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Study on the effects of sulphuric acid attack on Normal Concrete Replaced with fine Plastic Wastes

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Abstract: - This study investigated the performance of normal-concrete with fine waste plastic particles replacement against sulphuric acid attack by determining the workability, reduction of compressive strengths of cured specimens, and water absorption of waste plastic-concrete when exposed to sulphuric acid (H_2SO_4). Waste plastic was incorporated as a partial replacement for fine aggregate at 0%, 5%, 10%, 15%, and 20%. A total of one hundred and twenty cubes were cast, and they were cured in water for up to 56 days. The first 60 cubes underwent a compressive strength test at 7, 14, 28, and 56 days, whereas the remaining 60 cubes were cured in water for 28 days and later exposed to a 5% solution of sulphuric acid, and then tested for compressive strength at 7, 14, 28, and 56 days. Compressive strength test, water absorption test and Slump test were performed according to BS EN 12350-2 (2009), BS 1881-122 (2011), and BS EN 12350-2 (2009) respectively. According to the test result, the workability (slump) of waste plastic–concrete increases with an increase in waste plastic replacing fine aggregate in the mix. The compressive strength of waste plastic concrete shows an increase in strength with an increase in curing days even at and the incorporation of a higher percentage of waste plastic. The percentage increase of waste plastic in the mix yields more resistance to sulphuric acid. The research has shown a reduction in the weight of concrete with an increase in the percentage of waste plastic and an exposure period, while an increase in water absorption was observed. To increase concrete's resistance against sulphuric acid attack, it is concluded that an optimum replacement of fine aggregate with waste plastic in concrete production should be limited to 5% replacement.

Key Words: Concrete, Waste Plastics, Sulphuric Acid, Durability, Compressive Strength, Density, Water Absorption

I. Introduction

Concrete is made of mixtures of cementitious material, aggregate (fine and coarse), and water. It is the most frequently used construction material worldwide [1]. Concrete is recognized as the most popular construction material because of its high compressive strength, good fire resistance, and low maintenance cost [2]. Concrete is utilized extensively and plays a critical role in meeting the global need for globalization in infrastructural development. As a result, the increasing demand for concrete has led to significant consumption of fine aggregate, which makes up roughly 30% to 35% of the concrete mix ratio [3]. Material mined every year amounts to between 47 and 59 billion tonnes, with fine aggregate (sand) and coarse aggregate (gravel) accounting for the largest percentage (about 68–85%), as well as the fastest increase in its exploitation rate [4]. This level of exploitation has led to an increase in the cost of concrete production and environmental degradation. The dredging of creeks, riverbeds, and lake basins has resulted in an ecological imbalance, thereby, affecting bio-diversity and the landscape, as well as having socio-economic, cultural, and political consequences [5]. This motivated researchers in the academic and engineering fields to look for a suitable eco-friendly material that can be utilized efficiently in construction activities as a substitute for natural sand and can reduce the cost of producing concrete [6].

In engineering, plastics, which are also called polymers, are materials made of a wide range of organic compounds that can either be synthetic or semi-synthetic and are easily formed into different solid forms. [7]. Therefore, it is possible to trace the development of plastic forming to the methods used to process natural high polymers like amber, lacquer, shellac, horns, tortoiseshell, and tusks. Nigeria is Africa's largest producer and consumer of plastic [8]. Plastic suitability for numerous uses in a variety of items, comprising wide-ranging features like versatility and resilience, has led to increased manufacturing and use of plastic, surpassing many other man-made substances [9]. Plastics, which are natural organic polymers with a high molecular mass [7], could be recycled and used in the construction industry for reinforcing materials. Combining crushed plastic waste materials with concrete improves the composite material's mechanical and physical strength [10].

As a result, several studies on the viability of employing waste plastic as an alternative to fine aggregate have been carried out by different researchers. Ghernouti et al. [11] studied the use of waste plastic as a partial replacement for sand. The authors reported an increase in a slump and a decrease in density while the compressive strength remains close to control as the percentage of waste plastic increases. Suganthy et al. [12] reported a decrease in density as the percentage of waste plastic increased. Amalu et al. [13] reported an increase in slump as waste plastic content in the concrete increased. He further stated that, as the percentage of waste

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plastic increased, there was a decrease in compressive strength at 28 days, but it remained relatively constant at other curing days. Jaffe et al.'s [14] study show that the compressive strength at 28 days was relatively constant until a replacement of 30%, which had a reduced strength compared to the control. Sreenath & Harishankar [15] reported an increase in compressive strength of up to 10% by replacing sand with waste plastic.

Due to its wide range of applications, concrete is sometimes used in harsh environments like wastewater treatment facilities and sewage, where it can be attacked by acid and other chemicals, leading to the total collapse of the facilities it is used in before reaching its intended life span. Normal Portland Cement (NPC) concretes are susceptible to early-age cracking caused by drying shrinkage, just like any other type of concrete. This can reduce durability because the material's resistance to external attacks relies on both its inherent permeability and the pattern, form, and size of the cracks. Early cracking and the capillary network serve as the first contact points for outside elements that could shorten the lifespan of concrete [16]. Sulphuric acid (H_2SO_4) is one of the most damaging agents to concrete, degrading and damaging structures depending on concentration and method of formation [17]. The oxidation of iron sulfide minerals such as marcasite or pyrites in soils and groundwater can result in the production of sulfuric acid [18]. Hence, research has been carried out on the effect of these damaging acids on concrete.

Sakr et al. [19] studied the effects of a physical salt attack on concrete by exposing it to physical salt and salt-frost scaling. The investigation revealed that ethyl silicate, acrylic emulsion, and epoxy coatings can be used to protect concrete against physical attack, while a 50% concentration of colloidal nano-silica can minimize the effect of physical salt attack and salt-frost scaling against concrete. A set of six different concrete mixtures containing plastic waste was prepared as a partial substitute for sand with substitution levels 0%, 10%, 20%, 30%, 40% and 50%. It was tested to determine the behaviour of fresh and hardened concrete in terms of workability, unit weight, compressive strength, flexural strength, tensile strength, pulse velocity and fire-resistant behaviour. The results from the experiment showed a reduction in unit weight, the sand replacement harmed the concrete mechanical properties at varying rates and proved that plastic waste can be disposed of by specific ratios and therefore, can be effectively applied in industrial usage [20]. Ismail and El-Hashmi carried out study on plastic waste concrete. The study insures that reusing waste plastic as a sand-substitution aggregate in concrete gives a good approach to reduce the cost of materials and solve some of the solid waste problems posed by plastics [21]. Musa and Uche [22] researched the durability of concrete containing scrap tires as a replacement for fine aggregates. They reported an increase in slump, water absorption, and dry shrinkage. Babafemi et al. [23] assessed the effect of temperature on concrete incorporating waste plastic as a partial replacement for fine aggregate. They reported no significant change in the compressive strength. Murthi and Sivakumar [24] examined the resistance of ternary mixed concrete against sulphuric and hydrochloric acid solutions. The outcomes were contrasted with those of the binary blended concrete and the control. According to the experiment, ternary blended concrete outperformed binary blended concrete and plain concrete in terms of acid resistance.

The use of some waste materials such as quarry dust, fiber, and scrap tires in concrete has shown significant improvement in resisting sulphuric acid attacks. Also, studies on the use of ternary mixed concrete show durability against chemical attack, while ethyl silicate, acrylic emulsion, and epoxy have proven to be durable against physical salt attack and salt-frost scaling. Even though several studies have been conducted to improve the quality, longevity, compressive strength, and chemical resistance of concrete at the lowest possible cost, this study intends to investigate the effect of sulphuric acid on concrete when waste plastic is used as a partial replacement of fine aggregate.

The effect of substituting fine aggregate with waste plastic in various proportions (i.e., 0%, 5%, 10%, 15%, and 20%) by weight of fine aggregate and the impact of sulphuric acid on concrete were evaluated using a specified concrete mix ratio of 1:2:4 to target a concrete with compressive strength of $20N/mm^2$, and a water-cement ratio of 0.45 in order to reduce the fluidity of the concrete mix to a minimum. A total of 120 (100 x 100mm size) specimens were produced. Slump tests and compressive strength tests were carried out on the set of cube samples. A slump test was conducted on freshly mixed concrete as per BS EN 12350 part 2 (2009) [31] to determine the workability of the concrete.

II. Materials and Methods

a. Materials

The materials used for this research work include the followings: fine aggregate, Ordinary Portland Cement (OPC) cement, coarse aggregate, waste plastic, and water.

Cement: The hydraulic binder used for this research work was the Ordinary Portland Cement (OPC) of the Dangote 42.5N brand, which complies with BS 12 (1996) [25]. It was obtained from Danbare Market in Kano, Kano state, Nigeria.

Fine and Coarse Aggregates: For this research work, the fine aggregate used was obtained from Janguza town, Kano state. Sieve analysis and specific gravity tests were carried out per BS 812 (1995) [27].

Waste Plastic: The waste plastic used in this research work was obtained from Bayero University Kano (BUK) campus premises and crushed into smaller particle sizes. The preparation process for the waste plastics used as a fine aggregate in the concrete involves the following steps:

1. Collecting and sorting of waste plastic: The waste plastic bottles were collected from various sources such as households and commercial establishments. The waste plastic bottles were sorted based on the type of plastic and all contaminants such as paper, metals, or other non-plastic materials were removed.
2. Washing and drying of the plastic: The plastics were washed thoroughly to remove all dirt or debris. Then it was dried to completely remove any moisture content.
3. Shredding the plastic into small pieces: A shredder machine was used to shred the plastic into small pieces until the size of the plastic pieces becomes similar to that of the fine aggregate used in concrete. The shredded waste plastics were sieved through a 4.75mm sieve size. Then the plastic passing was used in concrete.

Only the shredded waste plastic material that passes through the 4.75mm sieve and is retained on the 0.075mm sieve (Sieve No. 200) was used for the research. The type of plastic used for this study was Polyethylene Terephthalate (PET). This is a thermoplastic polymer that is commonly used for making bottles and food packaging. The plastic bottles were sourced from coke village in the BUK campus, Kano.

Water: The water used for this research work was obtained from the Civil Engineering Laboratory of BUK, and it meets the specifications of BS EN 1008 (2002) [28].

b. Methods

i. Test on cement

The following tests were carried out on the cement material: Specific gravity as per ASTM C188-17 (2017) [34], initial and final setting time tests were conducted as per BS EN 197-1 (2011) [35].

ii. Test on Fine and Coarse aggregates

The following tests were carried out on fine aggregates: sieve analysis per BS 812-103.2 [29], specific gravity as specified in BS 812-1995 [27], and bulk density as per BS 812-3 (1989) [37]. On the other hand, the following tests were carried out on coarse aggregates: specific gravity per BS 812-1995 [27], aggregate crushing value as per BS 812-110 (1990) [36], aggregate impact value test per BS 812-112 (1990) [30], and bulk density as per BS 812-3 (1989) [37]. . It has a bulk density of 1602kg/m3 and a specific gravity of 2.61. Similarly, the coarse aggregate was obtained from the Janguza area in Kano State. The coarse aggregate has a bulk density of 1685kg/m3 and a specific gravity of 2.74. The fine aggregate used is classified as zone-1 as per BS 882 - Part 2 (1992) [26] classification

iii. Mixing process of fresh Concrete

From the mix design carried out, the proportions of cement, coarse aggregate, fine aggregate, water and plastic waste were presented in Table 1.

Table 1: mix proportion of each material from the concrete mix design

Mix	OPC (kg)	Waste Plastic (kg)	Fine Agg. (kg)	Coarse Aggregate (kg)	Water (kg)
A (0% WP)	5.05	-	11.28	23.76	2.78
B (5% WP)	5.05	5.64	10.72	23.76	2.78
C (10% WP)	5.05	1.13	10.15	23.76	2.78
D (15% WP)	5.05	1.69	9.59	23.76	2.78
E (20% WP)	5.05	2.26	9.03	23.76	2.78

iv. Compressive Strength Test on Waste Plastic Concrete

According to the requirements of BS EN 12390 Part 3 (2009) [32], specimens of hardened concrete containing various percentages of waste plastic at 0%, 5%, 10%, 15%, and 20% subjected to a compressive strength test. The 120 samples produced were cured in water tanks at the Civil Engineering Department laboratory, BUK. The compressive strength of 60 samples were tested after a

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period of 7, 14, 28, and 56 days of curing. After 28 days, 60 samples were exposed to a 5% sulphuric acid (H_2SO_4) solution with a molar concentration of 0.937M. The cube samples were tested to determine their compressive strength after 7, 14, 28, and 56 days of curing in the solution. A total of 15 cube samples were tested for each curing period using the Avery Universal Testing Machine with a capacity of 2000 KN in the concrete laboratory of the Civil Engineering Department, BUK. The compressive strength of each sample was determined using the formula below:

$$\text{Compressive Strength (N/mm}^2\text{)} = \frac{\text{Normal Load (N)}}{Area\ of\ Specime\ (mm2)} \quad (1)$$

v. Water Absorption Test on Waste Plastic-Concrete

The water absorption test was conducted per BS 1881-Part 122 (2011) [33]. A total of 15 samples were dried in an oven for 72 hours at the concrete laboratory of the Department of Civil Engineering BUK. After removing the samples from the oven, it was allowed to cool for 24 hours. The samples were weighed and immediately immersed in water for 24 hours. Upon removal, the excess water was wiped off with a cloth and the samples were weighed again. The water absorption of each sample is calculated using the below formula.

$$\text{Water absorption (\%)} = \frac{\text{Weight of sample immersed in water} - \text{Weight of dry sample}}{Weight\ of\ dry\ sample}\ x\ 100 \quad (2)$$

Plate 1 presents the pictures for the materials and concrete samples used in this study

	
Plastic waste grain	Coarse aggregate
	
fine aggregate	compressive strength test set-up

Plate 1: pictures of materials and test set-up

III. RESULTS AND DISCUSSION

a. Preliminary Test Results

Preliminary tests carried out on cement, coarse, and fine aggregate materials are presented in Table 1 and Table 2, below respectively. The results obtained have satisfied the specifications swith the relevant code recommendations.

Table -1: Test results on Cement

Test	Test Result	Specification	Code
Specific Gravity	3.15	3.10 – 3.16	ASTM C188-17 (2017) [34]
Initial setting time of Cement	70 min	should not be less than 45 minutes	BS EN 197-1 (2011) [35]
Final setting time of cement	390 min	should not be more than 6.5 hours	BS EN 197-1 (2011) [35]

Table 2 presents the physical and some mechanical properties of the materials used in this study. The tests give an idea on the properties of the materials and will definitely be reflected when materials are mixed in the concrete production.

Table 2. Physical and mechanical properties of aggregates

Test	Plastic waste grains	Fine aggregate	Coarse Aggregate	Specification
Water absorption (%)	7	9	6	ASTM D570
Bulk Density (kg.m^3)	1596	1602	1695	BS 812-3 (1989) [37]
Specific Gravity	2.58	2.61	2.74	BS 812-103 (1995) [27]
Aggregate crushing value (%)	-	-	17	BS 812-110 (1990) [38]
Aggregate Impact Value	-	-	23	BS 812-112 (1990) [30]

A graph of particle size distribution of the plastic waste, fine and coarse aggregate are presented in Figure 1.

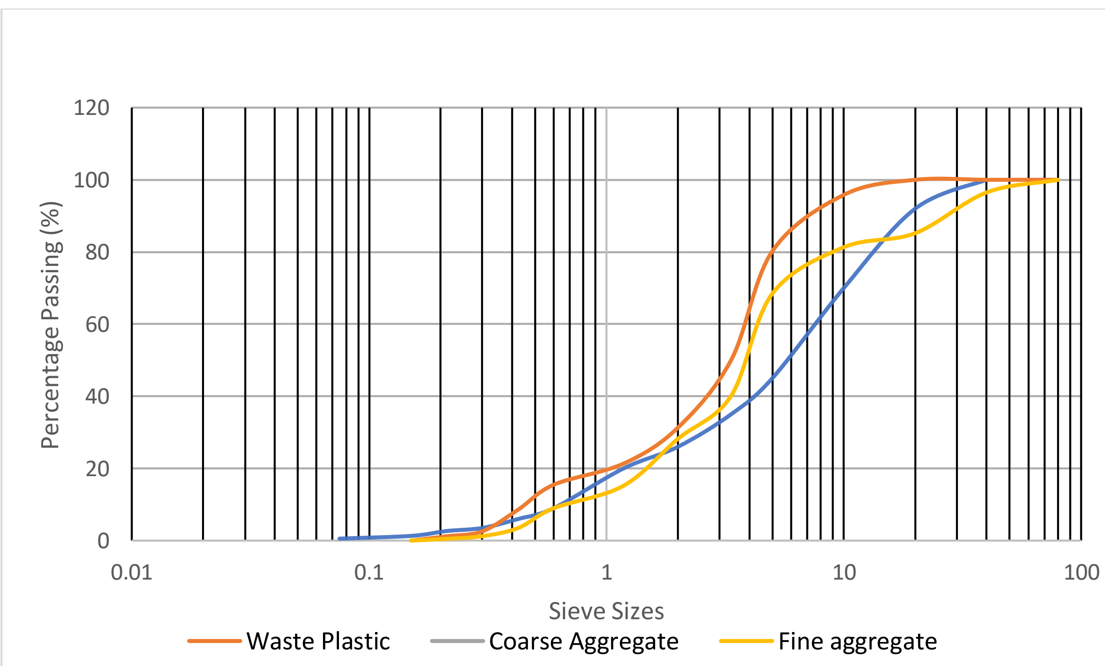

Figure 1. Graphs for sieve analysis of fine aggregates, course aggregates and plastic waste particles

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b. Slump Test Result

Figure 2 shows the result of slump tests carried out on fresh concrete mix of 0-20% plastic waste replacement. The result revealed that the slump increases as the percentage of waste plastic is increases. The maximum increase of 6.12% was observed at 5% replacement when the slump increased from 46mm to 49mm. This agrees with Ghernouti et al. [11], Amalu et al. [13], and Musa and Uche [22]. The finding shows that the concrete containing waste plastic has more ease of handling and placement than the control sample. The low cohesive ability of waste plastic in binding with other materials cause the increase in slump.

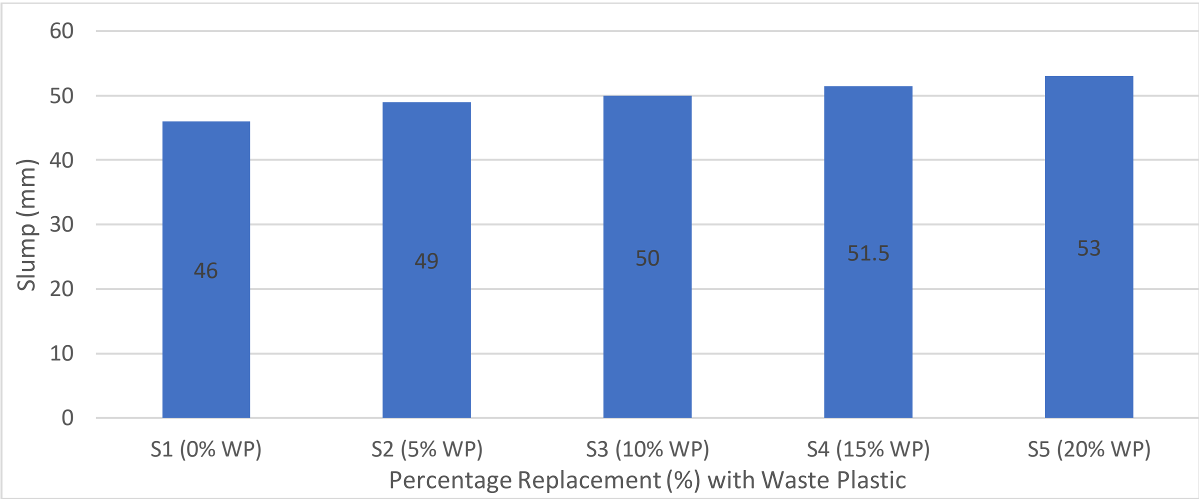

Figure -2: Slump versus percentage addition of Waste Plastic

c. Compressive Strength Test Result of Waste Plastic-Concrete

Figure 3 shows the results of the compressive strength test carried out on waste plastic – concrete. The result showed an increase in compressive strength with an increase in curing age and the addition of waste plastic at 5%. This agrees with Sreenath & Harishankar [15] and Aliyu et al., [20]. Slight increase in strength was observed at 5% replacement, while a decrease in strength was observed from 10% to 20% replacement. At 14 days, a maximum increase in compressive strength of 7.4% was observed at the 5% addition of waste plastic. The strength increased from 18.52N/mm^2 to 20.00N/mm^2. Further increases in waste plastic result in a decrease in concrete strength. The hydration of cement leads to an increase in compressive strength as the curing period increases. The presence of excess waste plastic in the mixture may have hindered the inter-particle bond between the cement particles and aggregates, which is why the compressive strength decreased with the addition of waste plastic at 10% when compared to the control mix.

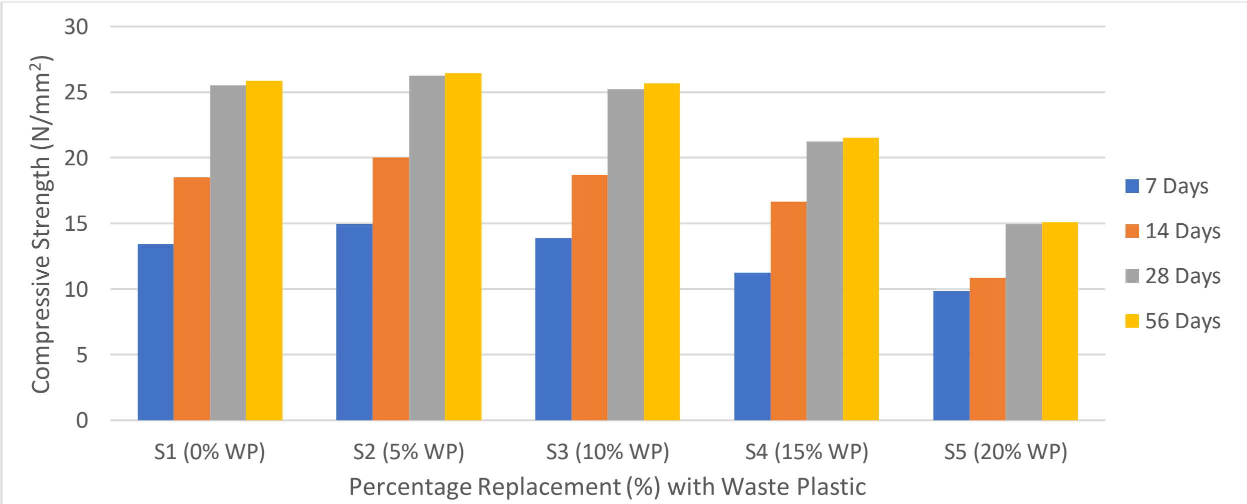

Figure -3: Compressive strength of Waste Plastic – Concrete

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d. Compressive Strength Test Result of Waste Plastic – Concrete Exposed to Sulphuric Acid

Figure 4 shows the result of the compressive strength of waste plastic concrete exposed to sulphuric acid. 0.5% concentration of sulphuric acid was used in this study. The concrete samples were completely immersed in acidic solution for the curing duration as the case may be. At 14 days, the result showed a maximum increase of 18.07% in compressive strength, when a compressive strength of 11.06 N/mm^2 was achieved at 0% replacement and the increases up to 13.50 N/mm^2 at 5% replacement. The maximum reduction of 43.15% in compressive strength was observed at 0% replacement when the strength reduced from 10.59 N/mm^2 at 28 days to 6.02 N/mm^2 at 56 days. Although the findings show that waste plastic slightly improves the resistance of concrete against sulphuric acid attack for a short period (i.e., 14 days), a significant decrease in compressive strength is observed as the curing days increase. This result agrees with Aliyu et al. [20], Kim et al. [21], and Babafemi et al. [23]. This can be attributed to the excellent resistance of high-density polyethylene (HDPE) plastics against sulphuric acid attacks. Plastics are nonpolar, so does not react with acid..

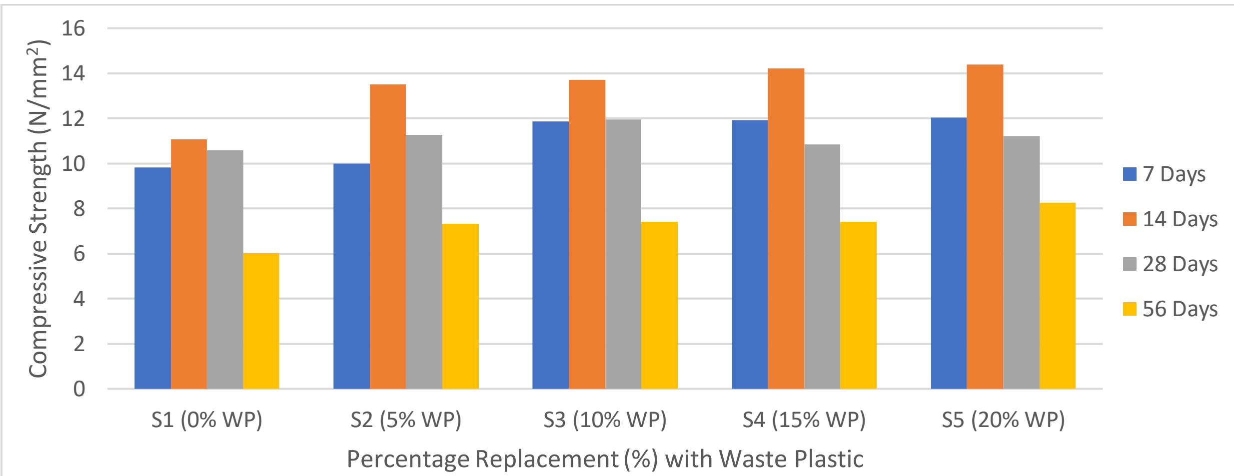

Figure -4: Compressive strength of Waste Plastic – Concrete exposed to Sulphuric Acid

e. Weight reduction

Figure 5 shows the weight reduction of waste plastic-concrete cube samples exposed to the sulphuric acid attack. The result shows a decrease in the weight of concrete with an increase in waste plastic content and also decreased as the exposure duration increases. At 0-day exposure to sulphuric acid, a maximum decrease of 3.5% was observed at 5% replacement of waste plastic, when the weight was reduced from 2544 kg/m3 to 2455 kg/m3. This finding agrees with Sakr et al. [19] and Kim et al. [21]. The weight reduction is a result of the aggressive nature of sulphuric acid towards concrete, which over time deteriorates the components of concrete.

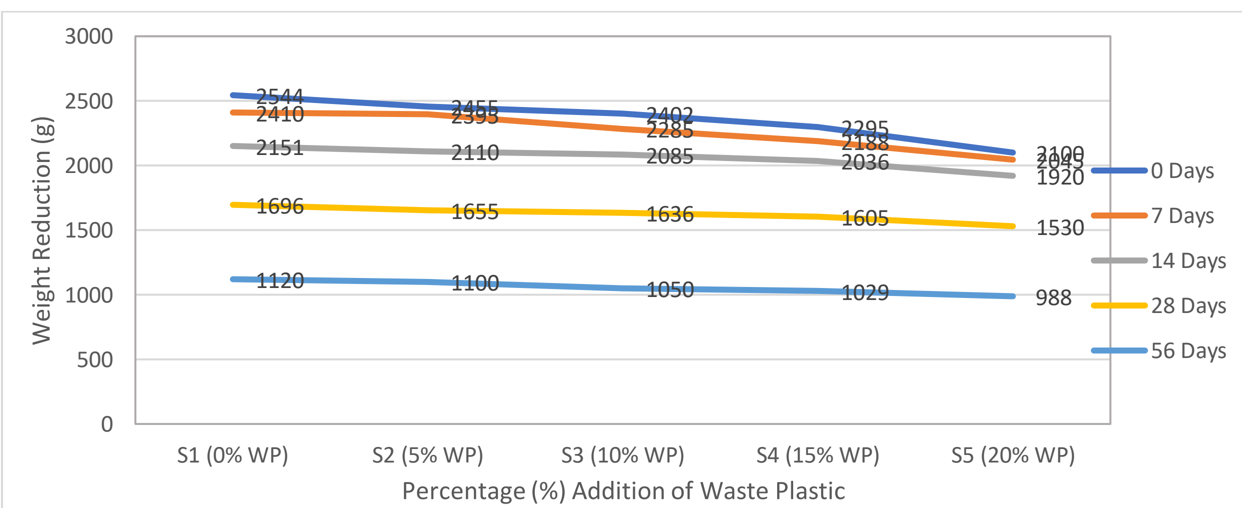

Figure -5: Weight of Concrete exposed to Sulphuric Acid

f. Water Absorption of Waste Plastic-Concrete

From Figure 6, it can be shown that an increase in waste plastic yields an increase in the water absorption rate of waste plastic–concrete. The maximum increase of 8.75% occurs at a 20% addition of waste plastic when the water absorption increases to 3.50% from 3.20%. This result agrees with the findings of Musa and Uche [22]. The ability of waste plastic to entrap air on rough surfaces causes an increase in water absorption. As a result, concrete containing waste plastic becomes porous, thereby enabling more water to be absorbed into the concrete.

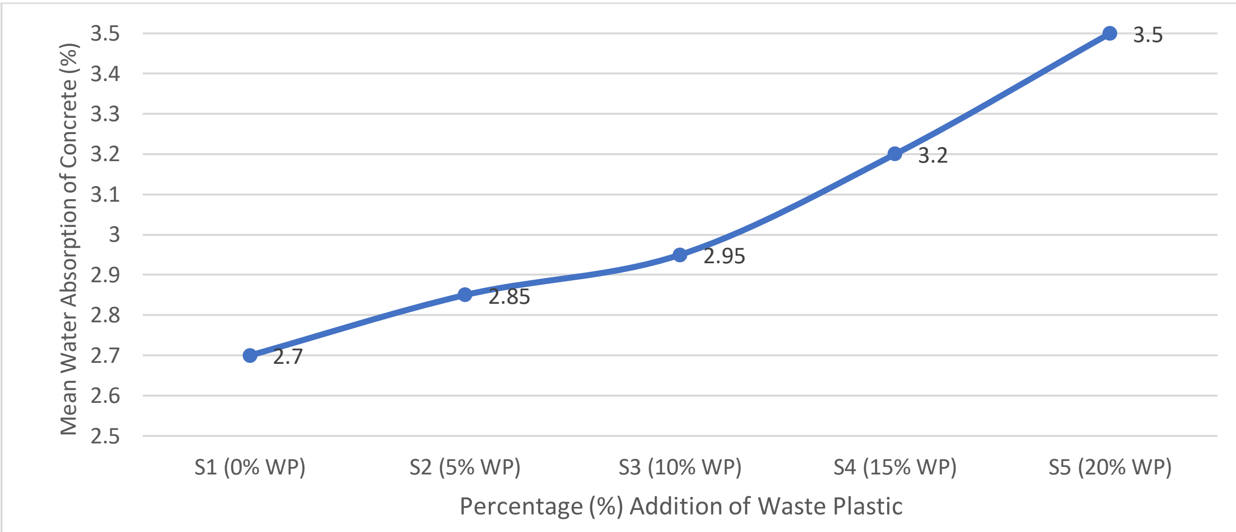

Figure -6: Water absorption vs percentage replacement of Waste Plastic – Concrete.

IV. Conclusion

According to the findings of this study, the addition of waste plastic to the fresh concrete mix increases its workability (slump) and strengthens the concrete's ability to withstand exposure to sulphuric acid attack. An increase in workability and water absorption was observed. The compressive strength of the hardened concrete was increased by 7.4% with the addition of 5% waste plastic, while further addition of waste plastic led to a reduction in the compressive strength of the concrete. As a result, the optimum value of fine aggregate replaced with waste plastic in concrete should be maintained at 5% replacement.

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