Suitability of Waste Glass Powder as Partial Cement Replacement in Concrete Subject to Chemical Aggressive Environment

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***Abstract* - Presently researches all over the world are focusing more on ways of utilizing either industrial or agricultural wastes or other natural material as a source of raw materials for the construction industry. However wastes utilization would not only be economical, but may also help to create a sustainable and pollution free environment. Waste glass is a waste by-product from construction activities and from human consumption of beverage which becomes waste from accidental means. Glass powder contains silica alumina and minute iron content. In this paper, waste glass powder has been 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. Specific gravity and bulk density test on waste glass powder were carried out. Setting time test was also carried out. Fresh concrete tests like compaction factor and slump cone test were carried out along-side hardened concrete tests like compressive strength, split tensile strength. The result shows that 10% replacement of cement with waste glass powder shows increased strength as compared to control concrete and it is considered as optimum percentage replacement.**

***Keywords:* Compressive strength, Split tensile strength, Magnesium sulphate, Tetraoxosulphate (vi) acid, waste glass powder, Ordinary Portland cement, Specific gravity, Bulk density, Void ratio, Setting Time, Consistency.**

I. INTRODUCTION

Concrete is an ubiquitous material and its versatility and ready availability have ensured that it will continue to be of great and increasing importance for all types of construction throughout the world [1]. However the rate of production of this ordinary Portland cement in the world is approximately 2.1 billion tons/year, and is expected to grow to about 3.5 billion tons/year by 2015 [2]. Cement is the most widely used material in building due to its performance in strength requirements and its ability to be cast into a different forms of shapes and sizes satisfactorily. According to [3] cement is one of the essential ingredients of concrete that both contributes to the construction industry and causes environmental problem. Manufacturing of cement (key ingredient used for the production of concrete) is a major source of greenhouse gas emissions [4]. It is expensive to buy when compared to other concrete materials such as gravel, sand, water. The problems of pollution and cost have led to researches on cement alternatives that will fully or partially replace cement in the construction industry [5]. [6]reported that the global move currently is to reduce the amount of Portland cement contents used in the concrete mixtures with cheaper Supplementary Cementitious Material (SCM)/pozzolans to improve certain strength and durability properties of concrete. 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.

The most important single property of concrete is strength this is because the major aim of structural design is that the structural elements must be capable of carrying the loads imposed on it. Strength is also important because it is related to several other important properties that are more difficult to measure directly, and a simple strength test can give an indication of these properties [7]. Concrete produced is presumed to have adequate strength and strong but not necessarily durable. Durability and strength are not synonymous when dealing with the term concrete but with slight difference insight. Durability in terms of concrete is the ability of the concrete material to sustain a particular and individual property and also maintain integrity and strength over time. Concrete durability is defined as the capability of concrete to resist deterioration from freezing and thawing, heating and cooling, the action of chemicals such as deicers and fertilizers, abrasion, or any other environmental exposure [8].

Currently concrete structures are being built in highly polluted urban and industrial areas which is adversely attacked by chemicals, aggressive marine environments, harmful sub soil, water in coastal areas and many other hostile conditions where other materials of construction are found to be not durable [9]. Aggressive chemical environment is an environment with the presence of chemicals such as acid, salt water which affects the properties of concrete. Cement and concrete products can be subjected to attack by various inorganic and organic acids including sulfuric, nitric, hydrochloric, and phosphoric. However, sulfuric acid can be considered as the most common cause of deterioration of these products [10]. There is need for further research on materials of concrete that can withstand the aggressive nature of the soil.

Different aggressive environmental conditions in which concrete are subjected to, are deleterious to concrete. Present world now exist an overwhelming body of laboratory research showing that the careful use of pozzolans is useful in countering all of these problems. Pozzolan is not just a filler material but a strength and performance-improving additive. In general the siliceous pozzolans react with the non-cementitious calcium hydroxide in hydrated cement paste to produce a highly cementitious calcium silicate hydrate that yield higher strength and significantly reduces permeability. The incorporation of pozzolanic material in concrete can significantly enhance its basic properties in both the fresh and hardened states [11]. These materials greatly improve the durability of concrete. The utilization of byproducts as partial replacement of cement has important economic, environmental and technical benefits such as the reduced amount of waste materials, cleaner environment, reduced energy requirement, durable performance during service life and cost effective structures. Pozzolans are used for both their cost reducing and enhanced performance properties. The use of this material can greatly enhance workability, setting times, density, permeability, porosity, durability, and increased strength properties. Another benefit is the reduction of environmental costs of cement production in terms of energy use, depletion of natural resources, and air pollution. Also, the tangible as well as intangible costs associated with landfilling the waste materials are eliminated. However, Pozzolanic materials have long demonstrated their effectiveness in producing concrete with highly required strength and durable performance. These supplementary cementing materials play an important role when added to Portland cement because they normally affect the pore structure of concrete to reduce its permeability and provide resistance to shrinkage in concrete, thus increasing its resistance to water penetration and water related deterioration such as reinforcement corrosion, sulphate and acid attack. Thus the usage of glass powder however reduces the production of waste disposal of glass waste which is of environmental concern resulting from its accumulation in a particular site or area.

The utilization of solid waste materials or industrial waste as partial substitution of cement in concrete is a feasible approach for reducing the usage of Portland cement and consequently decreasing the environmental and energy impact of cement used in concrete production [12]. Different types of bi-products from industrial process are currently used in the production of environmental friendly materials which replace the traditional construction materials. Amongst the various types of industrial bi-products, glass waste is considered appropriate for replacement of cement due to its properties and chemical composition [13]. Glass is very hard, durable and if finely ground, it can serve as a pozzolanic material thus making it suitable for use as partial substitution of cement. Partial replacement of cement with glass powder also improves the strength properties of concrete [13]. However glass waste can be used to make high strength concrete without using other super plasticizers [14]. Furthermore, recycling and re-using glass makes incineration cheap, save a lot of landfill space, decrease construction, reduce cement consumption and reduce greenhouse gases produced from manufacturing of cement. Recycling of glass in construction has been studied for a sometimes and till present. In 1963, glass was used for the first time in the construction industry for “architectural exposed concrete”, since then it has been used in roadway construction and as asphalt [15]. Glass was found to be pozzolanic if ground to particle size less than 75um [16]. Several researches were investigated the waste glass applications in concrete as partial substitution of cement and fine aggregate [13, 17, 18, 19]. The aim of this study is to use the waste glass as a cement replacement material to solve the problem of solid waste generated due to waste glass, to reduce cement consumption, to reduce the CO_2 emission and energy consumption due to production of cement, and to make housing affordable to low income earners through the adoption and utilization of supplementary cementitious materials. However, with the above factors, the objective of this research work is to evaluate the suitability of waste glass powder as partial cement replacement in concrete subject to chemical aggressive environment.

II. EXPERIMENTAL PROGRAMME

2.1 Materials

Materials used in carrying out this research activity include of cement, fine aggregate, coarse aggregate, waste glass powder and water. 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. Waste Glass was washed, dried, grinded and passing through sieve 75µm before using as cement replacement material.

2.2 Mix Proportions

Total 180 specimens were cast for cubes and cylinder keeping cement, fine aggregate and coarse aggregate in ratio of 1:2:4. Water binder ratio maintained as 0.5 for all the 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 mixture of modified concrete prepared with 5%, 10%, 15% and 20% replacement of cement by waste glass powder.

2.3 Testing Methodology

Workability and density of hardened concrete of all mixtures were determined as per [20] and [21] 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 waste glass at the age of 7 days, 14 days, 28days and 56 days for compressive strength while test was conducted for tensile strength at 28 days and 56 days as per [22] and [23] respectively.

2.4 Curing Media

The concrete samples were cured by completely immersing them into the 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 [24]. A bowl that has the capacity up to 200 litres of water was used to cure concrete samples, but only 100 litres 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 litres 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%

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

2.5 Specific Gravity

Specific gravity of waste glass powder was determined using the procedure in accordance with [25]. 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

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

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 according to the [26]. 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.

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

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

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

2.7 Setting Time Test

As described in [27], setting time test was conducted in which consistency, 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 waste glass powder paste was prepared for setting time test.

2.8 Consistency

Consistency was determined using equation 5

$$\text{Consistency} = \frac{\text{water consumed}}{\text{weight of cement cement sample}} \; x \; 100\% \text{- -} (5)$$

III. RESULTS AND DISCUSSION

3.1 Specific Gravity

Value obtained for specific gravity of waste glass powder as presented in Table 1 is 2.59.

3.2 Bulk Density

Values obtained for compacted and un-compacted bulk for waste glass powder as presented in Table 2 were 1504 and 1260 respectively, while the percentage void of waste glass powder is 19.36%.

3.3 Workability

The results of all the 5 mixtures of Workability of control concrete specimen and concrete prepared as partial replacement of cement with waste glass is presented in Figure1 and 2.The result shows that the workability of concrete increases as the cement replacement of waste glass powder is increasing. The maximum increase in workability was observed at 20% replacement of cement with waste glass.

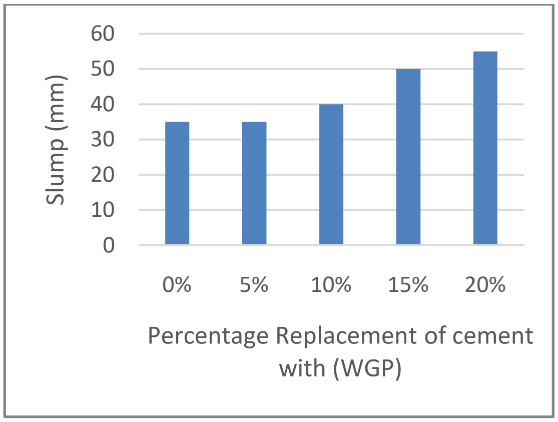

Figure 1: Slump Test Value

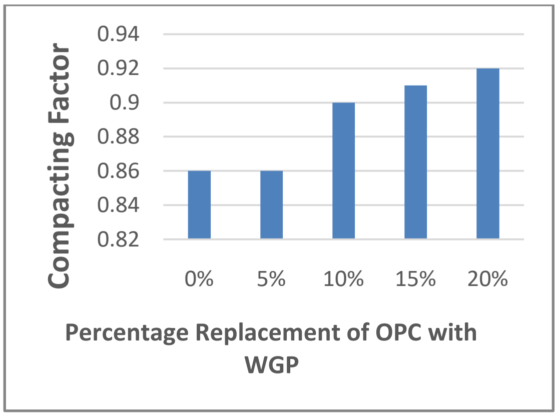

Figure 2: Compacting Factor Test Value

3.4 Setting Time

Values obtained as initial setting time for OPC and OPC/WGP pastes at different percentages of 5%, 10%, 15% and 20% were 47 minutes,53 minutes, 58 minutes, 1 hour 5minutes and 1 hour 15 minutes respectively. Final setting time values were obtained for OPC and OPC/WGP pastes as 4 hours 22 minutes, 4 hours 45 minutes,4 hours 48 minutes, 5 hours 25 minutes and 6 hours 45 minutes. The result is presented in Figure 3.

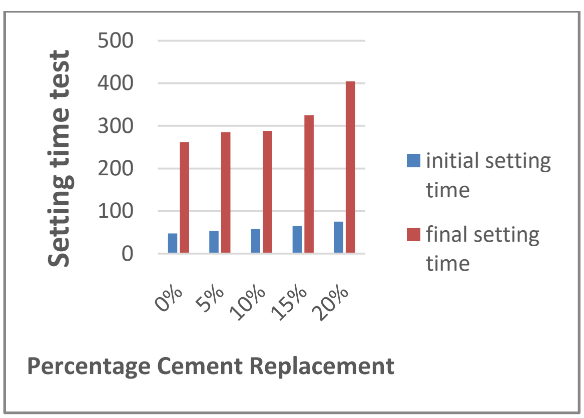

Figure 3: Setting Time Test

3.5 Consistency

Percentage consistency obtained for OPC and OPC/WGP pastes at different percentages of 5%, 10%, 15% and 20% were 27.5%, 27.75%, 28.25%, 28.75% and 29.25%.The result is presented in Figure 4.

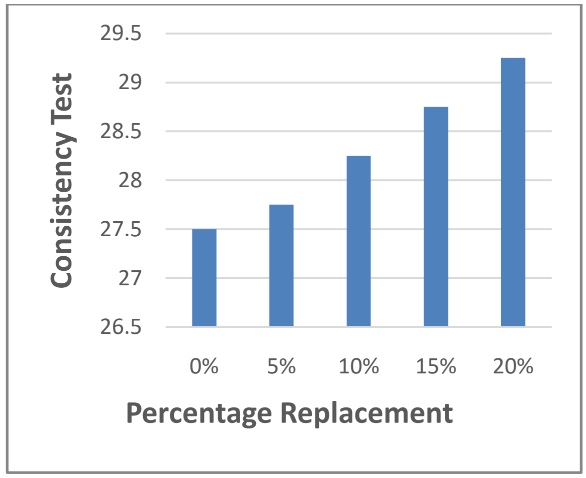

Figure 4: Consistency Value

3.6 Density of Hardened concrete

The results of all the 5 mixtures of density of control concrete and concrete prepared aspartial replacement of cement with waste glass is presented in Figure 5-8. The resultshows that the density of hardened concrete is increased with replacement of cement by waste glass from (5%-10%). The maximum increase at 28 days in H_2SO_4 curing media is 0.20% more density than that of control concrete which was observed at 10% cement replacement with waste glass powder. Also there is an increase of 0.59% at 10% replacement of cement with waste glass powder as compared to controlled concrete. Furthermore at 10% replacement of cement with waste glass powder there is an increase of 1.20% as compared to control concrete specimen cured in $MgSO_4$ medium at 28 days, while at 56 days it showed 0.40% increase in 10% replacement of cement as compared to control specimen in $MgSO_4$ solution. On further note the density of concrete at 10% shows maximum value at all curing days. While density of cylindrical specimen shows that at 10% there is increased in density of 1.23% to that of the control specimen at 28days, also there is increase of 1.79% at 56 days of 10% replacement as compared to that of control concrete in H_2SO_4 curing media. Also at 28 days there is an increase of 0.31% of 10% replacement as compared to that of control concrete, and an increase of 1.52% at 56 days of 10% replacement as compared to that of control concrete specimen in magnesium sulphate curing media. The result shows that waste glass powder has significant influence on the properties of concrete. In addition replacement of cement more than 10% with waste glass powder, the density of hardened concrete is decreased for both cube and cylindrical specimen.

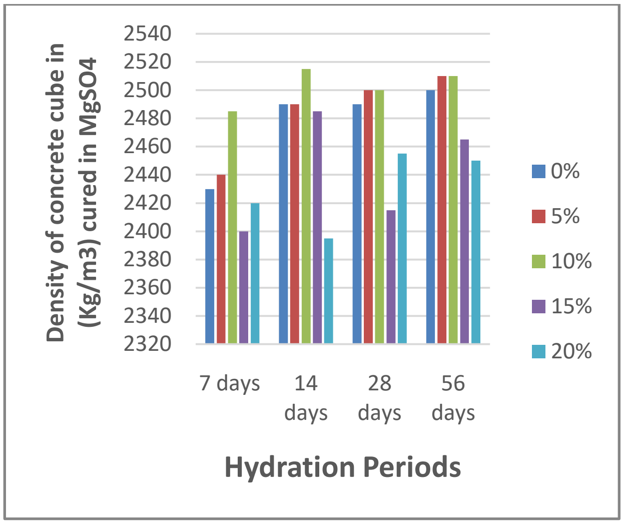

Figure 5: Density of Cubes in $MgSO_4$

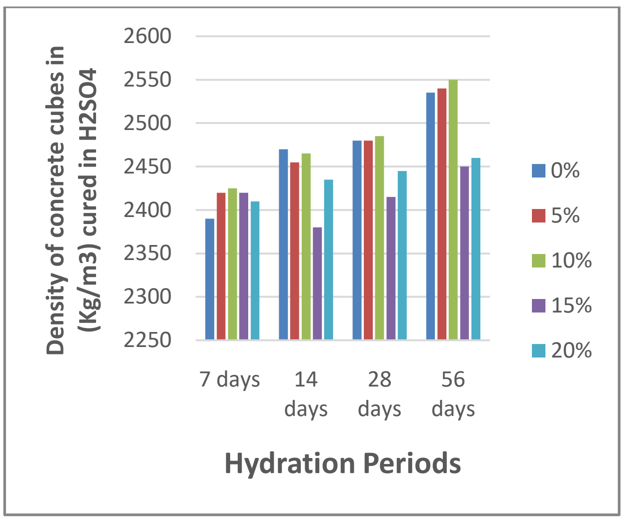

Figure 6: Density of Cubes in H_2SO_4

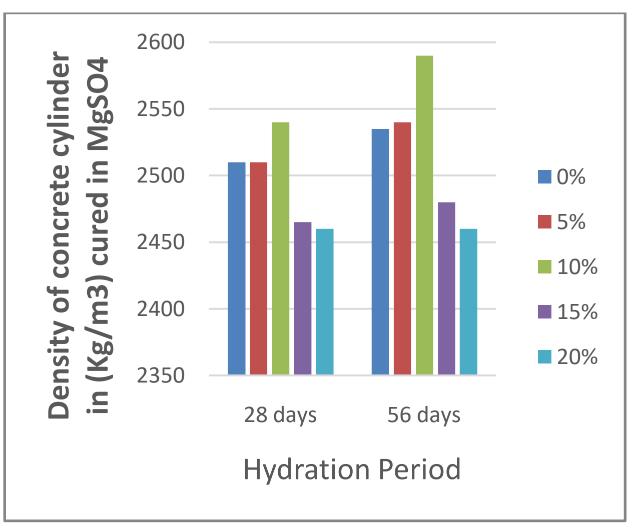

Figure 7: Density of Cylinder in $MgSO_4$

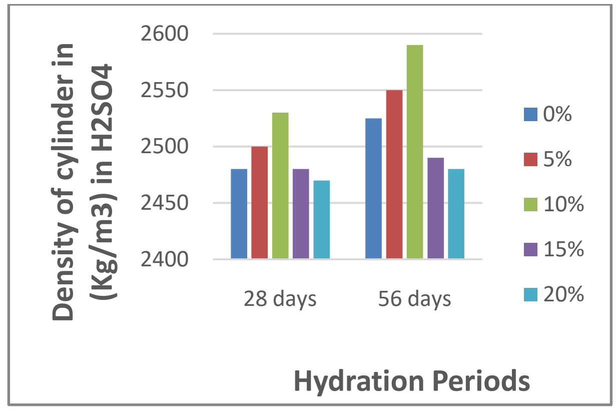

Figure 8: Density of Cylinder in H_2SO_4

3.7 Compressive strength

The results of compressive strength of control concrete and concrete prepared with partial replacement of cement with waste glass powder of all 5 mixes are shown in Figure 9 and Figure 10. The resultshows that the compressive strength of concrete is increases with substitution of cement with waste glass at 10%. Replacement of cement with waste glass powder at 5% shows insignificant increase in the strength index of the concrete specimen. At 28 daysshows 4.61% increase in strength index of 10% replacement of cement with waste glass powder as compared to that of control concrete cured in H_2SO_4 curing media, also at 56 days 10% replacement of cement shows 2.81% increase as compared to OPC concrete in H_2SO_4 curing media. While in $MgSO_4$ curing media, the maximum compressive strength of concrete at 28 days was observed at 10% with an increase of 5.1% as compared to control concrete, also at 56 days the maximum strength index was observed at 10% with an increase of 2.88% as compared to control concrete. However magnesium sulphate curing environment was more deleterious and harmful to the concrete specimen from the result obtained and from physical observation. On further replacement of cement with waste glass powder above 10%, the compressive strength of concrete decreased.

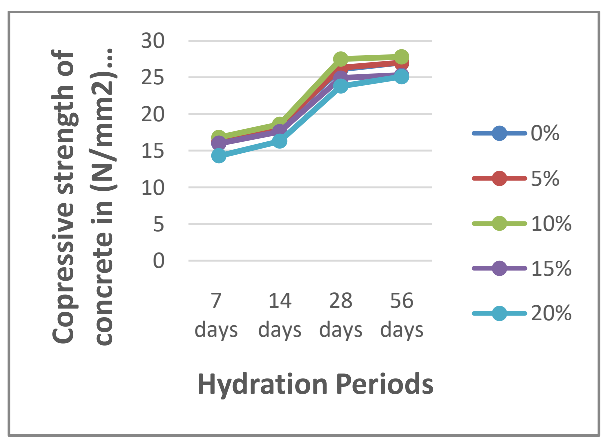

Figure 9: Compressive Strength of Concrete cured in $MgSO_4$

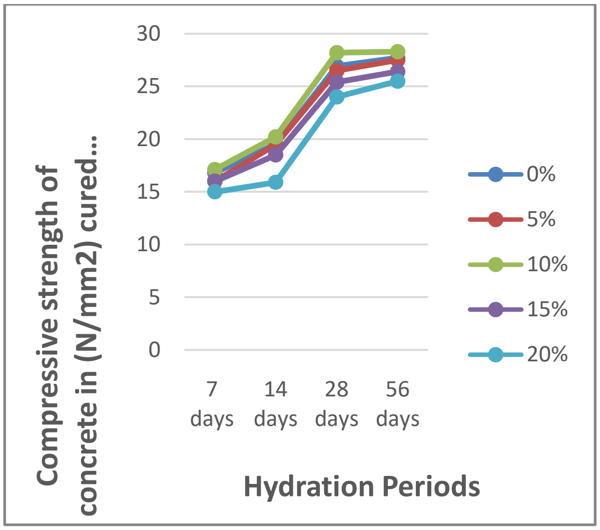

Figure 10: Compressive Strength of Concrete cured in H_2SO_4

3.8 Tensile strength

The results of tensile strength of control concrete and concrete prepared with partial replacement of cement with waste glass powder of all 5 mixes are presented in Figure 11 and 12. The result shows that the tensile strength of concrete is increases with replacement of cement with waste glass powder at 10%, while that of 5% shows no significant difference to that of control concrete. The maximum tensile strength of concrete cured in H_2SO_4 solution at 28 days is was observed at 10%with an increase of 1.23% as compared to control concrete specimen, also at 56 days there is 1.79% increase of 10% replacement as compared to control concrete. While in $MgSO_4$ solution, the maximum strength was observed at 10% replacement of cement with waste glass powder with an increase of 0.31% more than that of control concrete, also at 56 days there is an increase of 1.52% of 10% replacement of cement with waste glass powder as compared to that of control concrete. On further note magnesium sulphate environment has significant effect on concrete properties. However replacement of cement more than 10% with waste glass powder, the tensile strength of concrete decreased.

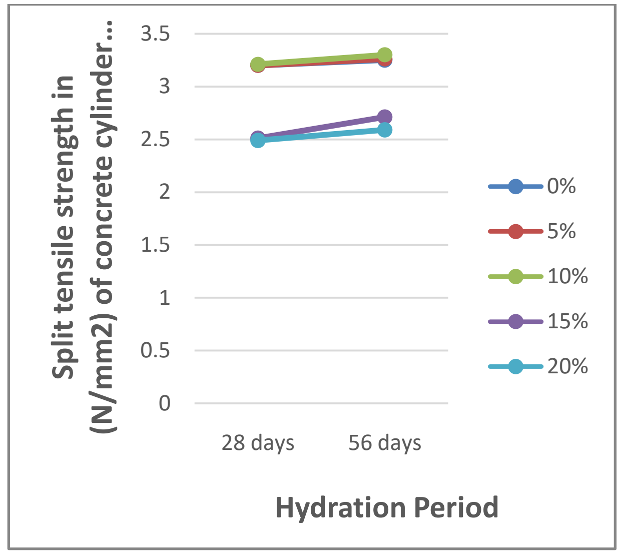

Figure 11: Split Tensile Strength of Concrete cured in $MgSO_4$

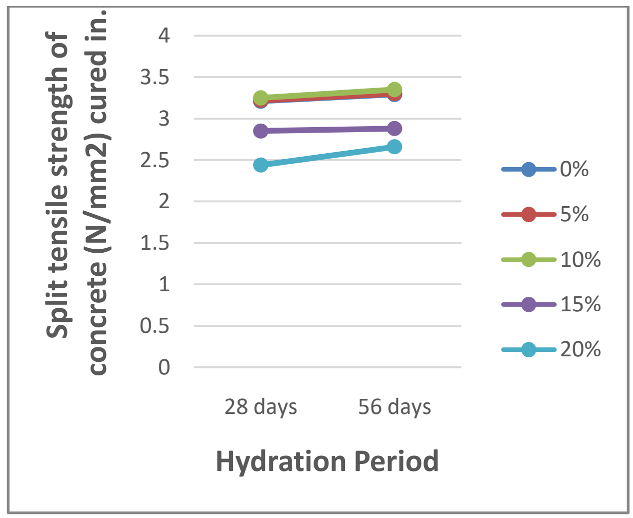

Figure 12: Split Tensile Strength of Concrete cured in H_2SO_4

Table 1: Specific Gravity Test on Waste Glass Powder

Trial	Trial 1	Trial 2	Trial 3
Weight of empty cylinder (M_1) g	13.6	13.6	13.8
Weight of cylinder + sample (M_2) g	68.1	68.2	68.2
Weight of cylinder + water + sample (M_3) g	117.9	118.2	118.5
Weight of cylinder + water (M4) g	84.8	84.7	84.8
Specific Gravity = $\frac{M2-M1}{(M4-M1)-(M3-M2)}$	2.55	2.59	2.63
Average Specific Gravity		2.59	

Table 2: Bulk Density of Waste Glass Powder

	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)	10.38	10.52	10.36	10.05	10.08	10.06
Weight of sample ($M_2 – M_1$) kg	2.28	2.42	2.26	1.95	1.98	1.96
Bulk density $\rho = \frac{M1-M2}{volume}$	1471	1561	1481	1258	1258	1265
Average = $\frac{C1+C2+C3}{3}$	1504			1260		
Percentage void $\rho = \frac{\text{weight of compacted WGP} - \text{weight of uncompacted WGP}}{\text{weight of uncompacted of WGP}}$			19.36			

IV. CONCLUSION

On the basis of conducted research it can be concluded that: Workability of concrete is increases as the dosage of waste glass powder is increasing. The maximum increase in workability was observed at 20% replacement of cement with waste glass powder. The initial setting time of cement material shows that for OPC mixes and percentage replacement of cement mixes at 5% and 10% was within 1 hour, while for 15% and 20% was above 1 hour. Furthermore the final setting time of OPC mix and cement replacement mix with waste glass powder was within 4 to 7 hours. Density of hardened concrete is increased with percentage replacement of cement with waste glass powder up-to 10%. The maximum increase in density of hardened concrete was observed at 10% of cement replacement with waste glass powder. Compressive strength of concrete is increased with replacement of cement with waste glass powder at 10% at both curing media of $MgSO_4$ and H_2SO_4. The maximum compressive strength of concrete was observed at 10% replacement of cement with waste glass powder. Split tensile strength of concrete increases with replacement of cement with waste glass powder up-to 10%. The maximum tensile strength of concrete was observed at 10% replacement of cement with waste glass powder. Hence, on the bases of the results, 10% replacement of cement with waste glass powder is optimum.

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