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Mechanical and Physical Properties of Sustainable Green Concrete Incorporating Pozzolanic Materials from Recycled Waste.

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Abstract: *This research aims to study some of mechanical and Physical Properties of Sustainable Green Concrete incorporating pozzolanic materials (silica fume, fly ash, blast furnace slag powder, metakaolin and glass waste powder) from recycled waste as replacement to the cement weight by 5%, 10%, and 15% and passed through a sieve opening 150 μm. The evaluation was based on the assessment of Physical Properties (consistency of all pozzolanic concrete and the reference mixture) and mechanical properties (compressive strength and indirect tensile strength) measured at 28, and 56 days. From the results obtained, there was a noticeable improvement in the consistency of all pozzolanic concrete mixtures compared to the reference mixture (M_R), glass waste powder concrete gives higher performance compared to other of the mixtures at all replacement ratios. At a curing age of 28 days, there was a noticeable improvement in the compressive strength of concrete up to 1.73%, containing 15% blast furnace slag powder (BFP) compared to the strength of M_R. While the compressive strength of the other pozzolanic mixtures is lower compared to the strength of M_R at replacement ratios of 5, 10, and 15%. At a curing age of 56 days, there was a significant improvement in the compressive strength of BFP and Metakaolin (MK) concrete with a 15% replacement ratio of 6.7% and 3.3% respectively and there is a significant improvement in compressive strength of up to 2% and 0.5%. for SF and BFP with 10%, respectively, compared to the M_R. The compressive strength of pozzolanic concrete improves with increasing concrete age at all replacement ratios. At the curing age of 28 and 56 days the compressive strength of SF and FA concrete increases up to 10% replacement, after which its value decreases, while BFP, MK and WGP concrete improve with increasing replacement ratio. Glass waste powder concrete (WGP) with 10% replacement gave a higher indirect tensile strength 7.1%, while the other of pozzolanic mixtures gave a lower tensile strength, compared to the tensile strength of M_R. Pozzolanic concrete made from (SF, FA, MK, and WGP), its strength to indirect tensile increases with an increase in the replacement ratio up to 10%, after which its value decreases. While the tensile strength of BFP concrete increases with an increase in the replacement ratio. The density of pozzolanic concrete, which includes SF, FA, MK and WGP at all replacement ratios, is lower compared to the density of MR. The density of SF and WGP concrete decreases with increasing replacement ratios and concrete age, while MK concrete density decreases with increasing replacement ratios and increases with increasing concrete age. However, the density of BFP concrete increases with the increase of both the replacement ratio and concrete age.*

Keywords: Pozzolanic materials – Silica fume- Metakaolin - Blast furnace slag powder- Glass waste powder -Fly ash-concrete - Compressive strength - Tensile strength.

1. INTRODUCTION

Concrete can be largely made from locally accessible components used in various fields and requires minimal maintenance. Now cement concrete has become one of the most widely used building materials, because of the widespread use of cement production quickly. The main pollutant emitted from cements industries are dust, carbon dioxide, nitrogen oxide and sulphur oxides which are very dangerous for our environment. Therefore, reducing the amount of cement in concrete by replacing cement with pozzolanic materials as a partial replacement. pozzolanic materials are considered as promising materials for high performance concrete. Improvement of the mechanical properties of concrete until certain replacement of cement. And consider it is very economical and widely available in our country which can be used to produce high performance concrete. Hence, by using pozzolan concrete, we can reduce the amount of cement in the field of construction, which leads to an environmentally friendly environment. The lack of natural aggregate leads to the necessity of finding solutions to use other materials, and from here the extent of the effect of pozzolanic materials on the properties of concrete was studied to improve those produced with other materials. The current study reveals the effect of pozzolanic materials on the mechanical properties of hardened concrete. To study this fact, concrete containing pozzolanic materials tends to have smaller pores, resulting in improved strength and density and to know the properties of pozzolanic materials. To achieve the research objectives, this study was structured into various phases. Firstly, essential information and data relevant to the subject were gathered through a comprehensive literature review. Subsequently, a practical program was devised and implemented to complete the study. This program involved the formulation of pozzolanic materials in varying proportions as substitutes for cement, incorporating ingredients such as silica fume, ground furnace slag, fly ash, metakaolin, and glass waste powder.

In addition to this, the study included the assessment of specifications and properties of other materials like cement, sand, and gravel. To facilitate this evaluation, cubes and cylinders were prepared for conducting both indirect compression and tension tests, along with determining the density of these materials. The results obtained from these tests were meticulously recorded, analyzed, and used to draw conclusions for the study's objectives.

2. LITERATURE REVIEW

In accordance with prior research findings, the incorporation of industrial byproducts such as slag, aluminum, and granite into concrete results in cost reduction and decreased carbon emissions. Furthermore, it enhances mechanical properties and durability. These modifications to concrete mixes involve the addition of substances that enhance the microstructure and decrease the concentration of calcium hydroxide through consumption in the pozzolanic reaction, leading to the formation of additional quantities of hydrated calcium silicate. The fine particle size of pozzolanic materials within the concrete mixes creates numerous nucleation sites for the precipitation of hydration products [1-3]. Consequently, the resulting concrete specimens exhibit improved homogeneity due to the interaction between the amorphous silica of the pozzolanic material and the calcium hydroxide produced during cement hydration processes. Additionally, the fine-grained nature of these materials allows for more densely packed cement specimens and mitigates the wall effect in the transition zone between the paste and the fine and coarse aggregates [4-5]. Portland cement concrete is the most widely used type of concrete worldwide, known for its attributes like durability, strength, cost-effectiveness, chemical stability, and flexibility in shaping. The increasing demand for concrete in the construction industry is primarily driven by these exceptional properties [6-7]. However, the environmental impact is also rising because the production of Portland cement involves the release of gases such as carbon dioxide (CO_2), sulfur oxide (SOx), and nitrogen oxides (NOx) due to the high-temperature calcination process of raw materials, contributing to global warming [8]. The construction industry has seen a gradual shift towards the use of alkali-activated mortar or concrete, with fly ash and granulated blast-furnace slag, rich in silica (SiO2), alumina (AL_2O_3), and/or calcium oxide (CaO), being prominent choices. This is attributed to their compatibility with alkaline processes that facilitate chemical reactions between various alumino silicate oxides and silicates or the formation of calcium silicate hydrate gel, thereby improving understanding of these binder systems and their properties [9]. A recent study investigated the replacement of 50% of Portland cement with ground granulated blast furnace slag, fly ash, and geothermal waste, both with and without external alkaline activation. Different alkali agents, including 4% and 7% Na_2O equivalent of sodium hydroxide, sodium silicate (water glass), and sodium sulfate, were used. After 90 days of curing, the study characterized the samples through compressive strength tests, scanning electron microscopy, X-ray diffraction, and thermogravimetric analyses. The results showed that sodium hydroxide led to an alkali-silica reaction, reducing strength, while sodium silicate and sodium sulfate improved strength and the formation of hydration products. The addition of fly ash decreased compressive strength but increased workability, whereas slag and geothermal waste increased strength and densified the matrix with additional hydration product formation [10]. Another study examined the mechanical properties of concrete containing ordinary Portland cement and metakaolin (MK), both with and without steel fibers. Cement was partially replaced with MK in various percentages (3%, 6%, 9%, 12%, 15%, 18% by weight of the total binder content). Steel fibers (50 mm in length and 0.70 mm in diameter) were used to create fiber-reinforced concrete. The study assessed water absorption and determined compressive strength and split tensile strength at curing ages of 7 days, 28 days, and 56 days. The results indicated that the replacement of MK increased compressive and split tensile strength up to 9% replacement, followed by a decrease. The addition of steel fiber to different percentages of MK further enhanced the strength of MK-reinforced concrete, highlighting the significant impact of combining metakaolin with various steel fibers on concrete's mechanical properties [11]. The use of mineral admixtures such as MK, silica fume, fly ash, and steel fibers in high-strength concrete yielded favorable results, enhancing its mechanical properties [12]. Additionally, the long-term durability of modified concrete, incorporating a blend of MK and polymer, was studied, revealing that the highest strength was achieved when Portland cement was replaced with MK and polymer [13]. The mechanical performance of high-strength concrete containing substantial amounts of MK and hybrid fibers demonstrated that replacing 15% of cement with MK improved mechanical properties [14]. Notably, the partial replacement of cement with MK proved to be effective in achieving high-strength concrete. A 15% replacement of cement with MK improved properties such as compressive strength, tensile strength, and flexural strength [15]. Currently, the development of environmentally friendly high-strength concrete for construction purposes is a global trend, with the use of supplemental cementitious materials (SCMs) such as granulated blast furnace slag (GBFS), wheat straw ash (WSA), fly ash (FA), and silica fume (SF). By incorporating SCMs, maximum strength and durability are attainable. For instance, fly ash, a byproduct of coal-fired power plants rich in silica and alumina, can replace up to 30% of cement. This substitution reduces energy consumption and greenhouse gas emissions during cement production while enhancing the workability, strength, and durability of concrete [16-19]. Furthermore, fly ash reduces concrete permeability and enhances its long-term durability, making it more resistant to harsh environmental conditions [20-22]. Fly ash in the construction section it has been used extensively. It was also found that the use of fly ash in concrete reduces permeability of concrete and improves its long-term durability, making it more resistant to aggressive environmental conditions. In high strength concrete, silica fume is used as filler or as a limited replacement for cement [23]. In high-strength concrete, silica fume serves as a filler or a limited substitute for cement. Studies have shown that replacing cement with silica fume in percentages from 0 to 15% improves strength while slightly decreasing workability and modulus of elasticity. The increase in strength is attributed to the reduced voids in the concrete, while the decrease in slump value results from increased surface area and water absorption during mixing [24].

Another study investigated the use of 25% to 40% wheat grass powder (WGP) in combination with granulated blast furnace slag and metakaolin, testing the mechanical and fresh properties of concrete. The optimal substitution for WGP was found to be 35%, although an increase in WGP content decreased mechanical properties. The study also developed an artificial neural network to evaluate workability and mechanical properties, demonstrating its effectiveness in assessing these aspects [25].In conclusion, this study thoroughly examined the influence of pozzolanic materials, such as silica fume, blast furnace slag, fly ash, metakaolin, and glass waste powder, as mineral admixtures on the physical and mechanical properties of concrete specimens. The primary goal of this research was to produce sustainable concrete and reduce carbon emissions by utilizing local waste materials as substitutes for cement in Egypt.

3. EXPERIMENTAL STUDY

3 .1 Materials Used

3.1.1 Coarse Aggregate (Gravel): In this investigation, gravel aggregate obtained from authorized quarries in Egypt was utilized. The maximum nominal size of the gravel for all the mixtures was 14 mm. This size was chosen for its ease of handling and because of its successful use in previous research. Table 1 outlines the tests conducted to determine the physical and mechanical properties of the gravel. As per the standards (ESS1109 and ASTM C637), the coarse aggregates were manually sieved into size fractions ranging from 5 to 14 mm. Figure 1 illustrates the sieve analysis of the gravel.

3.1.2 Fine Aggregate (Sand): The sand employed in this study is natural sand sourced from approved quarries in Egypt, and it underwent laboratory testing. Figure 2 displays the grading curve for the sand used, while Table 2 provides information on the natural properties of the sand.

3.1.3 Cement: Ordinary Portland cement (CEM I-42.5N) was the cement used in the concrete mixtures for this study. It was supplied by the Suez cement company in Suez, Egypt, and it complied with the Egyptian Standard Specifications (4756-1/2007). The cement content for the reference concrete mixture in this study was 439.6 kg/m3, with a specific gravity of 3.15 and a fineness of 300 m^2/kg.

3.1.4 Mixing Water: Potable water was employed in the concrete mixtures for this study, and water was added to all mixtures in a consistent proportion to the weight of the cement materials (w/cm = 0.48).

3.1.5 Pozzolanic Materials: In this study, pozzolanic materials were used as replacements for cement at rates of 5%, 10%, and 15%, and they were screened through a sieve with a 150 µm opening. The following pozzolanic materials were employed.

Silica Fume (SF): The silica fume used in this study was supplied by the Building Research Center in Egypt, as depicted in Figure 3. Silica fume is a highly reactive pozzolanic material derived as a byproduct from the production of silicon or ferro-silicon metal. It is composed of flue gases from electric arc furnaces. Silica fume is an extremely fine powder, with particles approximately one-hundredth the size of an average cement grain (30000 m^2/kg). It has a specific gravity of 2.28 and a density of 550 kg/m^3.

Waste Glass Powder (WGP): The waste glass used in this study was obtained from a damaged building. The collected glass was cleaned, crushed to a size of 0.1–10 mm using a crusher machine, and manually ground to produce a powdered glass, as shown in Figure 3. It has a specific gravity of 2.85 and a density of 1700 kg/m^3.

Fly Ash (FA): The fly ash used in this study was supplied by the Building Research Center in Egypt, as depicted in Figure 3. It has a specific gravity of 2.95 and is primarily composed of calcium oxide and silicon dioxide.

Blast Furnace Slag Powder (BFP): Blast-furnace slag from iron and steel factories was utilized, which underwent a slow cooling process. It was initially broken into aggregates of various sizes and then ground into a powder, as shown in Figure 4. The blast furnace slag powder has a specific weight of 2.95 and a fineness of 350 m^2/kg.

Metakaolin (MK): Metakaolin, a high-quality pozzolanic material, was supplied by the Building Research Center in Egypt, as depicted in Figure 3. Unlike other materials, metakaolin is neither a byproduct of an industrial process (like BFP) nor entirely natural. It is specially manufactured from high-quality kaolin clay. Metakaolin has a specific gravity of 2.5 and a fineness of 15000 m2/kg. The chemical composition of ordinary Portland cement and pozzolanic materials powder is presented in Table 3.

Table 1. Physical and mechanical properties of gravel aggregates

Property	Results	BS-En-1197-2009
Absorption,%	2.5 %	Not more than 3%
Impact coefficient	25 %	Not more than 45%
Crushing coefficient	25 %	Not more than 45%
Specific gravity	2.7	2.6-2.7
Weight unite volume	1616.1 Kg/m^3	1400-1800 Kg/m^3

Table 2. Physical properties of sand

Property	Results	BS-En-1197-2009
Absorption,%	0.28 %	Not more than 3%
Specific gravity	2.5	2.5 – 2.7
Weight unite volume	1692	1400 - 1800 Kg/m^3
Fineness modulus	2.4	2.0 - 3.75

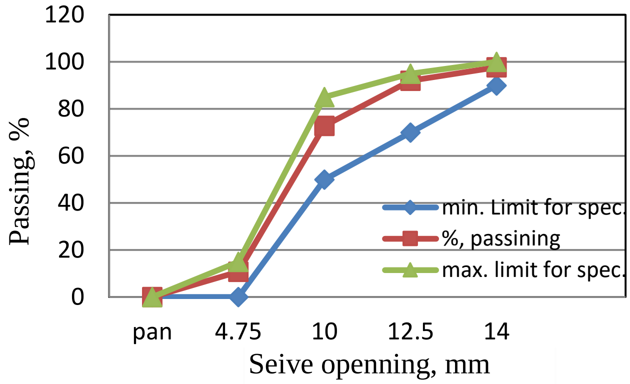

Figure1. Grading curve for gravel

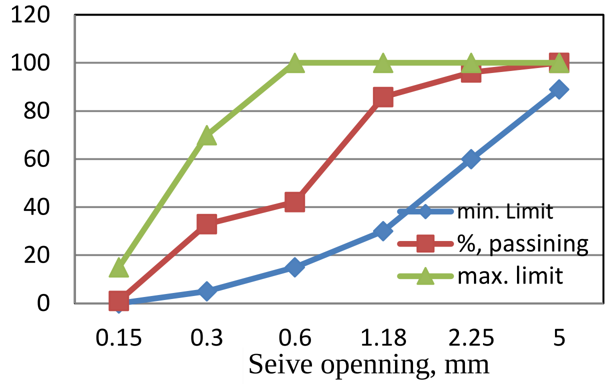

Figure 2. Grading curve for sand

Figure3. Pozzolanic materials used in this study

1- The location of Blast-Furnace slag, Waste from iron and steel factories
2- Crusher machine
3- Slag aggregate
4-Milling machine for slag aggregate
5- blast- furnace slag powder (BFSP)

Figure 4. Shows the stages of preparing blast- furnace slag powder (BFSP)

Table 3. Chemical composition of portland cement and pozzolanic materials powder

Oxide, %	OPC (CEM I, 42.5)	Pozzolanic Materials Powder				
		Silica Fume (SF)	Fly ash (FA)	Blast furnace slag powder (BFP)	Metakaolin (MK)	Waste glass powder (WGP)
SiO_2	28.2	92.3	57.2	39.5	43.72	69.87
AL_2O_3	4.12	1.2	26.04	11.2	21.35	2.27
CaO	63.4	0.31	3.7	37.6	35.8	7.8
Fe_2O_3	3.9	0.02	6.22	1.25	2.54	0.83
Na_2O	0.32	-	0.2	0.74	0.49	12.69

K_2O	2.5	0.25	1.26	0.8	0.99	0.54
MgO	0.21	0.18	1.04	8.23	1.18	2.74
SO_3	0.28	0.05	0.13	-	1.53	0.26
Loss on ignition (LOI,%)	2.3	2.05	0.51	-	7.9	0.46
TiO_2	0.09	-	2	-	1.4	0.03

3 .2 Mix Design

In this study, the design of the concrete mix was based on both the American Concrete Institute (ACI) method and the absolute volume equation. These methods were employed to determine the required material quantities by weight for the test mix. The proportions selected for this study included gravel, sand, cement, and water for one cubic meter of freshly compacted concrete. The water-to-cement materials (w/cm) ratio was set at 0.48 for all concrete mixtures in the study, while the cement content was fixed at 439.6 kg/m^3 for the reference concrete mixture. Table 4 provides a breakdown of the components and the mixing proportions for the concrete mixes in this study, per one cubic meter of freshly prepared concrete.

Table 4. Ingredients and mix proportion of concrete used in this study per 1 m^3.

Mix type	Cement Kg/m^3	water		Aggregates		Pozzolanic Materials				
		percentage	Weight, Lit	Gravel Kg/m^3	Sand Kg/m^3	Silica fume (SF), Kg	Waste glass powder (WGP), Kg	Fly ash (FA), Kg	Metakolina (MK), Kg	Blast - furnace slag powder (BFP), Kg
M_R	439.6	0.48	212	1002	638.35	-	-	-	-	
$M_{SF,5\%}$	417.6			1002	614.25	21.98	-	-	-	-
$M_{SF,10\%}$	395.6			1002	590.13	43.96	-	-	-	-
$M_{SF,15\%}$	373.7			1002	566.1	65.94	-	-	-	-
$M_{WGP,5\%}$	417.6			1002	619.1	-	21.98	-	-	-
$M_{WGP,10\%}$	395.6			1002	599.8	-	43.96	-	-	-
$M_{WGP,15\%}$	373.7			1002	580.5	-	65.94	-	-	-
$M_{FA,5\%}$	417.6			1002	619.72	-	-	21.98	-	-
$M_{FA,10\%}$	395.6			1002	601.1	-	-	43.96	-	-
$M_{FA,15\%}$	373.7			1002	582.45	-	-	65.94	-	-
$M_{MK,5\%}$	417.6			1002	616.36	-	-	-	21.98	-
$M_{MK,10\%}$	395.6			1002	594.38	-	-	-	43.96	-
$M_{MK,15\%}$	373.7			1002	572.4	-	-	-	65.94	-
$M_{BFP,5\%}$	417.6			1002	619.72	-	-	-	-	21.98
$M_{BFP,10\%}$	395.6			1002	601.1	-	-	-	-	43.96
$M_{BFP,15\%}$	373.7			1002	582.45	-	-	-	-	65.94

3.3 Specimens and Tests Used in This Study

The specimens utilized in this study consisted of metal cube models with dimensions measuring (15x15x15) cm for the purpose of conducting compressive strength tests. Additionally, metal cylinder models, with a diameter of 15 cm and a height of 30 cm, were employed for the indirect tensile tests, as depicted in Figure 5.

To assess the consistency of the fresh concrete after the mixing process, a slump test was conducted in accordance with ASTM C143. Subsequently, all samples were cast into molds by a process involving rough layering and compaction on a vibrating table, as illustrated in Figure 6b. Immediately after casting, the concrete specimens were placed within the laboratory environment for a duration of 24 hours, maintaining a temperature of 23°C and a relative humidity of 100%. Subsequent to this initial period, the specimens were submerged in water until the time of testing.

For mold preparation, greasing was carried out prior to casting. The concrete mixes were placed in the molds in three distinct layers, followed by compaction using an electrical vibrating table. After a 24-hour curing period, the samples were extracted from the molds, marked, and then immersed in a curing medium. In line with ASTM C511 guidelines, the compressive strength and indirect tensile tests were conducted on cube and cylinder samples, respectively, for the hardened concrete after 28 and 56 days from the casting date.

For the testing procedure, a universal hydraulic testing machine with a capacity of 1000 kN was employed. Each test involved three samples, as shown in Figure 7, and was conducted at a consistent loading rate of 1 kN per minute. Any results deviating by more than 25% from the mean value were discarded, in accordance with the Egyptian specification.

The density of the concrete was determined by weighing the sample after it had been cured for 28 days (W) and had its surface dried. The volume of the sample (V) was calculated, and then the density was determined using the following formula: [Include the formula for density calculation here.Layout for samples and tests in this study are listed in table 5.

$$P = \frac{w}{v}$$

(a) (b)

Figure 5.Specimens for compressive and splitting tensile strength test:

(a) Metal cylinders with dimensions 15 cm x 30 cm. for splitting tensile strength test

(b) Metal cubes with dimensions 15 cm x 15 cm x 15 cm for compressive strength test

(a) (b)

Figure 6. (a) Slump value test for fresh concrete. (b) Filing the molds

(a) (b)

Figure 7. (a) Compression test (b) Splitting tensile test

Table 5. layout for samples and tests in this study.

Mix type	Pozzolanic Materials					Hardened concrete test			Samples No.	
	Silica fume (SF), Kg	Waste glass powder (WGP), Kg	Fly ash (FA), Kg	Metakolina (MK), Kg	Blast - furnace slag powder (BFP), Kg	Compressive strength at ages 28, 56 day	Indirect Tensile Strength at age 28	Density	Cubes 10×10×10 cm	Cylinder 15×30 cm
M_R	-	-							6	-
									-	3
$M_{SF,5\%}$	5 %	-	-	-	-				6	-
									-	3
$M_{SF,10\%}$	10 %	-	-	-	-				6	-
									-	3
$M_{SF,15\%}$	15 %	-	-	-	-				6	-
									-	3
$M_{WGP,5\%}$	-	5 %	-	-	-				6	-
									-	3
$M_{WGP,10\%}$	-	10 %	-	-	-				6	-
										3
$M_{WGP,15\%}$	-	15 %	-	-	-				6	-
									-	3
$M_{FA,5\%}$	-	-	5 %	-	-				6	-
									-	3
$M_{FA,10\%}$	-	-	10 %	-	-				6	-
									-	3
$M_{FA,15\%}$	-	-	15 %	-	-				6	-
									-	3
$M_{MK,5\%}$	-	-	-	5 %	-				6	-
									-	3
$M_{MK,10\ \%}$	-	-	-	10 %	-				6	-
									-	3
$M_{MK,15\%}$	-	-	-	15 %	-				6	-
									-	3
$M_{BFP,5\%}$	-	-	-	-	5 %				6	-
									-	3
$M_{BFP,10\%}$	-	-	-	-	10 %				6	-
									-	3
$M_{BFP,15\%}$	-	-	-	-	15 %				6	-
									-	3
					Total				96	48

4. RESULTS AND DISCUSION

4.1 Properties of Fresh Concrete

The study on the consistency of various concrete mixes was conducted using the standard slump test, wherein the slump measurement was determined for all the mixtures immediately after the mixing process. The results are presented in Figure 8. Evidently, there is an enhancement in the consistency of all the pozzolanic concrete mixes when compared to the reference mix. Notably, concrete mixtures containing glass waste powder exhibited superior performance, surpassing the other mixtures. It was observed that with an increased percentage of glass powder replacement, workability improved significantly, with increases of 169.5%, 170.2%, and 191.30% for mixtures containing 5%, 10%, and 15% of glass powder, respectively, as compared to the reference mixture.

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Furthermore, it is worth mentioning that the consistency of the remaining concrete mixtures containing pozzolanic materials also improved with increasing replacement rates. However, it is noteworthy that the consistency of the concrete mixture containing silica fume was less than that of the other pozzolanic concrete mixes. This can be attributed to the high fineness of silica fume, which results in a larger surface area compared to other pozzolanic materials. On average, the consistency of the silica fume mixture was higher by 24.6% compared to the reference mixture.

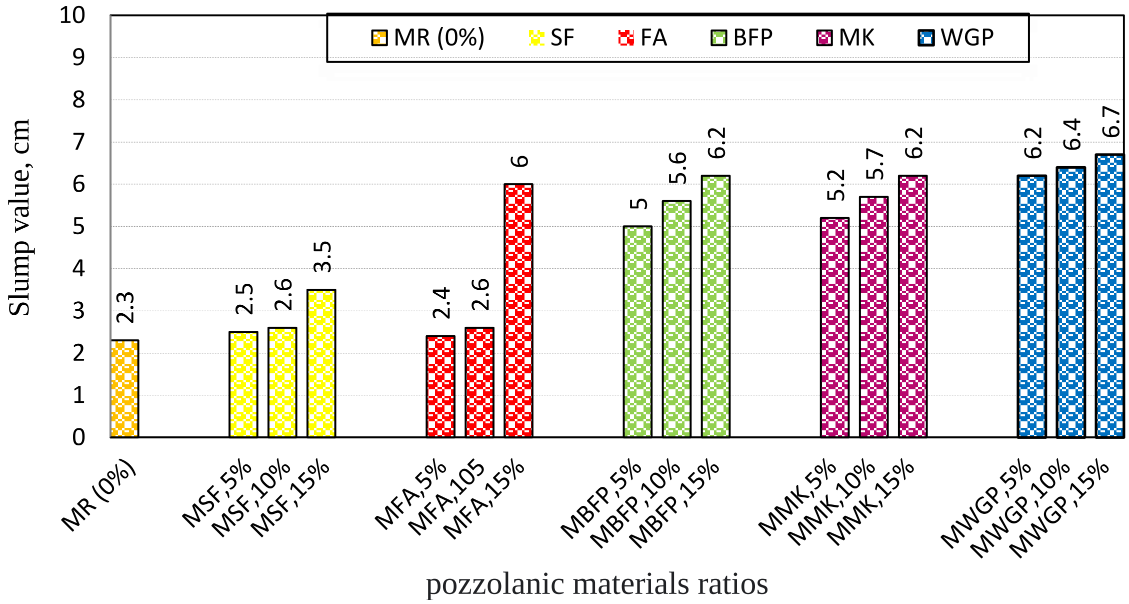

Figure 8. Slump values for concrete mixes with Partial replacement for cement wt. by pozzolanic materials

4.2 Compressive Strength Test

4.2.1 Effect of pozzolanic materials on compressive strength for concrete mixtures at curing age of 28 day.

Figure 9 illustrates the impact of substituting a portion of the cement weight with pozzolanic materials on the compressive strength of concrete mixes at a 28-day curing age. For all the pozzolanic materials considered in this study, concrete mixtures with a 5% partial replacement of cement weight exhibited lower compressive strength compared to the reference mixture. Conversely, both blast furnace slag and glass powder concrete demonstrated higher compressive strength, followed by fly ash concrete, and then by the compressive strength of silica fume and metakaolin concrete.

Similarly, as depicted in Figure 9, when the weight of cement was replaced by 10%, it resulted in reduced compressive strength values for all the pozzolanic mixtures compared to the reference mixture. Nevertheless, concrete containing blast furnace slag powder showed the highest compressive strength among the various pozzolanic materials, followed by the strength of glass powder concrete and silica fume concrete. Subsequently, the compressive strength of fly ash and metakaolin concrete followed.

Figure 9 further demonstrates that when cement weight was replaced by 15%, a decrease in compressive strength values was observed for all mixtures containing pozzolanic materials, except for the mixture containing blast furnace slag. In this case, there was a slight improvement in compressive strength, up to 1.73%. The order of strength, in this scenario, was as follows: first, the strength of concrete with blast furnace slag; followed by glass powder and metakaolin concrete; and then, the compressive strength of silica fume and fly ash concrete.

Figure 10 displays the failure of concrete cubes subjected to axial compression loads from the compression machine for both reference concrete and concrete containing pozzolanic materials, considering the replacement ratio for the cement weight, at a 28-day curing age.

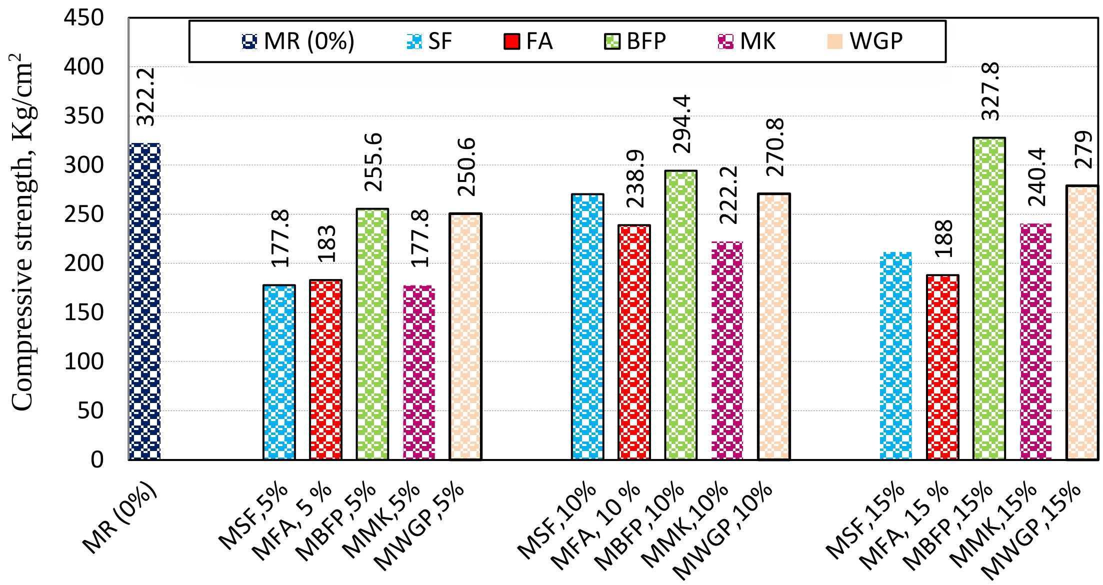

Figure 9. Compressive strength of concrete mixes with partial replacement for cement wt.

Refrence concrete **Silica fume concrete** **Fly ash concrete** **Blast furnace slag concrete** **Metakolain concrete**

Figure 10. Failure models for specimens of refrence and pozzolanic concrete under axial compression

4.2.2 Effect of pozzolanic materials on compressive strength for concrete mixtures at curing age of 56 day.

concrete mixes at a 56-day curing age. For concrete with a 5% partial replacement of cement weight, the compressive strength of blast furnace slag concrete matches that of the reference concrete. Conversely, there is a decrease in compressive strength by 16.7%, 18.3%, 23.5%, and 36.7% for concrete containing waste glass powder, metakaolin, silica fume, and fly ash, respectively, when compared to the reference concrete.

When a 10% replacement of the cement weight is considered, there is a slight improvement in the compressive strength of silica fume and blast furnace slag concretes, by 2% and 0.5%, respectively. However, the compressive strength of fly ash, glass waste powder, and metakaolin concrete decreases by 13.3%, 15%, and 16.7% compared to the reference concrete.

At a 15% replacement of the cement weight, a notable improvement in compressive strength is observed for both blast furnace slag and metakaolin concrete, increasing by 6.7% and 3.3%, respectively. In contrast, the compressive strength of glass waste powder, fly ash, and silica fume concrete decreases by 11.7%, 14.2%, and 22.3%, respectively, when compared to the reference concrete.

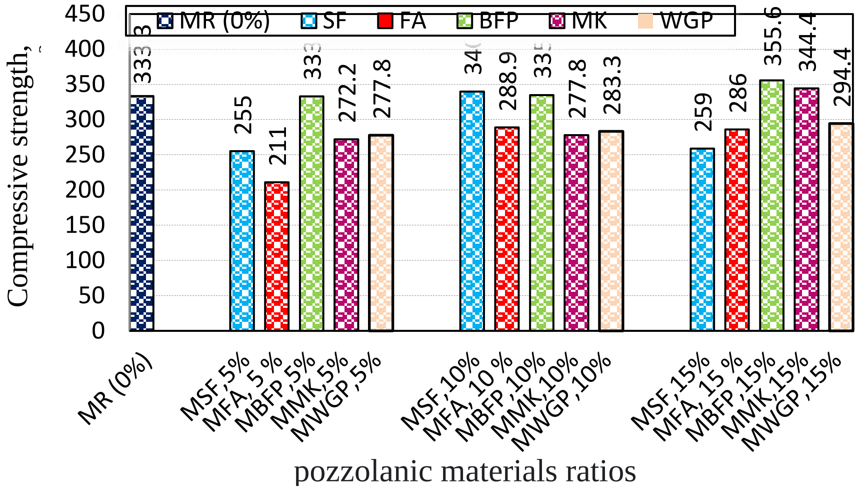

Figure 11. Compressive strength of concrete mixes with partial replacement for cement wt. by pozzolanic materials at a

It is also noted that at curing age of 28 and 56 days in figures 9 and 11, that the concrete of both silica fume and fly ash improves up to 10% of its replacement to the weight of the cement, after which its value decreases. As for the concrete of both blast furnace slag powder, metakaolin and glass waste powder, it is improved by increasing its replacement percentage for the weight of cement.

4.2.3 Effect of curing age on the compressive strength of concrete containing pozzolanic materials a partial replacement for cement weight

In Figures 12 and 13, the compressive strength of both silica fume and metakaolin concrete shows improvement as the curing age in the water basin increases across all levels of partial replacement of cement by weight. Additionally, at a curing age of 56 days, the compressive strength of silica fume concrete, with a 10% partial replacement, exhibits a 2% increase, while metakaolin concrete, with a 15% partial replacement at the same curing age, experiences a 3.33% increase when compared to the reference concrete. It's important to note that the reference concrete also demonstrates improved strength as it ages.

In Figures 14 and 15, the compressive strength of both fly ash and waste glass powder concrete improves as the curing age in the water basin increases for all levels of partial replacement by weight of cement. However, at curing ages of 28 and 56 days, the strength values of these concretes decrease in comparison to the reference concrete. Once again, the reference concrete exhibits improved strength as it ages.

In Figure 16, the compressive strength of blast furnace slag powder concrete improves with increasing curing age for all percentages of partial replacement by weight of cement. Its strength is only 1.5% higher than that of the reference concrete at the age of 28 days, with a 15% partial replacement. At the age of 56 days, the strength values are 0.5% and 6.7% higher than the reference concrete for partial replacements of 10% and 15% by weight of cement, respectively. Interestingly, the strength remains equal to that of the reference concrete when the partial replacement is 5% by weight of cement. As with other concrete types, the reference concrete displays strength improvement with age

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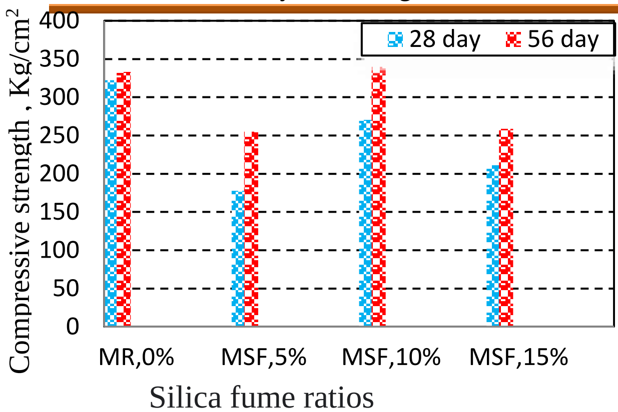

Figure 12. Compressive strength of concrete containing silica fume at a curing age of 28 and 56 days

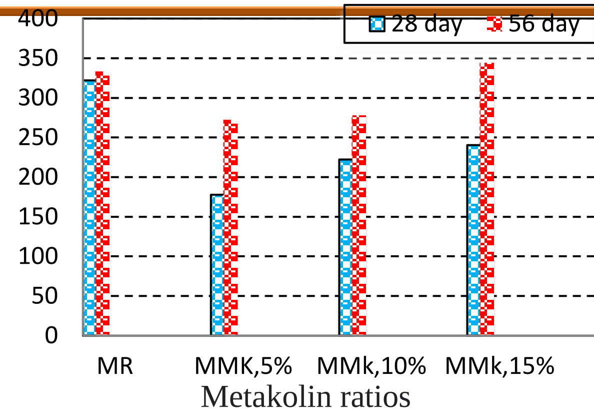

Figure13 . Compressive strength of the concrete containing metakolin at a curing age of 28 and 56 days

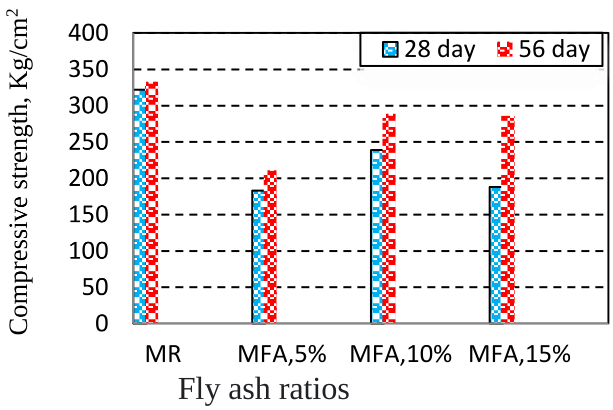

Figure 14. Compressive strength of concrete ontaining fly ash at a curing age of 28 and 56 days

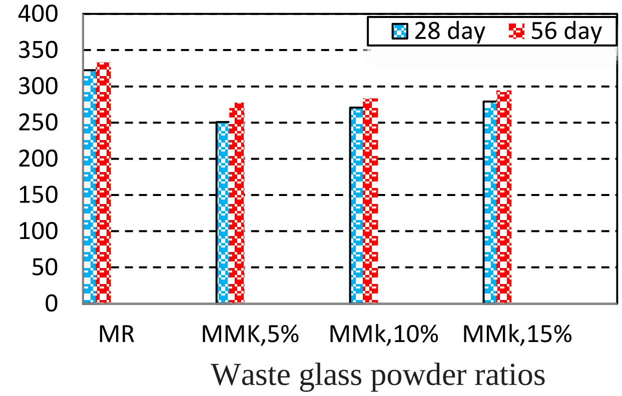

Figure 15. Compressive strength of the concrete containing waste glass powder at a curing age of 28 and 56 days

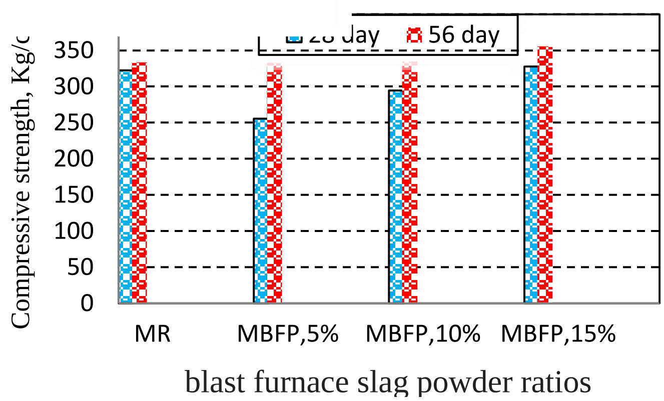

Figure 16. Compressive strength of concrete containing blast furnace slag powder at a curing age of 28 and 56 days

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4.3 Indirect Tensile Strength

The assessment of tensile strength values for the concrete mixes was conducted at day 28. The outcomes are presented in Figure 17. Notably, the indirect tensile strength of concrete containing 10% replacement of cement weight with glass powder achieves the highest value, showing a 7.1% increase. In contrast, the rest of the pozzolanic mixtures exhibit lower values compared to the reference concrete. It's important to note that tensile strength exhibits an improvement as the partial replacement percentage increases, up to 10%, and subsequently decreases for concrete mixes containing silica fume, fly ash, metakaolin, and glass waste powder. However, for blast furnace slag concrete, the tensile strength improves as the replacement rate increases, up to 15%.

Figure 18 displays the failure of the reference concrete cylinder and the pozzolanic concrete at a 28-day curing age due to the impact of the indirect tensile test performed using the compression machine.

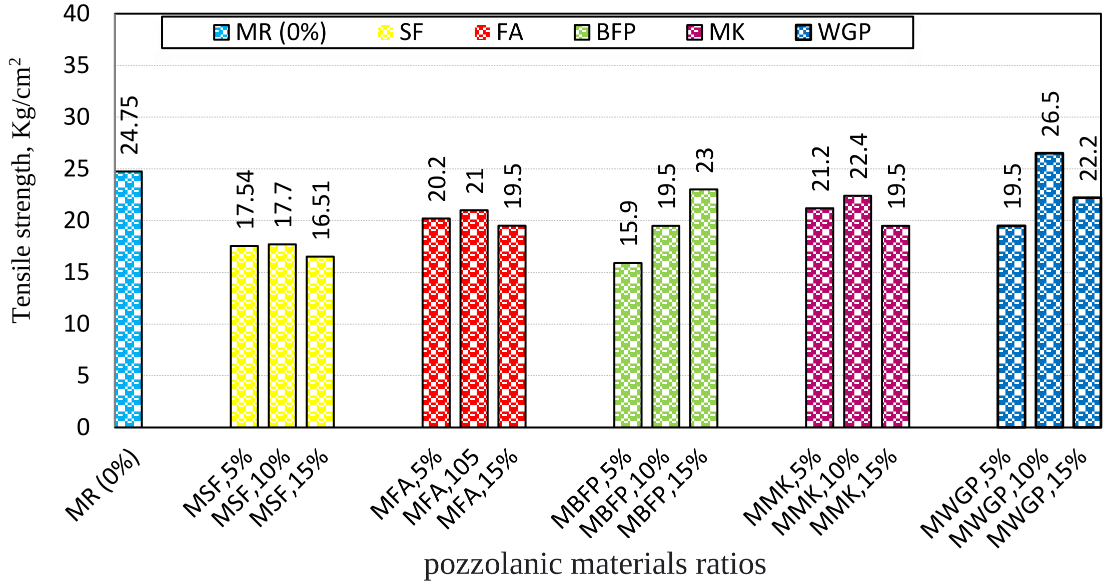

Figure 17 . Tensile strength of concrete mixes contaning pozzolanic material ratios at a curing age of 28 days

Figure 18. Failure models for specimens of refrence and pozzolanic concrete under indirect tensile by compression machine

4.4 Strength Ratio

Figure 19 presents the strength ratio (F_t/F_c) between the indirect tensile strength and the compressive strength for all mixtures at a 28-day curing age. At a 5% partial replacement of cement, metakaolin concrete ($M_{MK,\ 5\%}$) demonstrates the highest strength ratio,

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owing to the decrease in compressive strength at this percentage. Subsequently, the strength ratio decreases but remains higher than the reference concrete at 10% and equals it at 15% for M_{MK}.

Following a similar trend, fly ash concrete ($M_{FA, 5\%}$) also displays the highest strength ratio (F_t/F_c) at a 5% partial replacement of cement, attributed to the decrease in compressive strength at this ratio. This strength ratio subsequently decreases but remains higher than the reference concrete at $M_{FA, 10\%}$ and $M_{FA, 15\%}$.

In the case of silica fume concrete, the highest (F_t/F_c) compared to the reference concrete is observed at a 5% partial replacement ratio. This is due to the decrease in compressive strength at this percentage, after which the strength ratio decreases at 10% and 15% compared to the reference concrete, yet it remains higher than the reference concrete at 15%.

As for glass waste powder concrete, the highest (F_t/F_c) is achieved at a 10% partial replacement of cement, primarily due to the increase in indirect tensile strength at this percentage. At replacement rates of 5% and 15%, the strength ratio is nearly equivalent to that of the reference concrete.

Finally, for blast furnace slag powder concrete, it exhibits the lowest (F_t/F_c) in comparison to the reference concrete at all partial replacement ratios by weight of cement. This is attributed to the increase in the compressive strength of blast furnace slag concrete as the partial replacement ratios (5%, 10%, and 15%) increase.

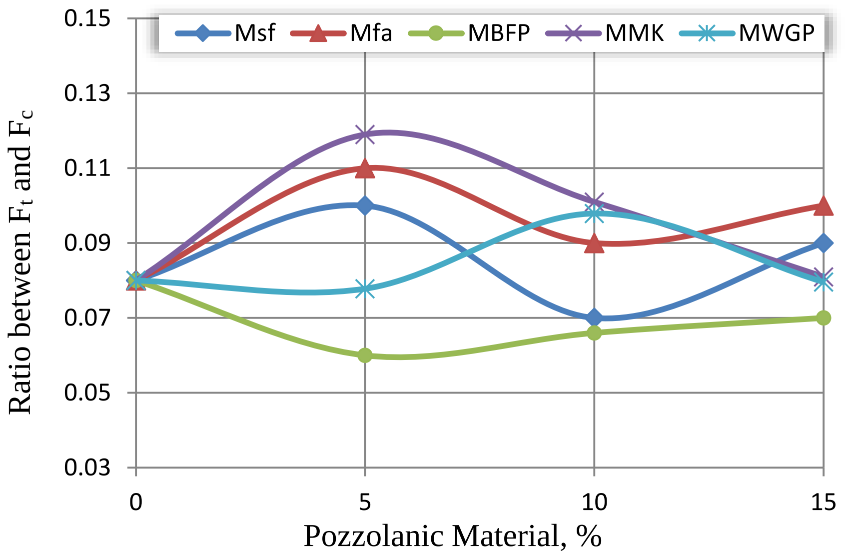

Figure 19 . The ration between tensile strength and compressive strength for concrete mixes contaning pozzolanic material ratios

4.5 Concrete Density

The study investigated the density of reference concrete and concrete mixes incorporating pozzolanic materials at curing ages of 28 and 56 days. Figures 20 and 21 illustrate the results.

For concrete incorporating silica fume, the density at both curing ages (28 and 56 days) decreases in comparison to the reference concrete. This reduction in density is more pronounced as the cement replacement ratio increases. Interestingly, the density of silica fume concrete at the age of 56 days is lower than at 28 days, especially at replacement ratios of 5%, 10%, and 15%.

In the case of fly ash concrete, its density decreases compared to the reference concrete at both 28 and 56-day curing ages. However, as the cement replacement ratios increase, the density of fly ash concrete increases. Notably, at a curing age of 56 days, the density is higher than that at 28 days.

The density of blast furnace slag concrete increases with the rise in the cement replacement percentage at both curing ages (28 and 56 days). At the age of 28 days, in comparison to the reference concrete density, the density of blast furnace slag concrete is higher only at a 15% replacement ratio, showing an increase of 1.85%, while it remains stable at 10% and decreases at 5%. At a curing age of 56 days, the density of blast furnace slag concrete is higher than the reference concrete density at all cement replacement ratios, with increases of 1%, 1.44%, and 2.1%, respectively.

For metakaolin concrete, its density decreases as the cement replacement ratios increase at both curing ages. In comparison to the reference density, it is lower at all replacement ratios, except for the 5% replacement at the curing age of 56 days, where the density is higher by 0.74%. At a curing age of 56 days, the density of metakaolin concrete is higher than at 28 days.

The density of concrete incorporating glass waste powder decreases as the cement replacement percentage increases at both curing ages. The density at the age of 56 days is lower compared to its density at the age of 28 days. In terms of density compared to the reference concrete, the density of glass waste powder concrete is generally lower at both curing ages, except for the 5% replacement at the age of 28 days, where the density is nearly equal. These findings suggest that the use of waste glass can lead to the production of lightweight concrete.

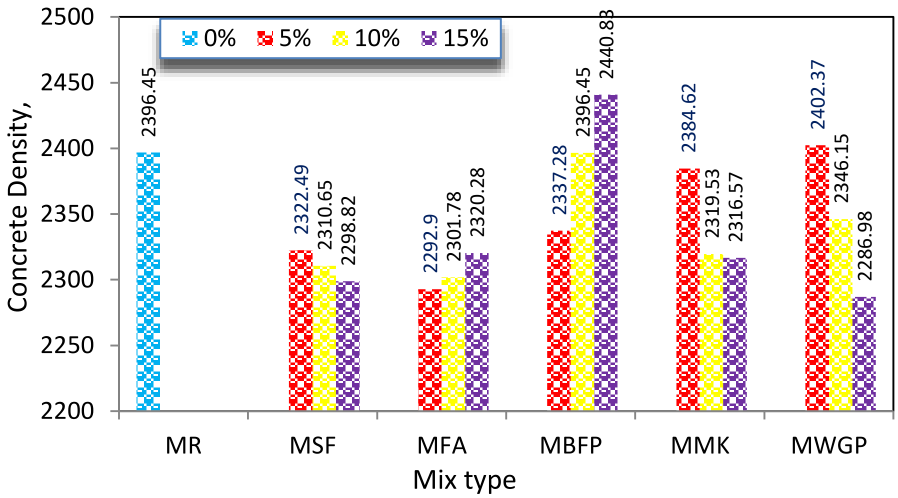

Figure 20. Concrete density vs mix type containing on pozzolanic materials with different percentage at curing age of 28 day

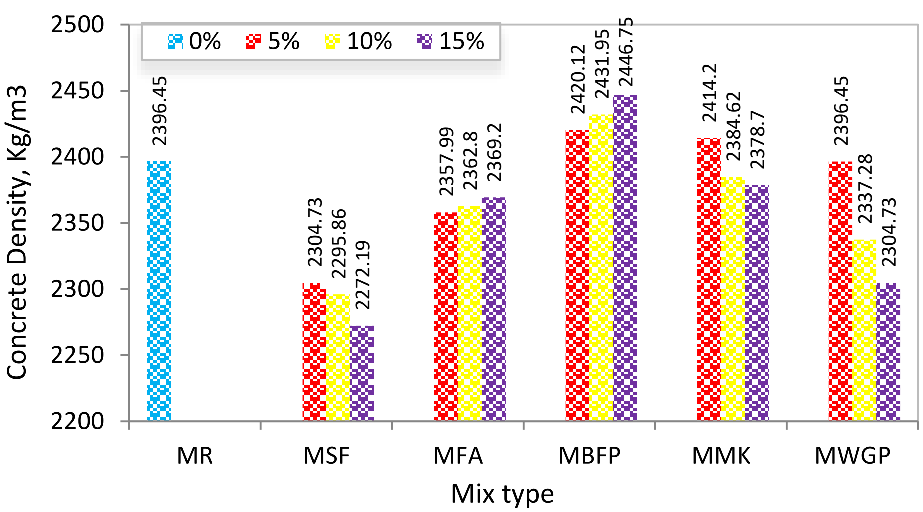

Figure 21. Concrete density vs mix type containing on pozzolanic materials with different percentage at curing age of 56 day

5. CONCLUSIONS

This study preser ... zzolanic materials. Based on the newly acquired results, the following conclusions can be drawn:

- The consistency of all pozzolanic concrete mixtures showed a significant improvement compared to the reference mixture (M_R). Notably, concrete mixtures containing glass waste powder exhibited superior performance at all replacement ratios.
- The consistency of concrete mixtures with pozzolanic materials improved as the replacement ratios increased, with the exception of concrete mixtures containing silica fume (SF), which displayed slightly lower consistency but still had an average increase of approximately 24.6% compared to M_R.

- At a curing age of 28 days, a noticeable enhancement in compressive strength was observed in concrete containing 15% blast furnace slag powder (BFP), increasing by up to 1.73% compared to M_R. In contrast, the compressive strength of other pozzolanic mixtures was lower than MR at replacement ratios of 5%, 10%, and 15%.
- At a curing age of 56 days, there was a significant improvement in the compressive strength of BFP concrete and metakaolin concrete (MK) at a replacement ratio of 15%, increasing by 6.7% and 3.3%, respectively, compared to M_R. Additionally, there was a significant improvement in compressive strength at 10% for SF and BFP, with increases of up to 2% and 0.5%, respectively, compared to M_R. At a 5% replacement ratio, the compressive strength of BFP was similar to M_R. However, the other pozzolanic mixtures did not exhibit strength improvement compared to MR at any replacement ratio.
- The study revealed that the compressive strength of pozzolanic concrete improves with increasing concrete age at all replacement ratios.
- It was observed that the compressive strength of SF and fly ash (FA) concrete increased up to 10% replacement, after which it decreased. In contrast, BFP, MK, and waste glass powder (WGP) concrete improved with an increase in the replacement ratio.
- Glass waste powder concrete, at a 10% replacement, displayed a higher indirect tensile strength of 7.1% compared to the reference mixture. Conversely, other pozzolanic mixtures had lower tensile strength compared to the reference mixture.
- For the ratio of tensile strength to compressive strength (F_t/F_c), metakaolin concrete achieved the highest percentage (F_t/F_c) at the 5% and 10% replacement ratios compared to other mixtures, primarily due to the lower compressive strength of metakaolin concrete at these replacement ratios. In contrast, blast furnace slag concrete had a lower (F_t/F_c) compared to the reference mixture and other pozzolanic mixtures at all replacement ratios.
- The density of pozzolanic concrete, including SF, FA, MK, and WGP, was lower compared to the density of the reference mixture (M_R) at all replacement ratios, except for WGP, which closely matched the density of M_R at the 5% replacement ratio for curing ages of 28 and 56 days. BFP concrete had higher density compared to M_R at all replacement ratios at a curing age of 56 days, as well as at the 15% replacement rate at a curing age of 28 days.
- The density of SF and WGP concrete decreased with increasing replacement ratios and concrete age, while MK concrete density decreased with increasing replacement ratios but increased with increasing concrete age. On the other hand, the density of BFP concrete increased with both the replacement ratio and the age of the concrete.

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