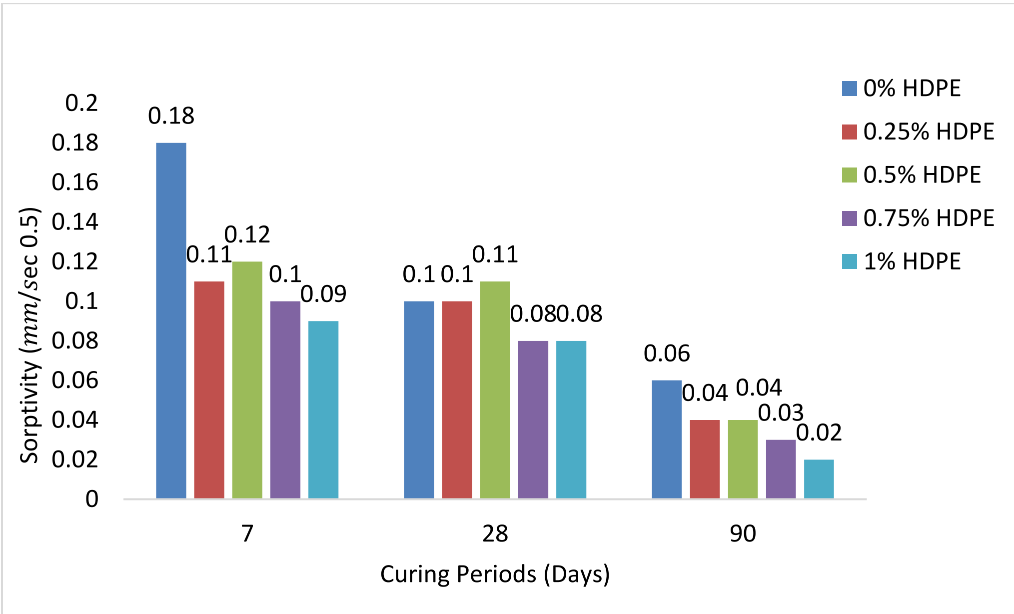

Figure 3. Sorptivity with Curing Periods for M25 Concrete

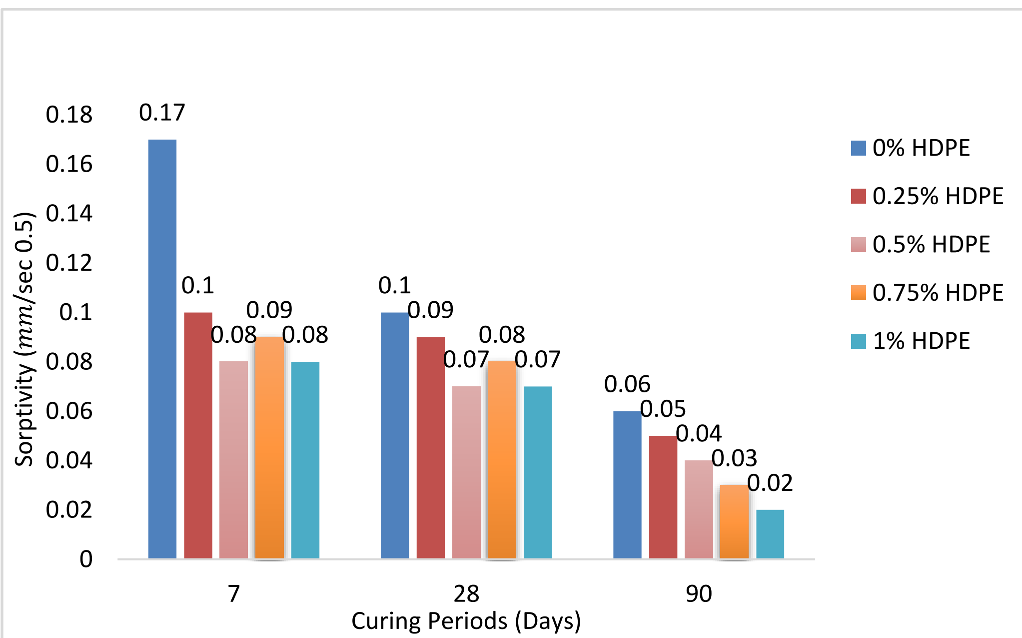

Figure 4. Sorptivity with Curing Period for M50 Concrete

The treatment is believed to have modified the surfaces of the plastics through increased surface energies, increased wettability and improved adhesion, enabling them to cling to cement paste more effectively and improving on porosity of concrete. Improved structure of the pore and non-absorbent nature of the HDPE material (with water absorption capacity of 0.067 %) present could be responsible for the decrease in sorptivity. The findings presented here are in line with those of Drochytka et al. [24] that water-proofing admixtures improve concrete pores system. The results of findings in this study were comparable to the results obtained by Karashan and Atis [40], Saika and de Brito [41] and Silva et al. [42] who variously reported a decrease in water absorption on concrete samples using different types of plastics fibres in concrete. It was also observed from the results that the sorptivity values for grade M50 concretes were lower (higher resistance of the concrete towards water absorption) compared to the grade M25. This could be obviously as a result of the denser microstructure expected for grade M50 concrete occasioned by a lower water to cement ratio resulting to less sorptivity.

4. Conclusion

The impact of high-density polyethylene (HDPE) admixtures on water sorptivity behaviour of medium and high strength concrete was examined in this study. The result of the study established that pulverisation of the HDPE into finer particles with improved surface areas and the chemical treatment of the surfaces decreased sorptivity of the modified concrete with good promise of improved durability of concrete. The non-absorbent nature of HDPE with 0.067 % water absorption capacity and the enhanced covering of the plastic surfaces with reactive hydroxyl group (R-OH) and reactive hydroperoxy functional group (R-COOH) created by the oxidising hydrogen peroxide used in therapy may be the causes of the modified concrete's lower sorptivity. It was also established that high strength concrete prepared with more quantity of cement and less water to cement ratio with superior and denser microstructure exhibited higher resistance towards water ingress into the concrete. It was concluded from this findings that treated HDPE enhanced the resistance of concrete to ingress of water, hence improved its durability and contributes to the environmental friendliness of the modified concrete. Based on this findings, the study suggested that pulverised HDPE concrete could be of useful application in water retaining structures, drainage systems and constructions areas where damp is a challenge to infrastructure. The study also recommend the use of high strength concrete in deleterious environment to increase its durability. This research work has made contribution to the current body of knowledge by identifying the benefits of chemical treatment on pulverised high density polyethylene and also provided data and guide to practitioners on HDPE usage in enhancing durability of concrete through decreased sorptivity.

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