Water Permeability Properties of Concrete Containing Waste High Density Polyethylene

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ABSTRACT

Incorporation of waste materials such as plastics into concrete has become one of the most common techniques of sustainable waste disposal while enhancing concrete quality. This study aims to evaluate the permeability properties of concrete containing High Density Polyethylene (HDPE) that has been pulverised and chemically treated with 20% hydrogen peroxide before being used as an admixture in concrete. Concrete cubes were prepared using 150mm^3 steel moulds adopting the Building Research Establishment (BRE) mix design method. The pulverised and treated HDPE was added in percentages of (0, 0.25, 0.5, 0.75 and 1%) by weight of cement. A superplasticiser (Hydroplast-500) was used and water/cement ratios of 0.4 and 0.36 were adopted for requisite workability respectively for grades 25 and 50 concretes. After 7, 28 and 90 days of curing in water, the concrete cubes were removed, dried and tested for permeability. Results obtained show that inclusion of pulverised HDPE to concrete significantly reduced permeability of the modified concrete up to 62% with 1% HDPE. The study recommends the use of 1% HDPE by weight of cement for the production of impermeable concrete for building and civil engineering infrastructure, while reducing environmental pollution.

Keywords: Concrete, High Density Polyethylene, Permeability, Pulverisation, Waste Plastic

1. INTRODUCTION

An estimated 2.24 billion tons of municipal solid waste (MSW) was generated globally in 2020 amounting to a footprint of 0.79 kilograms per person per day. With urbanization and rapid population growth, the annual waste generation is expected to reach 3.88 billion tones in 2050 (Abeysinghe et al., 2021). According to the United Nations Environment Report (2018), plastic waste accounts for 12 per cent of the total amount of municipal solid wastes generated globally, out of which only 14% are collected for recycling while only 9% are recycled. Plastics consumption per head in Nigeria has increased by roughly 5% per year over the last ten years, growing to 6.5 kg in 2017 and expected to reach 7.5 kg in 2020 (Bokani, 2019). This fast growth has been attributed to the boost in industrialisation and the rapid improvement in standards of living (Babafemi et al., 2018).

High density polyethylene (HDPE) is a type of thermoplastic defined by density of greater or equal to 0.941g/cm^3 and accounts for 46% in total polyethylene production globally. According to Plastic Insight Report (2019), polyethylene is one of the most used polymers globally with 103 million tons produced globally in 2016 and high-density polyethylene accounting for 47.5 million tons representing 46% in total polyethylene production globally.

HDPE possesses special properties such as high resistance to permeability, good chemical resistance, high rigidity, high toughness and flexibility, improved heat resistance, good impact resistance and light weight which makes it a material of choice for many engineering applications (Plastic Insight Report, 2019; Dorigato et al., 2012). The use of pulverised High-Density Polyethylene (HDPE) as an admixture in concrete production is a promising method of improving the quality of concrete, especially in developing countries such as Nigeria where high-density polyethylene contributes significantly to waste disposal crisis.

Concrete is ranked as the topmost man-made resource utilised in the construction industry worldwide. The wide usage of concrete according to Anderson (2019) is also attributed to its contribution to social progress, economic growth and environmental protection. Nwankwo and Achuenu (2014) have agreed that the wide usage justifies why this conventional material is being continuously modified and developed to perform better in many situations. According to Rutkowska, Wichowski, Franus, Mendryk and Fronczyk (2020) concrete has shown beyond doubt to be an exceptional disposal means for industrial wastes such as fly ash, silica fume, ground granulated blast furnace which traps the hazardous materials and also enhance the properties of concrete. Sandanayake et al. (2020) have suggested that the concrete industry should make contributions to sustainable development in the 21st century by adopting new technologies for sustainable concrete production. It is against this backdrop that research and development in waste materials which are environmentally friendly, structurally safe, with elevated durability and acceptable mechanical performance, becomes a real challenge facing researchers in the 21st century (Nwankwo &Achuenu, 2014). This approach contributes to the development of concrete that may likely conserve resources as well as prevent pollution.
Interestingly, the Global construction industry consumes an estimated 20 billion tons of concrete every year and this large annual production of concrete consequently leads to an equally large estimated consumption of component materials of about 15 billion tons of aggregates and 4.2billion tons of cement (Tosi, Marinkovi & Stojanovi, 2017). Given the high volume of concrete produced annually for construction projects, the concrete industry is unquestionably one of the ideal media for the economic and safe use of millions of post-consumer waste plastics (Sandanayake et al., 2020).

The American Concrete Institute ACI (1992) defines concrete permeability as a measure of the amount of water, air, and other substances that can enter the concrete matrix. Permeability is one of the primary parameters responsible for concrete deterioration due to corrosion of reinforcing steel and other deterioration mechanisms (Ahmad and Hossain, 2017). Therefore, the durability of concrete is largely dependent on the ingress and movement of liquids and fluids through the concrete (IRICE, 2007).

Studies by Anum and Job (2021); Anum, Job and Dakas (2019) have sufficiently shown that the inclusion of pulverised and chemically treated high density polyethylene to concrete improves its compressive strength, flexural strength as well as its performance at elevated temperatures. The improvement in the properties of concrete according to the aforementioned studies is attributed to the improved bonding that plastic develop with the surrounding matrix. The current study is motivated by the desire to clarify the aspects of the effects of permeability on the modified concrete that remain unknown. Findings from this study are expected to also help in minimising carbon (iv) oxide (CO_2) emission into the atmosphere since the typical disposal method of waste plastics is primarily by burning. This study also has potential application for the production of light weight concrete, cost savings for raw materials and the creation of decorative and attractive landscaping for sustainable natural environment (Al Bakri, Tamizi, Rafiza & Zarina, 2011).

2. MATERIALS AND METHODS

2.1. Materials

2.1.1. *Cement*

Ordinary Portland cement 42.5R grade “BUA” conforming to ASTM C 150/150M (2022) was used for the preparation of all concrete samples used for this study.

2.1.2. *Fine Aggregate*

Good quality river sand belonging to zone I and passing through 4.75mm BS sieve sourced from Jere town in Kagarko Local Government Area of Kaduna State was used. The suitability of the sand for the intended use was ascertained in the laboratory in accordance with the provisions of BS EN 12620 (2013).

2.1.3. *Coarse Aggregate*

The coarse aggregates used for this study were 20mm nominal sizes natural machined crushed rock sourced at Dutse Alhaji, Abuja. The suitability of the crushed stones was ascertained in the laboratory in accordance with the provisions of BS EN 12620 (2013).

2.1.4. *Pulverised High-Density Polyethylene*

The high-density polyethylene (HDPE) was sourced from landfills in Jimeta, Yola North local government Area of Adamawa State, Nigeria. The preparation of the high-density polyethylene was as reported by Anum, Job and Dakas (2019); Anum and Job (2021). They were first sorted, cleaned and washed properly to remove impurities. The HDPE were then mechanically pulverised into smaller particles passing 2 mm BS sieve using a locally fabricated pulverising machine. The powder was chemically treated with 20% hydrogen peroxide by immersion to make the particles hydrophobic. Sieve analysis was then performed on the pulverised high-density polyethylene after taking the samples to approximately saturated surface dry (SSD) condition as shown in Figure 1.

Fig. 1: Pulverised and Sieved High Density Polyethylene

2.1.5. *Superplasticiser*

The superplasticiser used in this study was Hydroplast - *500* conforming to ASTM C 494 (2022). This product was procured at Armosil West Africa Garki, Abuja and used throughout the experiment for requisite workability of the matrix.

2.1.6. *Water*

The water used for this research work was Potable water sourced from Nigerian Building and Road Research institute laboratory, supplied by the Federal Capital Territory Water Board. The water was used throughout this research work both for mixing as well as curing of the concrete and in accordance with the provisions of ASTM C192(2018).

2.2. *Methods*

2.2.1. *Preparation of Specimen*

The concrete cube specimens were prepared using 150mm^3 steel moulds and in accordance with the provisions of ASTM C 192 (2018) at the Materials and Concrete laboratory of the Nigerian Building and Road Research Institute (NIBRRI) Abuja, Nigeria. Concrete mixes were prepared adopting the BRE method of mix design and the quantity of materials required per cubic metre of concrete as computed by the mix design is shown in Table 1 as reported by

Anum and Job (2021). The samples were prepared with pulverised HDPE of fine consistency 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 to enhance the workability of the matrix. A constant water/cement ratio of 0.4 and 0.36 for requisite workability was adopted for grades 25 and grades 50 concrete respectively. Investigation was carried out on the hardened concretes cubes to determine the effects of permeability on them.

Table 1: 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*

Fig. 2: Casting and vibration of concrete cubes using hand vibrator

2.2.2. *Determination of Water Permeability*

The coefficient of water absorption is a measure of permeability of concrete according to Ganesan et al. (2008) and Abalaka and Okoli (2013). The coefficient of water absorption according to the authors is determined by measuring water uptake in dry concrete in a time of 1 hour. This implies that the method adopted in this study for the measure of permeability characteristics is the coefficient of water absorption (m^2/s). The concrete specimens were heated in an oven at 50 ^{0}C until a constant weight was attained and the cubes were allowed to cool gradually to room temperature for 24hrs. Four sides of 150mm cube samples were sealed with 1mm thick silicone sealant to a height of 30mm to allow water absorption on only one surface of the cube. The samples were immersed to a depth of 10mm in water on only one surface as shown in Figure 3 (a) and (b). After immersion in water for one hour, the cubes were taken out and the wet surface was wiped of excess water and weighed. Consequently, the coefficient of water permeability of the specimen at 7, 28 and 90 days was calculated from equation 1. (Ganesan et al. 2008).

$$Ka = \left(\frac{Q}{A}\right)^2 \text{ x} \left(\frac{1}{t}\right) \quad \ldots\ldots (1)$$

Where:

Ka = the coefficient of water absorption

t = time taken to absorb the water in seconds

Q = Quantity of water absorbed)

A = Surface Area through which water was absorbed

Figure 3 (a) Test for Coefficient of water absorption = Permeability

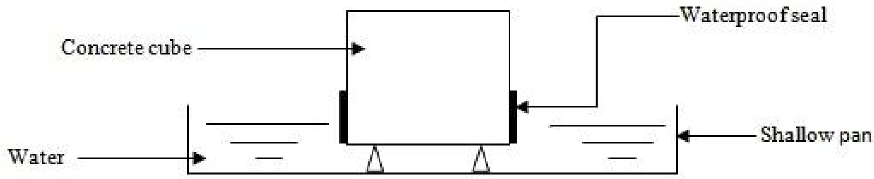

Fig. 3 (b): Test for Coefficient of water absorption = Permeability (Schematic)

3. RESULTS AND DISCUSSION

The properties of the materials used in this work are presented in Table 2 as reported by Anum and Job (2021)

Table 2: Properties of Materials Used

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

Figures 4 and 5 show the relationship between coefficients of permeability of the various grades of concretes with hydration period of up to 90 days of curing in water. The results indicated that in all the grades of concrete investigated, coefficient of permeability decreased with the curing age. The trend of decreasing permeability in all the mixes with HDPE content between 7 and 90 days was observed to be similar to that of the control mixes. This decrease could be attributed to the increase in formation of calcium silicate hydrate gel in the concrete.

For Grades M25 concrete at early age (7days) test, 1% HDPE content gave the highest percentage reduction (33.3%) in coefficient of permeability compared to control samples while at maturity age (90days) recorded the highest percentage reduction (50%) with the same 1% HDPE content compared to the control mixes. Similarly, for Grades M50 concretes at early age (7days) test, 1% HDPE dosage gave the highest percentage reduction (61%) compared to control mixes while at maturity age (90days) recorded the highest percentage reduction (62%) at the same highest HDPE dosage of 1% compared to the control samples.

It was generally observed that the reduction in coefficient of permeability increased with increase in HPDE content in the mixes. The treatment on the HDPE is thought to have affected the surfaces of the polymers by increasing surface energies, wettability, and adhesion, allowing them to attach to cement paste more efficiently and improving concrete porosity. This decrease in the coefficient of permeability of the modified concrete recorded could also be attributed to the hydrophobicity of the high-density polyethylene (with water absorption capacity of 0.067%) which is almost negligible and lower than that of the natural aggregates present. The above findings were comparable to the results obtained by Bayasi and Zeng (1993) who reported a decrease in permeability of concrete containing polypropylene fibres; similarly, Wang and Meyer (2012) also reported a decrease in permeability of concrete containing high impact polystyrene fillers in concrete. It was also observed from the results that permeability values for Grade M50 concretes were lower (less impervious) compared to the Grade M25. This could also be as a result of the denser microstructure of the Grade M50 concrete occasioned by a lower water to cement ratio resulting to less permeability.

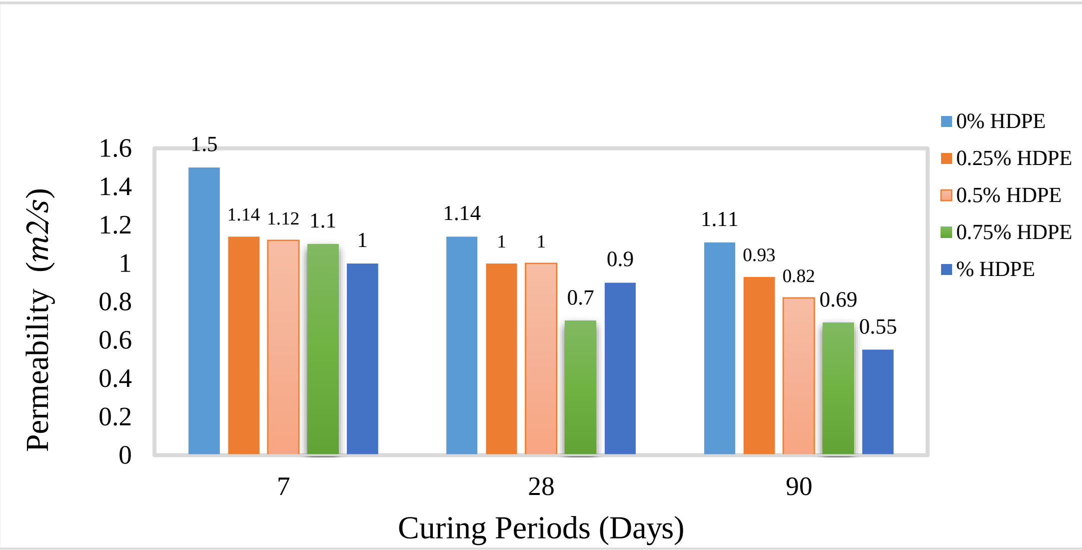

Fig. 4: Coefficient of Permeability with Curing Period for M25 Concrete

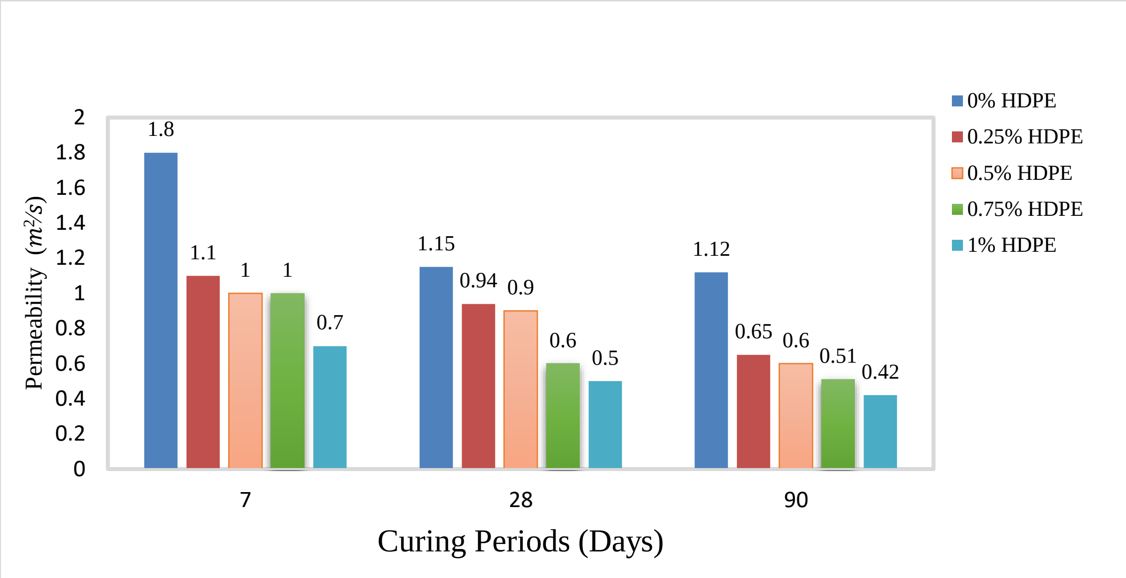

Fig. 5: Coefficient of Permeability with Curing Period for M50 Concrete

4. CONCLUSION

The findings of this investigation established that coefficient of water permeability in all grades of concrete investigated decreased with the curing age but increased with HDPE content compared to control mixes. A maximum reduction of 50% (0.55m^2/s) for grade M25 and 62% (0.42m^2/s) for grades M50 with 1% HDPE content at 90 days respectively. It was further observed that the values of the coefficient of permeability of grades M50 concretes were lower (less impervious) compared to that obtained for grade M25 concretes as a result of the denser microstructure of grade M50. Permeability of the modified concrete was minimal with 1% weight fraction of pulverised HDPE for both grades of concrete investigated. Based on the findings, the study suggests that HDPE concrete could be useful in building and civil engineering infrastructure that require impermeable concretes, such as swimming pools, roof parapets, and water retention structures, while also lowering environmental pollution. The study also recommends using grade M50 (high strength concrete) in harsh situations due to its lower permeability and promise of improved durability.

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