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EFFECT OF VOLCANIC ASH AS PARTIAL REPLACEMENT OF CEMENT IN CONCRETE SUBJECT TO AGGRESSIVE CHEMICAL ENVIRONEMNT

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ABSTRACT - Presently researches all over the world is concentrating on alternative materials as partial cement replacement in concrete production. The use of pozzolanic material in concrete is becoming increasingly important because of the need for more sustainable cementing products. Volcanic ash is a form of natural pozzolan and has a chemical composition comparable to other supplementary cementitious materials. In this paper, volcanic ash was used to partially replace cement in the ratio of 0%, 5%, 10%, 15% and 20% by volume in concrete and cured in H_2SO_4 and $MgSO_4$ environment. 28-day target strength was adopted and concrete tested at 7, 14, 28 and 56 days' hydration period. Specific gravity, bulk density and setting time test on volcanic ash were carried out. Fresh concrete tests such as slump and compacting factor test were carried out along-side hardened concrete tests like compressive strength and split tensile strength. The result shows that the maximum compressive strength at 28 days was at 0% control concrete, while at 56 days the maximum strength was observed at 10% replacement of cement with volcanic ash and it is considered as optimum percentage replacement.

Key words: Compressive strength, split tensile strength, magnesium sulphate, tetra-oxo sulphate (vi) acid, Volcanic ash, ordinary Portland cement, specific gravity, bulk density, void ratio, setting time, consistency.

I. INTRODUCTION

Concrete is still the most extensively used construction material, it is versatile in nature and application. Concrete as the most utilized number one structural material is a composite mixture of cement, aggregate, water and admixture. With the global pandemic issues coupled with the imbalance in market trends in terms of cost, the materials used in the production of building and structures has been on the increase, therefore leading high cost of construction as a whole, and the general practice in the practice of building and civil engineering construction largely depend on conventional construction material to a large extent. Reduction in the overdependence on conventional material used in manufacture of building and structural element is presently the trend in the field of construction by resulting to alternative construction material. Also concrete as a versatile material and an important construction material over the world have great impact on the environment. Cement is unarguable an important material in the production of concrete. Cement which is the binder in concrete and one major component and key ingredient in the production of concrete have impact on the environment. Manufacturing of cement is a major source of greenhouse gas emissions [1]. The billions of tons of raw materials of cement mined and processed each year leave a mark on the environment. During the production of Portland cement great amount of energy is required and large quantities of CO_2 is produced and released into the atmosphere. The growing concern of resource depletion and global pollution has led to researches to develop alternative material in construction. The use of supplementary cementitious materials (SCMs) to offset a portion of the cement in concrete is a promising method for reducing the environmental impact of producing cement from the industry. The development of supplementary cementitious materials (SCMs) is said to be fundamental not to only in terms of low-cost but also to improving concrete properties. The main benefits of SCMs include saving natural resources and energy as well as protecting the environment through

the use of these main admixtures [2]. The use of supplementary cementitious materials (SCMs) to offset a portion of the cement in concrete is a promising method for reducing the environmental impact from the industry. Several industrial byproducts have been used successfully as SCMs, including silica fume (SF), ground granulated blast furnace slag (GGBS) and fly ash [3]; also natural occurring materials such as volcanic ash have also been used successfully as SCMs [4]. Another material which has potential as a SCM, however, has not yet achieved the same commercial success is waste glass [5-6]. Supplementary cementitious material and or pozzolans are used to improve strength and certain durability properties of concrete.

According to [7] the use of pozzolan to replace OPC in concrete lower heat development during hardening and improve durability of the final concrete structures. Among the pozzolans used in concrete, volcanic ash has been identified as having potential for use as partial replacement of cement in the production of concrete. Volcanic ash is a form of natural pozzolan and has a chemical composition comparable to others SCMs [4]. Natural pozzolans include; clay and shales, opalinc cherts, diatomaceous earth, volcanic ash, volcanic tuffs and pumicites, Artificial pozzolans include; fly ash, blast furnace slag, silica fume, rice husk ash, metakaoline and surkhi. Volcanic ash, being one of the classifications of natural pozzolans, is environmentally friendly, economical and accessible.

According to [2], volcanic rock is formed as a result of volcanic eruption which can be found in volcanic areas around the world e.g. Japan, USA, Iranian plateau, Adamawa highlands extending to Cameroonian highlands. [4] carried out research on natural pozzolan (volcanic ash) to replace ordinary Portland cement (OPC) in concrete, the result showed that the material can be used to partially replace ordinary Portland cement. This can lead to reactions between major constituents of Portland cement and that of the volcanic ash known as pozzolanic reaction. Pozzolanic reactions are silica reactions that take place in the presence of calcium hydroxide and water to produce calcium silicate hydrates(C-S-H). This calcium silicate hydrate creates a denser microstructure that increases strength, reduces the permeability of concrete and improves its resistance to chemical attack [8]. [4] carried out a research on volcanic ash and the results showed that volcanic ash possessed pozzolanic characteristics of natural pozzolans and recommend that it can be used to partially replace cement in concrete. These materials are used to create blended cements which can improve concrete durability, early and long term strength, workability and economy [9].

Concrete structures are built in highly polluted urban and industrial areas, aggressive marine environments and many other hostile conditions where materials of construction are found to be non-durable. Aggressive chemical environment is an environment with the presence of chemicals such as acid, salt water which affects the properties of concrete. When a concrete member is exposed to harsh environment area, the surrounding environmental factors can affect concrete durability. This environmental factors cause several types of deterioration in concrete. In most of the cases, the concrete degradation process involves the penetration and subsequent movement of water, air, or other fluids which are transporting aggressive agents into concrete pore system [10]. According to [7] use of pozzolan to replace OPC in concrete lower heat development during hardening and improve durability of the final concrete structures. Concrete can be proportionally made strong but not durable. [11] considered long service life as synonymous with durability and further stated that durability of concrete is the ability to perform satisfactorily in the exposure condition to which it's subjected to, over an intended period of time with minimum of maintenance. [12] stated that in the past, concrete researchers and designers paid too much attention on compressive strength neglecting other properties of concrete like durability.

One of the most important aspects of durability which is of concern is chemical attack which results in volume change, cracking of concrete and the consequent deterioration of concrete. However, it has now been recognized that compressive strength of concrete alone is not sufficient to judge the quality of concrete, the degree of aggressiveness of the environment to which the concrete is subjected to, is equally important to look upon. Consequently, both strength and durability have to be considered thoroughly at both the research and design stage [12]. Therefore, this study aims to investigate the effect of volcanic ash as partial replacement of cement in concrete subject aggressive chemical environment.

II. EXPERIMENTAL PROGRAM

2.1 Materials

Materials used in carrying out this research activity include cement (CEM 1 of strength grade 42.5R). The percentage of clinker and gypsum in the cement was 95–100% and 0–5% respectively, while the specific gravity of OPC was found to be 3.15 according to [13], fine aggregate, coarse aggregate, water and volcanic ash. Ordinary Portland cements obtained from the cement vendors was used. Locally available clean river sand passing from 4.75 mm sieve free from

inorganic materials was used. Coarse aggregate having maximum size of 20 mm clean and free from clay and other ingredients was used in the preparation of concrete mix. Volcanic ash was grinded and passed through sieve 75µm before using it as cement replacement material.

2.2 Mix Proportions

Total 180 specimens were cast for cubes and cylinder produced with cement, fine aggregate and coarse aggregate and volcanic ash using a design mix of 1:2:4 and a water binder ratio of 0.5 for all batches. Dimensions of specimens were 100x100 x100mm for cubes and cylinder specimen of 150mm diameter and height equal to 300mm. One mixture of plain concrete and four other mixture of concrete prepared with 5%, 10%, 15% and 20% replacement of cement with volcanic ash.

2.3 Testing Methodology

Workability and density of hardened concrete of all mixtures were determined as per [14] and [15] respectively. Compressive and split tensile strength was conducted on the specimen of plain concrete, and concrete prepared with substitution of cement by different proportions of volcanic ash of 0%, 5%, 10%, 15% and 20%, at a curing age of 7 days, 14 days, 28 days and 56 days for compressive strength while test was conducted for tensile strength at 28 days and 56 days as per [16] and [17] respectively.

2.4 Curing Media

Two types of curing medium were used which included; 1.2% concentration of H_2SO_4 and 1.2% concentration of $MgSO_4$. 1.2% concentration of $MgSO_4$ and H_2SO_4 used for this research were severe concentration range as indicated by [18]. A bowl that has the capacity up to 200 liters of water was used to cure concrete samples, but only 100 liters of water was poured. This was done to allow the specimens to be placed and cured properly without overflow. The calculation was done in this way:

100 liters of water is equivalent to 100,000g by weight
100,000g of water to 100% concentration of chemical
Unknown gram of water to 1.2% concentration of chemical, therefore mathematically:

50000 = 100%
x = 1.2%

$$x = \frac{100{,}000\, x\, 1.2}{100} = 1200g \text{ - - - - - - - - } (1)$$

2.5 Specific Gravity

Specific gravity of volcanic ash was determined using the procedure in accordance with [19]. The apparatus used during the test include density bottle and stopper, funnel, spatula and weighing balance.

The specific gravity of aggregates was calculated using equation (2)

$$Gs = \frac{M2-M1}{(M4-M1)(M3-M2)} = \text{ - - - - - - } (2)$$

Where: M_1 is the weight of empty cylinder
M_2 is the weight of empty cylinder plus sample
M_3 is the weight of empty cylinder plus water plus sample
M_4 is the weight of empty cylinder plus water

2.6 Bulk Density and Voids

The test was carried out in accordance with [20]. The bulk density of aggregates was calculated using equation 3.

$$D = \frac{M}{V} = \text{ - - - - - - - - - - - - - - } (3)$$

Where D is the density of the specimen in kg/m^3
M is the mass of the specimen in kg
V is the volume of the specimen in m^3

Also mass of the sample was determined by subtracting the weight of empty container from the weight of container plus sample using equation 4.

$$M = B - A \text{ - - - - - - - - - - - - - } (4)$$

Where M is the mass of the aggregate specimen in kg
A is the weight of the empty container in kg
B is the weight of container plus sample in kg

While percentage void was calculated using equation 5

$$\rho = \frac{\text{weight of compacted VA} - \text{weight of uncompacted VA}}{\text{weight of uncompacted VA}} \text{ - } (5)$$

2.7 Setting Time Test

Setting time test and consistency was conducted in accordance with [21]. Initial setting time and final setting time were carried out using Vicat apparatus with the plunger and needle. Five different mixes with 0%, 5%, 10%, 15% and 20% replacement of Portland cement with volcanic ash paste was prepared for setting time test. However, Consistency was determined using equation 6

$$\text{Consistency} = \frac{water\ consumed}{\text{weight of cement cement sample}}\ x\ 100\% \text{ - - } (6)$$

III. RESULTS AND DISCUSSION

3.1 Specific Gravity

Value obtained for specific gravity of volcanic ash as presented in Table 1 is 3.28.

3.2 Bulk Density

Values obtained for compacted and un-compacted bulk for volcanic ash as presented in Table 2 were 1703 and 1499 respectively, while the percentage void of volcanic ash is 13.61%.

3.3 Workability

The results of all the 5 mixtures of the workability of control concrete specimen and concrete prepared as partial replacement of cement with volcanic ash is presented in Figure 1 and 2. The result shows that the workability of concrete increases as the cement replacement with volcanic ash increases. The

maximum increase in workability was observed at 20% replacement of cement with volcanic ash.

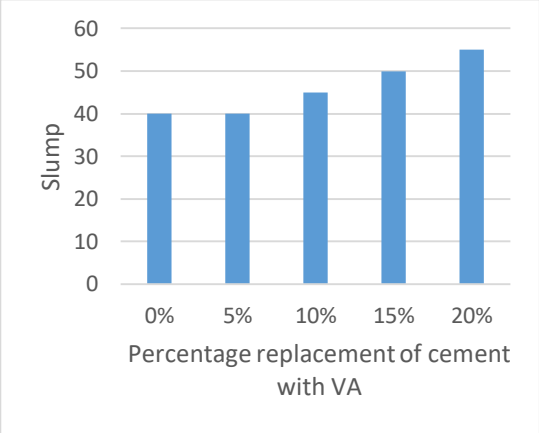

Figure 1: Slump Test Value

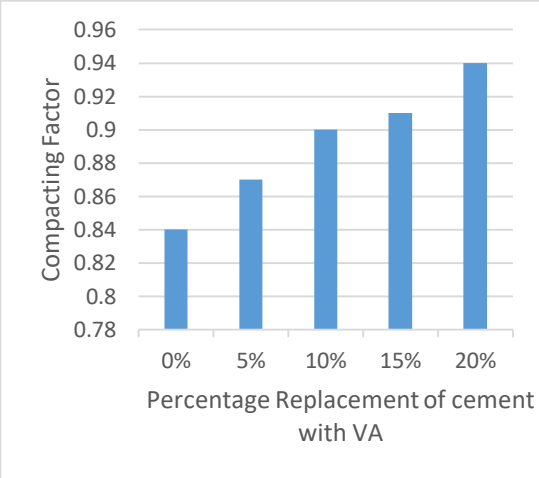

Figure 2: Compacting Factor Test Value

3.4 Setting Time

Values obtained as initial setting time for OPC and OPC/VA pastes at different percentages of 0%, 5%, 10%, 15% and 20% were 47 minutes, 55 minutes, 1hour 5minutes, 1 hour 5minutes and 1 hour 15minutes respectively. Final setting time values were obtained for OPC and OPC/VA pastes as 4 hours 22 minutes, 4 hours 50 minutes, 4 hours 55 minutes, 5 hours 45 minutes and 6 hours 30 minutes. The result is presented in Figure 3.

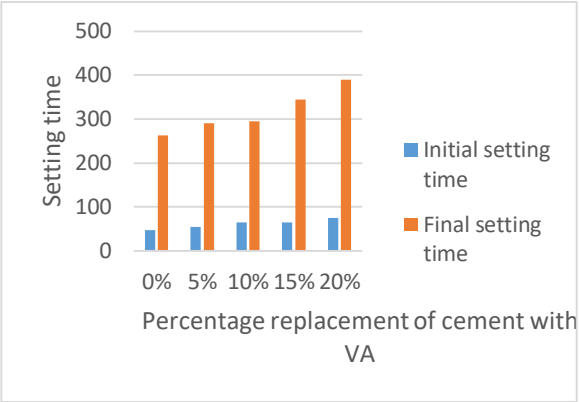

Figure 3: Setting Time Test

3.5 Consistency

Percentage consistency obtained for OPC and OPC/VA pastes at different percentages of 0%, 5%, 10%, 15% and 20% were 27.25%, 28.75%, 29.5%, 29.5% and 30.25%. The result is presented in Figure 4.

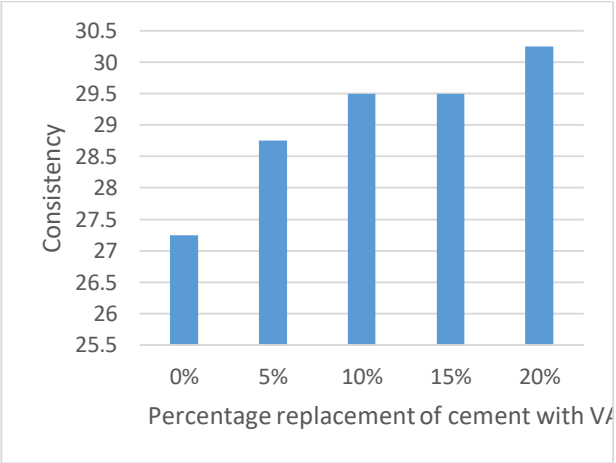

Figure 4: Consistency Value

3.6 Density of Hardened concrete

The results of all the 5 mixtures of density of control concrete and concrete prepared with volcanic ash as partial replacement of cement is presented in Figure 5-8. The result shows that control concrete has increased density above all other concrete using volcanic ash as partial replacement of cement at 28 days, beyond 28days density of concrete partially replaced with volcanic ash up-to 15% shows increased density. Also the density of hardened concrete is increased with volcanic partially replacing cement from (5%-15%). The maximum density at 28 days of concrete specimen in H_2SO_4 curing media was at 0%, 10% and 15%, these shows that the density of concrete partially replaced with volcanic ash is comparable to that of control concrete cured in H_2SO_4 environment. Also the maximum density of specimen cured in H_2SO_4 at 56

days was observed to be at 10% and 15% partial replacement of cement with volcanic ash. The result shows same density for concrete with 10% and 15% partial replacement of cement with volcanic but shows an increase in density of 1.39% as compared to control concrete. Furthermore, the result for concrete cured in $MgSO_4$ solution and at 28days curing period shows same density for concrete produced with 10% replacement of cement with volcanic ash and that of control concrete. There is an increase of 0.60% of concrete produced with 10% and 15% volcanic ash as partial replacement of cement as compared to control concrete specimen cured in $MgSO_4$ medium at 56 days. On further note the density of concrete at 0%, 10% and 15%, shows higher value at all curing ages. While density of cylindrical specimen shows that 10% and 15% have same density and also shows that they have an increase in density of 0.20% as compared to that of the control specimen at 28days in H_2SO_4 curing environment, while at 56 days for concrete cured in H_2SO_4 environment, 15% volcanic ash as partial replacement of cement shows maximum density and it has an increase in density of 0.79% as compared to the control concrete specimen. The density of cylindrical specimen at 28days curing in $MgSO_4$ environmental condition shows higher density for the control concrete as compared to other percentage replacement of cement with volcanic ash, while at 56 days, partial replacement of cement with 15% volcanic ash shows higher density than the control specimen. The result shows that volcanic ash has significant influence on the properties of concrete. In addition, replacement of cement more than 15% with volcanic ash showed reduced density for both cube and cylindrical specimen cured in H_2SO_4 and $MgSO_4$ environment.

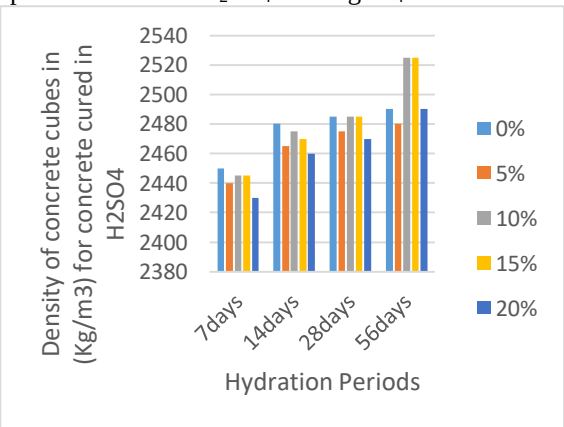

Figure 5: Density of Cubes in H_2SO_4

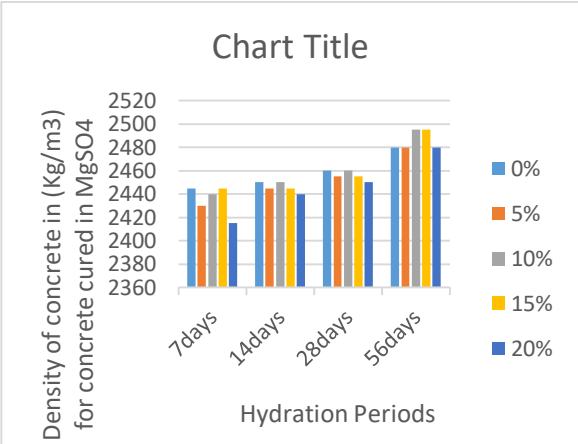

Figure 6: Density of Cubes in $MgSO_4$

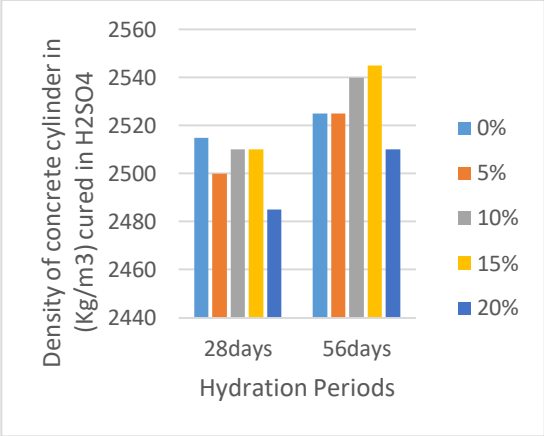

Figure 7: Density of Cubes in H_2SO_4

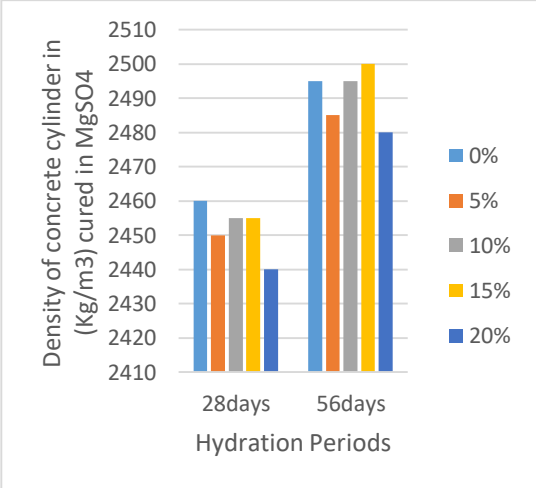

Figure 8: Density of Cubes in $MgSO_4$

3.7 Compressive strength

The results of compressive strength of control concrete and concrete prepared with partial replacement of

cement with volcanic ash of all 5 mixes are shown in Figure 9 and Figure 10. The maximum compressive strength of concrete cured in H_2SO_4 solution at 28 days was observed at 0% control concrete specimen which is above all percentage replacement of cement with volcanic ash. While at 56 days the maximum strength was observed at 10% replacement of cement in concrete with volcanic ash which shows an increase of 2.25% as compared to control concrete specimen. In $MgSO_4$ solution, the maximum strength at 28 days of curing was observed at 0% control concrete which shows an increase in strength over all other cement replacement in the concrete mixes. At 56 days curing age in $MgSO_4$ environmental conditions, the maximum strength was observed at 10% replacement of cement with volcanic ash with an increase of 1.23% as compared to that of control concrete, while 15% percentage replacement of cement with volcanic ash exhibit same strength index with the control concrete. From the result of the study, it can be deduced that volcanic ash as a pozzolanic material has effect on concrete properties at higher curing age above 28 days. On further note, $MgSO_4$ environment has deteriorative effect on concrete properties more than H_2SO_4. However, replacement of cement more than 15% with volcanic ash shows decrease in the compressive strength of concrete. This current study at 56 days shows 10% cement replacement level gave the greatest compressive strength in concrete. However, this means as the curing age increase the strength of concrete produced with volcanic ash as partial replacement of cement to 15% replacement level is increased.

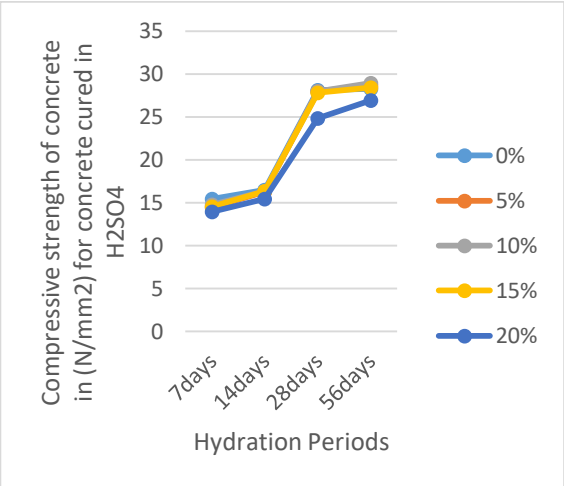

Figure 9: Compressive Strength of Concrete cured in H_2SO_4

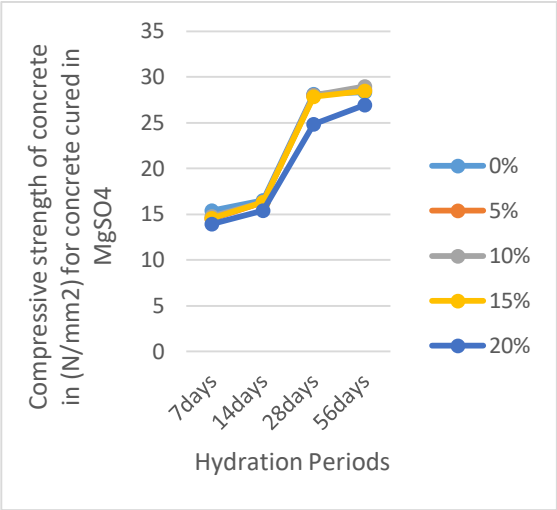

Figure 10: Compressive Strength of Concrete cured in $MgSO_4$

3.8 Tensile strength

The results of tensile strength of control concrete and concrete prepared with partial replacement of cement with volcanic ash of all the 5 mixes are presented in Figure 11 and 12. The maximum tensile strength of concrete cured in H_2SO_4 solution at 28 days was observed at 0% control concrete specimen which is above all percentage replacement with volcanic ash. While at 56 days the maximum strength was observed at 10% replacement of cement in concrete with volcanic ash which shows an increase of 4.32% as compared to control concrete specimen. While in $MgSO_4$ solution, the maximum strength was observed at 0% control concrete which shows an increase in strength over all other cement replacement level in the concrete mixes. At 56 days curing age in $MgSO_4$ environmental conditions, the maximum strength was observed at 10% replacement of cement with volcanic ash which shows an increase of 2.37% as compared to that of control concrete. However, replacement of cement more than 15% replacement level with volcanic ash shows decrease in the tensile strength of concrete.

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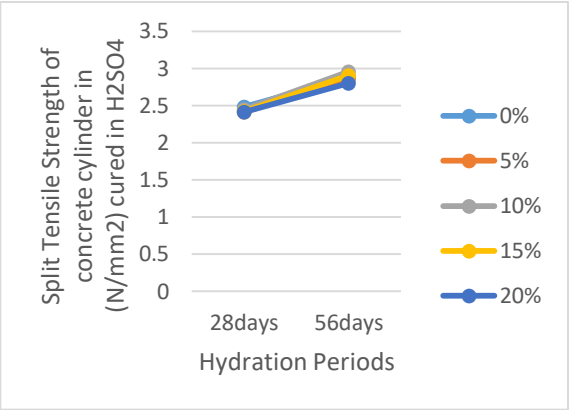

Figure 11: Split Tensile Strength of Concrete cured in H_2SO_4

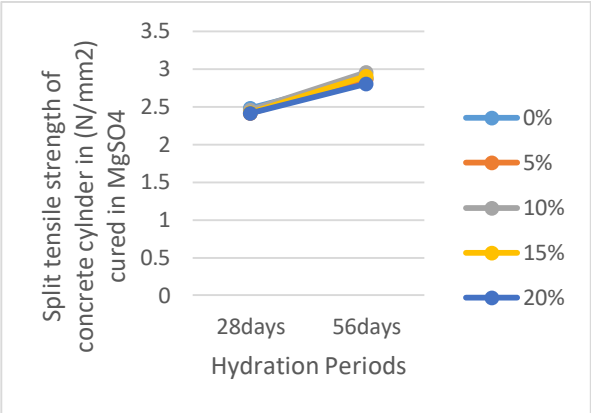

Figure 12: Split Tensile Strength of Concrete cured in $MgSO_4$

Table 1: Specific Gravity Test on Volcanic Ash

Trial	Trial 1	Trial 2	Trial 3
Weight of empty cylinder (M_1) g	13.4	13.6	13.7
Weight of cylinder + sample (M_2) g	64.5	65.2	65.2
Weight of cylinder + water + sample (M_3) g	119.6	119.3	119.6
Weight of cylinder + water (M4) g	84.1	83.8	83.4
Specific Gravity $= \frac{M2-M1}{(M4-M1)-(M3-M2)}$	3.28	3.20	3.37
Average Specific Gravity		3.28	

Table 2: Bulk Density for Volcanic Ash

		COMPACTED			UNCOMPACTED		
Trials		C1	C2	C3		C1	C2	C3
Weight of empty cylinder (M_1) kg	8.10	8.10	8.10		8.10	8.10	8.10	
Volume of cylinder ($x10^{-3}$) m^3	1.55	1.55	1.55		1.55	1.55	1.55	
Weight of cylinder + sample (M_2)	10.72	10.75	10.75		10.41	10.43	10.43	
Weight of sample ($M_2 - M_1$) kg	2.62	2.65	2.65		2.31	2.33	2.33	
Bulk density $\rho = \frac{M1-M2}{volume}$	1690	1710	1710		1490	1503	1503	
Average $= \frac{C1+C2+C3}{3}$		1703				1499		
Percentage void $\rho = \frac{\text{weight of compacted} - \text{weight of uncompacted VA}}{\text{weight of uncompacted of VA}}$				13.61				

IV. CONCLUSION

On the basis of the conducted research, it can be concluded that: the specific gravity of volcanic ash is 3.28. Bulk density of volcanic ash for compacted volume is 1703 Kg/m^3 while the un-compacted bulk is 1499 Kg/m^3.Workability of concrete increases as the dosage of volcanic ash increases, the maximum increase in workability was observed at 20% replacement of cement with volcanic, which mean as the percentage replacement of cement with volcanic ash increase the workability also increases. The initial setting time of cement material shows that for OPC mixes and percentage replacement of cement mixes with 5% volcanic ash was within 1 hour, while for 10%, 5% and 20% was above 1 hour. Furthermore, the final setting time of OPC mix and cement replacement mix with volcanic ash was within 4 to 7 hours. Density of hardened concrete is increased with percentage replacement of cement with volcanic ash up-to 15%. The maximum increase in density of hardened concrete was observed to be 0% at 28 days while at 56 days the maximum density was at 10% and 15% cement replacement with volcanic ash. The maximum compressive strength of concrete at 28 days was at 0% control concrete in both curing media of $MgSO_4$ and H_2SO_4, while at 56 days, 10% replacement of concrete

with volcanic ash gave maximum strength in both curing media of $MgSO_4$ and H_2SO_4. The maximum split tensile strength of concrete at 28 days was observed at 0% control concrete, which was above all other replacement level with volcanic ash. At 56 days curing, the maximum tensile strength of concrete was observed at 10% replacement of cement with volcanic ash in both curing media. The production of volcanic ash for concrete production results in the reduction of CO_2 emission from cement production and save the environment significantly by reducing green-house gas and particulate production. Hence, on the bases of the results, 10% replacement of cement with volcanic ash is optimum. However, further research on microstructural characterization aspect and other durability properties of volcanic ash as partial replacement of cement in concrete is required for sustainable concrete construction practice.

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