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Study on Mechanical and Durability Characteristics of Sustainable Geopolymer Concrete

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Abstract: The concentration of greenhouse gases in the atmosphere has increased quickly as a result of anthropogenic activities that cause global warming. To solve this issue, Portland cement-free geopolymer concrete is created by using ground granulated blast furnace slag (GGBS) as the primary binder and micronized biomass silica (MBS) in varying proportions in composition of GGBS. The outcomes of this experimental investigation demonstrate the mechanical properties and robustness of geopolymer concrete. In the creation of MBS, rice husk is utilized. Besides from compression, flexural, split tensile strength, and elastic modulus testing, further measurements of water absorption, water sorptivity and rapid chloride permeability test were also carried out. It is found that a geopolymer concrete mix with 10% MBS and 90% GGBS as a binder had the best strength and durability. Also, the compressive strengths of each geopolymer concrete mixture exceeded the required design strength. This experimental investigation shows the possibility of employing MBS as a binder raw material in the production of geopolymer concrete.
Keywords: Geopolymer concrete, Ground granulated blast furnace, micronized biomass

I. INTRODUCTION

Geopolymers are non-crystalline Si-O-Al networks that have SiO4 and AlO4 tetrahedral frameworks covalently bound together and connected by shared oxygen to form a dense, amorphous to semi-crystalline three-dimensional framework. The development of cementitious materials is moving quickly in the direction of the trend towards sustainability and environmental friendliness. It is crucial to create building materials with the attributes of being ecologically friendly, affordable, and reusing resources that have been left unused in order to reduce resource consumption and carbon dioxide emissions [1]–[9]. Due to the geological origins of their initial raw materials, these materials are known as geological polymers.

Both condensation and inorganic polymerization are used in the manufacture of geo-polymers. Green cementitious materials without cement were referred to as geopolymers. These are inorganic polymers produced by the activation of aluminosilicate materials such as fly ash, by alkalis. Concrete manufacturing no longer uses OPC due to geopolymer concrete (GPC). Geo-polymers are mineral binders that may be created by polymerizing an alkaline liquid with a base material made of aluminium (Al) and silicon (Si), which are chemically identical to zeolites but differ in having an amorphous structure. These zeolitic polymers outlast OPC concrete in terms of durability.[10], [11]

Geopolymers can surpass the constraints of ordinary Portland cement (OPC) while also replacing it. While geopolymer production does not require high temperatures for calcinations, OPC manufacturing must. According to Adak et al., 6% nano-silica was added to fly ash-based GPC to increase strength and durability.[12]

In contrast to OPC, geopolymers have superior chemical and mechanical properties and produce no CO2 during production. As a result of being more environmentally friendly than OPC, geopolymers are frequently referred to as "green cement." Kusbiantoro et.al.[13] uses GGBS and RHA, which have higher calcium and silica contents than fly ash, to produce high strength GPC. Additional dissolution and polycondensation of aluminate precursors from fly ash particles with silicate monomer and small oligomer supplied by MIRHA particles resulted in a higher geopolymer matrix quality with denser-gel structure, thus improving the performance of fly ash based geopolymer concrete.

Geological or industrial by-products such fly ash, GGBS slag, red mud, paper waste sludge, rice husk ash, wheat straw ash and other minerals can be used for production of geopolymers. Cost, availability, and specialized application all play a role in the source material selection process for geo-polymerization.

A.N.Givi et al. examined the mechanical and durability properties of concrete. They discovered that adding ultrafine rice husk ash to cement reduced water permeability while increasing workability and compressive strength [14]. Fly ash [Class F] based geo-polymerization has got a lot of scientific attention lately.

Thermal power plants create this by-product of coal combustion, which has a high alumina and silica concentration. Natural resources rich in alumina and silica that have been alkali activated provide a dense polymerization network. The compressed 3D framework created after hardening is referred to as a geopolymer, and the complete process is known as geo-polymerization. An inventive and environmentally sustainable alternative to Portland cement concrete is geopolymer concrete. Portland cement, which produces a lot of CO_2 , can be used less often when geopolymer is used. Concrete made using geopolymer cement can be made from waste materials like fly ash and ground-granulated blast furnace slag (GGBS).

Thermal power plants generate fly ash as a waste product, whereas steel mills generate ground granulate blast furnace slag as a waste product. Both fly ash and GGBS are processed using the proper technology and used in geopolymer concrete for concrete operations. By decreasing the need for Portland cement, the use of this concrete seeks to minimize waste stock and lower carbon emissions. In comparison to regular concrete, it offers a number of benefits. The strong compressive and tensile strengths of geopolymer concrete make it more resistant to fire and corrosion. It swiftly reaches its full strength, cures totally faster and experiences less shrinkage than conventional concrete. Because it emits less carbon dioxide during construction, geopolymer concrete is a viable building material.

Sustainable and green concrete, which are more important in today's society, might include concrete composites including MBS and GGBS. Promoting green concrete that efficiently uses MBS and GGBS is crucial for lowering cement use and waste. It has not been sufficiently investigated how MBS and GGBS affect the workability, mechanical properties, durability, and sorptivity of GPC. Examining how MBS and GGBS affect the workability and mechanical properties of concrete was one of the main objectives of this study. GPC conserves the environment by turning agricultural and industrial waste into a valuable resource for building new infrastructure.[15]–[21]

The purpose of this work is to investigate the engineering properties of GGBS-MBS blended GPC and to fill a research gap. In previous geo-polymerization research, fly ash served as the main binder. In this investigation, both agricultural and steel industry waste (GGBS and MBS) were used. To find the optimal ratio, different MBS substitutions for GGBS were tried. Compared to GGBS, which has a larger calcium content, MBS includes a higher amount of silica oxide. There should be more silica available for polymerization reactions if additional silica is added to the GGBS-based geopolymer process, which should enhance the properties of GPC. Throughout the course of 28 days, the following properties are evaluated: sorptivity, water permeability of chloride, compression, split tensile, and compression [22].

A compressive strength of up to 70 MPa (N/mm2) can be found in geopolymer concrete. Much faster than conventional Portland cement concrete, the concrete gains compressive strength. A strength of more than 25 MPa was discovered in the concrete after 24 hours. It was discovered that the compressive strength was between 60 and 70 MPa after 28 days. Drying shrinkage is significantly lower than cement concrete. For thick, tightly confined structural concrete members, this makes it perfect. Its heat of hydration is lower than cement concrete's.

Compared to concrete made with OPC, this material has a substantially higher fire resistance. This concrete was demonstrated to have exceptionally strong acid resistance when exposed to 2 percent and 10% sulfuric acids. Substantial strength loss at the initial temperature increased up to 200^{o}C and not higher than 600^{o}C. Up to 600^{o}C, no cracks are apparent. At 800 ^{o}C there were less major cracks seen due to greater compatibility between the aggregates and matrix. Bond Strength is three times greater than its compressive strength and four times better than OPC.

S.Vediyappan et.al [23] aimed this laboratory study was to see how MBS inclusion in various amounts of slag- based alkali activated mortar and concrete affected the final product. The use of industrial by-products such as GGBS and MBS in the manufacturing of geopolymer concrete can be profitable when ambient air curing is employed. In terms of weight replacement, the optimum percentage replacement of GGBS. with MBS is found to be 20%. As a result, MBS is used to create a new type of geopolymer composite.

MBS polymer composites have a good impact on the environment. To Discover the ideal mixture for geopolymer concrete that produces stronger and more durable results and do an experimental analysis of the geopolymer concrete mixture for compressive strength, split tensile strength, flexural test, water absorption, water sorptivity, and RCPT using various amounts of ground granulated blast furnace slag and micronized biomass silica. The outcomes of Geopolymer Concrete and Regular Portland Concrete should be compared.

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II. EXPERIMENTAL PROGRAM

A. Material And Its Preliminary Test

A by product of the controlled burning of rice husk and grinding in jar mills is micronized biomass silica (MBS), a type of agricultural waste. Rice husk, a by-product of rice mills, is the tough, protective outer layer of rice grains. Environmental pollution and water body contamination result from the disposal of rice husk in water streams, on land, and for open burning. Paddy is produced in excess of 500 million tonnes annually worldwide. Around 20 million tonnes of RHA are generated in India each year. Rice husk is burned in a rotary furnace between 5000 and 6000 degrees Celsius and then ground in a jar mill to a particle size of fewer than 25 microns to create MBS.

Secondary calcium silicate hydrates (CSH) were created as a result of MBS's pozzolanic reaction with cement hydrates, and MBS, which has the potential to lessen the intensity of Ca(OH)2, also demonstrated better characteristics. In accordance with Le Chatelier's Principle, the specific gravity of micronized biomass silica is calculated using the Le Chatelier Flask method. Moreover, the Specific Gravity Test IS code is IS 2720-Part 3. The Specific Gravity of MBS is 2.3.

GGBS Slag from blast furnaces is a by-product of the method used to extract iron from iron ore. A variety of slag varieties, including air-cooled slag, expanded or foamed slag, granulated slag, and pelletized slag, are feasible. Only the granulated slag is utilised as a mineral additive often among these. Both cementitious and pozzolanic characteristics can be found in GGBFS. To hydrate the slag, an activator is required. The concrete takes longer to set up initially when using GGBFS. Yet, because its fineness is nearly identical to that of the cement, it has little impact on how easily concrete may be worked. By replacing the slag, the concrete gains overall strength while also becoming more durable. The Specific Gravity of GGBS is 2.9. Sieve analysis of aggregates is very important because their particle size distribution affect the properties such as the strength of concrete, solubility of the mix and their properties. The fineness modulus is Fine Aggregate = 2.568. The fineness modulus is Coarse Aggregate = 2.577.

B. Mix Design

The Geopolymer concrete mix design is the process of finding rightdd proportions of MBS, GGBS, sand and aggregates for concreteto achieve target strength in structures. The M30 grade mix is created with some adjustments from the recommendations in IS 10262-2019. The geopolymer mixture is created by completely substituting MBS and GGBS in varied ratios for cement. There is no geopolymer concrete IS standard code. The concrete is demoulded after it has solidified for a day after being cast. The concrete is examined after being allowed to cure at ambient conditions.

Table 3.1 Geopolymer mix proportion

Mixes	MBS (kg)	GGBS (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Activators (kg)		Molarity
					AAS	SH/SS	
GPC M1	-	340	740	1146	186	1:2	3
GPC M2	34	306	740	1146	186	1:2	3
GPC M3	68	272	740	1146	186	1:2	3
GPC M4	102	238	740	1146	186	1:2	3
GPC M5	-	340	740	1146	186	1:2	5
GPC M6	34	306	740	1146	186	1:2	5

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GPC M7	68	272	740	1146	186	1:2	5
GPC M8	102	238	740	1146	186	1:2	5
GPC M9	-	340	740	1146	186	1:2	7
GPC M10	34	306	740	1146	186	1:2	7
GPC M11	68	272	740	1146	186	1:2	7
GPC M12	102	238	740	1146	186	1:2	7

C. Method of Preparation of Mix

Concrete performance is evaluated using mechanical factors such as shrinkage and creep, compressive strength, tensile strength, flexural strength, and modulus of elasticity. However, all mechanical properties are not directly related to compressive strength in concrete where mineral admixtures partially replace cement, and the effects of the same amount of various mineral admixtures on the mechanical properties of hardened concrete are not directly related to compressive strength. The specimens are put to the test for flexural strength, modulus of elasticity, split tensile strength, and compressive strength. For durability, water absorption and rapid chloride penetration test is also done for the specimens.

Due of the exothermic process, sodium hydroxide (SH) flakes are first dissolved in water to create the alkali activator solution (AAS). Two minutes prior to casting, sodium silicate is then added to the SH solution. Depending on the viscosity and price of the substance, sodium hydroxide or potassium hydroxide, as well as sodium silicate or potassium silicate, can be used. Geopolymers can be made from a variety of alumino silicate sources, including red mud, fly ash, blast furnace slag, kaolinite, rice husk ash, micronized biomass silica, and others.

The physiochemical and mechanical properties of geopolymer materials are greatly influenced by these materials. First, materials such river sand, 40% of 12mm aggregate, and 60% of 20mm aggregate are put to the mixer and thoroughly mixed with the ground granulated blast furnace and micronized biomass silica. The calculated AAS is gradually added, taking into account the consistency of the mixture, after 3-5 minutes of mixing. In addition, the silicate and hydroxide ratios are kept constant at 1 to 2 and 0.65 for the liquid to binder ratio. 28 days of ambient curing are used to cure the geopolymer concrete.

III. RESULTS AND DISCUSSION

A. Compressive Strength

Compressive strength is the maximum compressive stress that a solid material can withstand without cracking under a progressively applied force. Compressive strength tests must be done on the test material with equal opposing pressures. Normally, test materials are in the form of cylinders,cubes, or spheres. The compressive strength test was done as per IS 516(Part 1):2018.

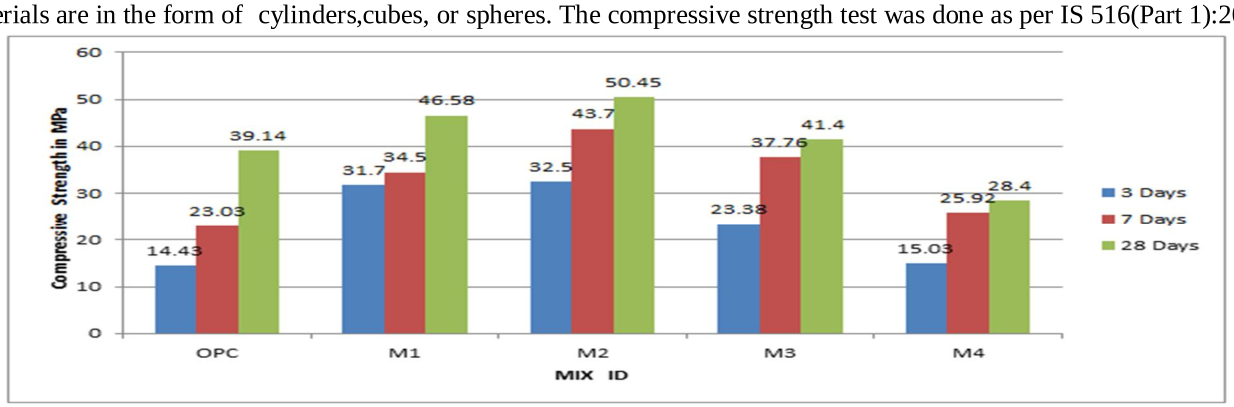

Figure 4.1 Compressive Strength of Molarity 3 at different curing periods.

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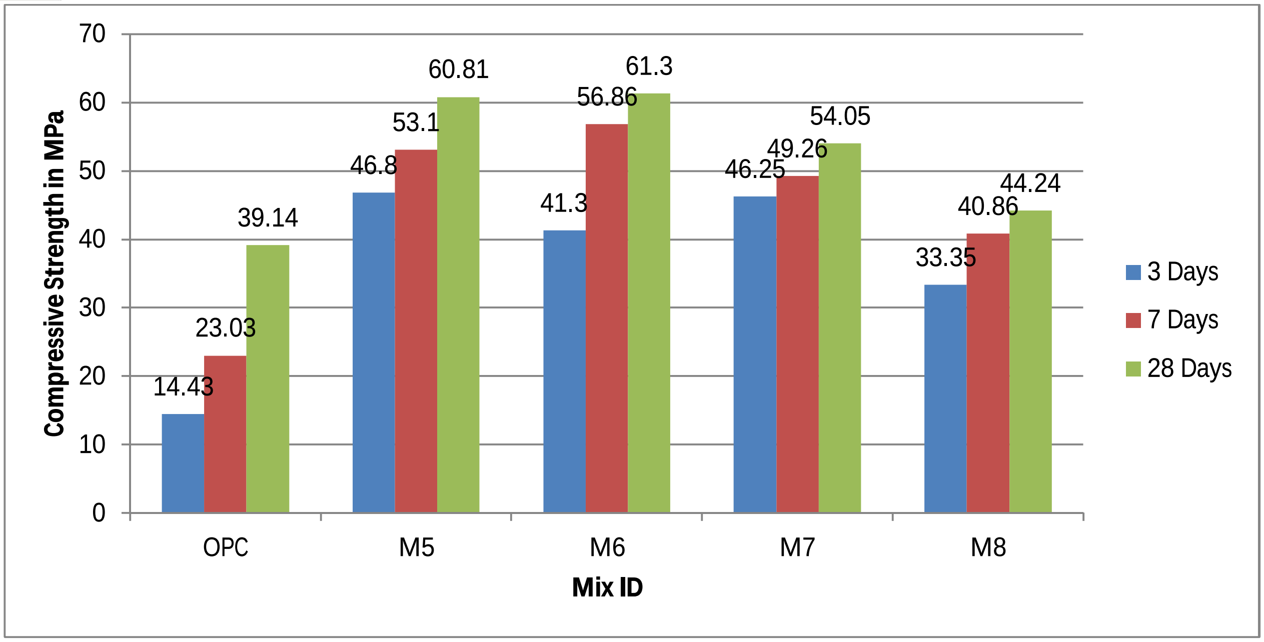

Figure 4.2 Compressive Strength of Molarity 5 at different curing periods.

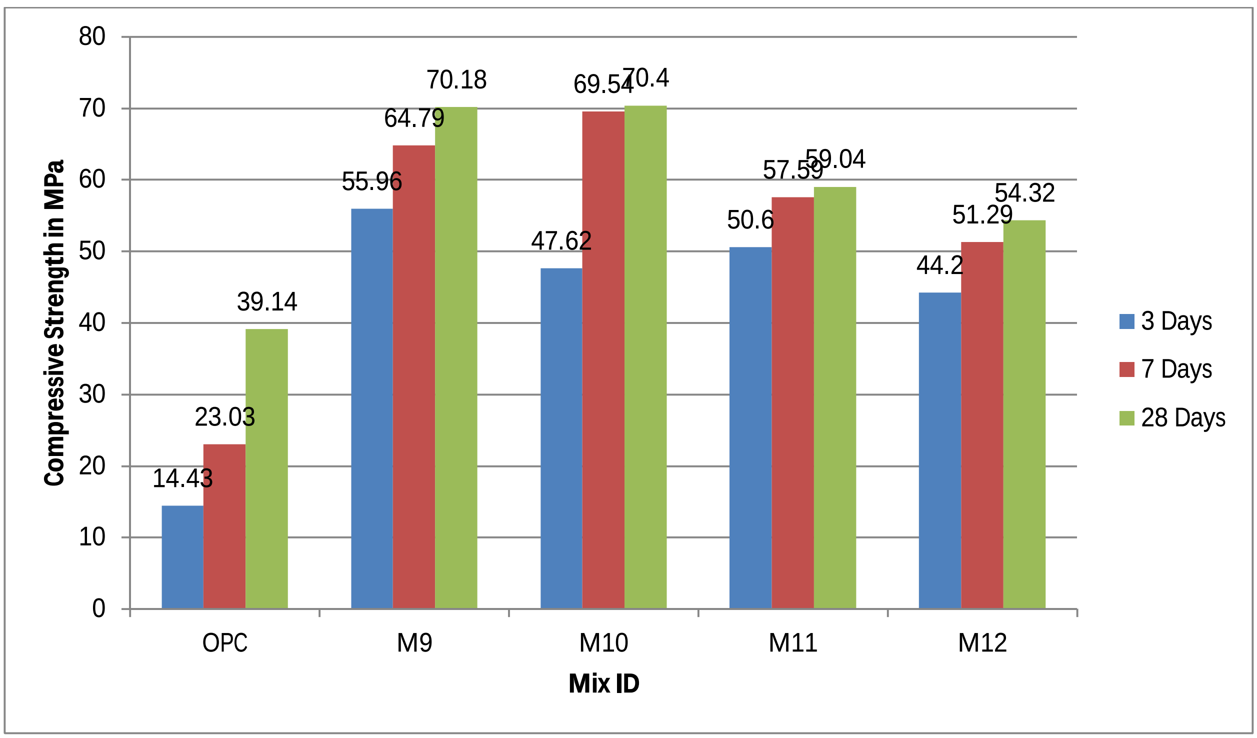

Figure 4.3 Compressive Strength of Molarity 7 at different curing periods.

B. Split Tensile Strength

To evaluate the tensile strength of hardened concrete, a splitting tensile strength test is employed. Little adjustments to the liquid to binder ratio, component proportioning, slump increase, and other factors can affect the intended concrete strength. This in turn affects the stability and strength of the structural elements. The tensile strength of concrete is described by this characteristic. To obtain this information, a split tensile test on a concrete specimen is used. The concrete test sample has a cylindrical shape. The tensile strength of the concrete specimen is defined as the tensile stresses produced as a result of applying the compressive load at which the concrete specimen may crack. According to IS 5816, a split tensile test was conducted.

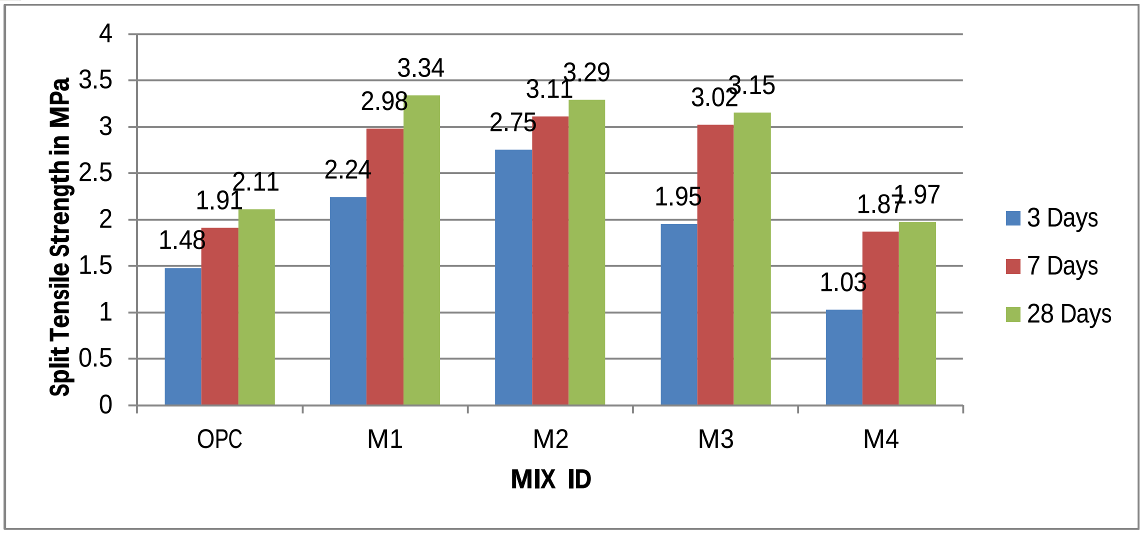

Figure 4.4 Split Tensile Strength of Molarity 3 at different curing periods.

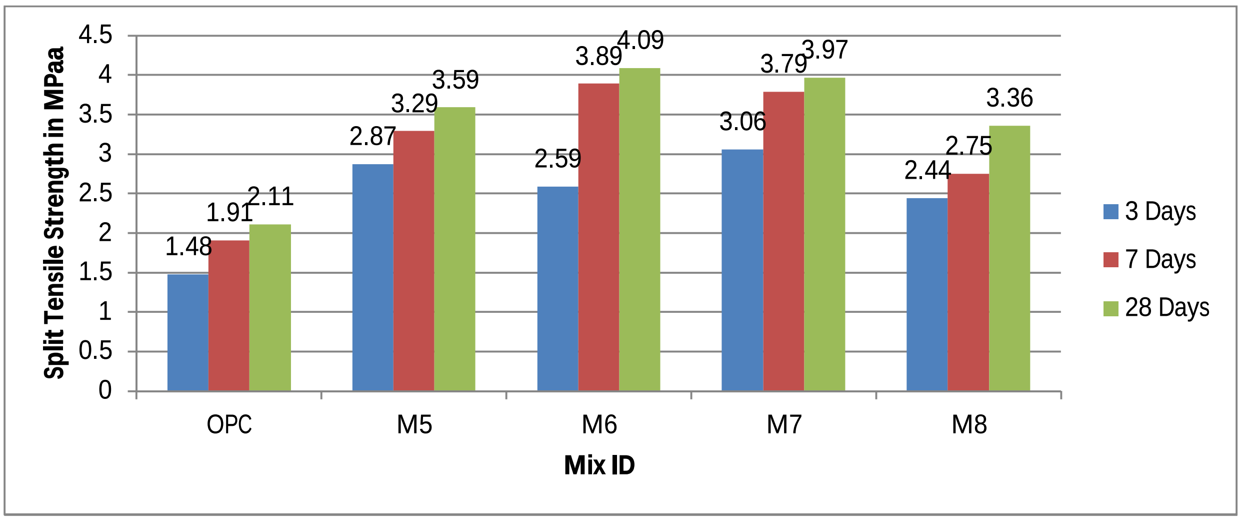

Figure 4.5 Split Tensile Strength of Molarity 5 at different curing periods.

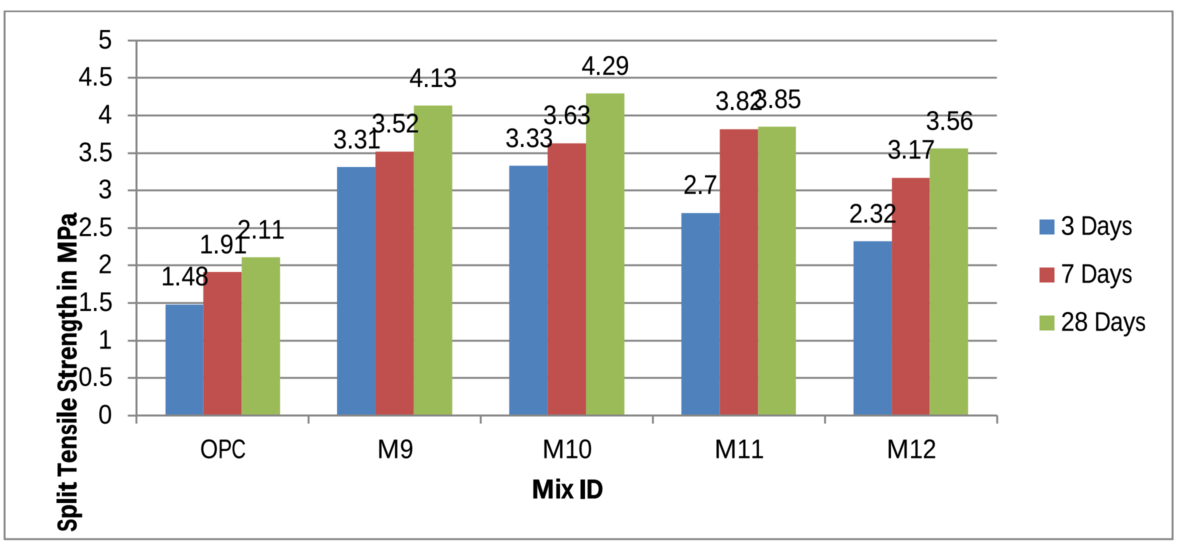

Figure 4.6 Split Tensile Strength of Molarity 7 at different curing periods.

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C. Flexural Strength

The implicit measure of the stiffness of unreinforced concrete is the modulus of rupture, also referred to as the flexural strength of concrete. Instead, the modulus of rupture can be characterised as a measurement of the excessive fibre stresses when a member is bent. Together with external force, other factors such as warping, steel corrosion, drying shrinkage, and temperature gradient can also cause tensile stresses.

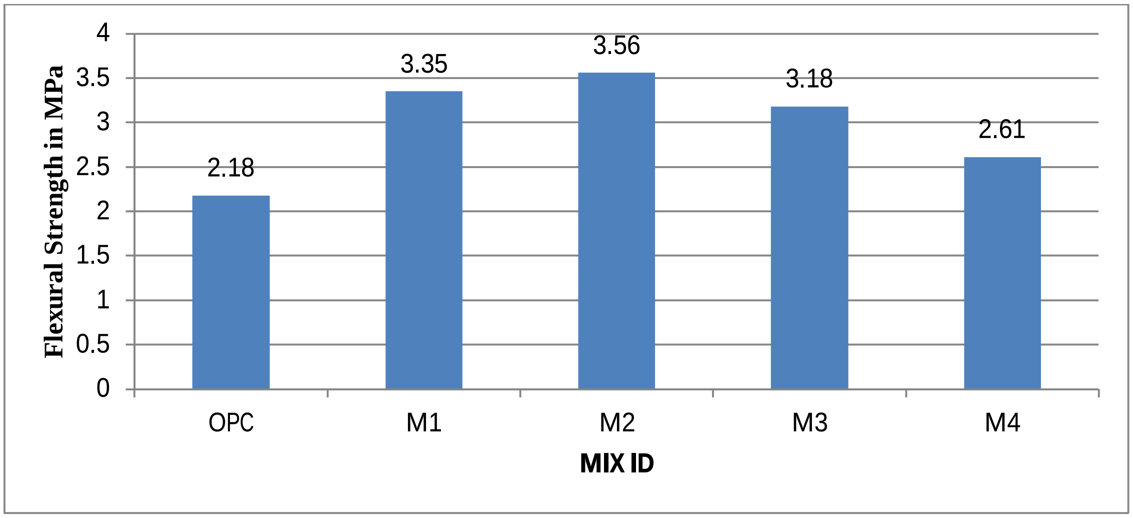

Figure 4.7 Flexural Strength of Molarity 3 at 28 days

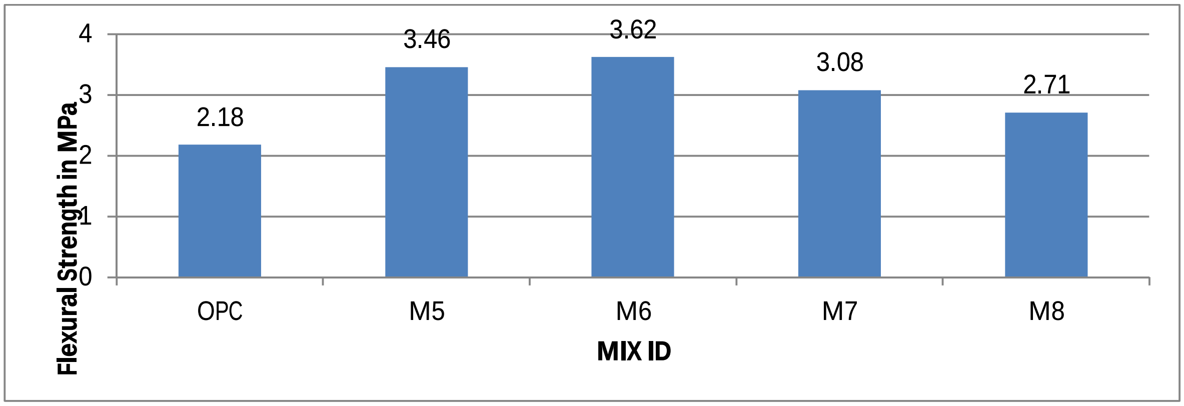

Figure 4.8 Flexural Strength of Molarity 5 at 28 days

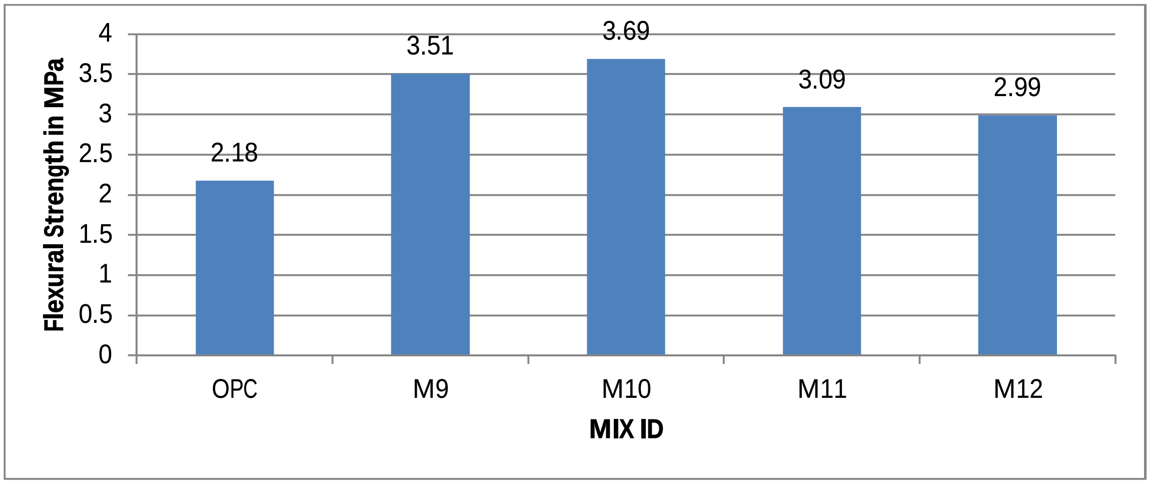

Figure 4. 9 Flexural Strength of Molarity 7 at 28 days

IV. CONCLUSION

GPC that uses by-product materials is highly sought after for more environmentally friendly construction. The goal of this study was to improve the qualities of high-strength ecologically friendly concrete by adding MBS and GGBS to the mix. The main goal of this experimental inquiry is to ascertain the effects of mixing MBS with various amounts of concrete and mortar that have been alkali activated using slag.

Also to determine the effects of MBS inclusion on the final product, which included testing various amounts of slag-based alkali activated mortar and concrete,

1) From the process used, it can be deduced that the geopolymer mix with 90% GGBS and 10% MBS has a compressive strength that is 22.41% higher than regular portland cement.
2) Because of the replacement materials' ability to bond, it has been found that when the amount of micronized biomass increases gradually, silica gradually loses some of its mechanical qualities.
3) Comparing the observed concrete to regular portland cement, the split tensile strength is 37.75% higher.
4) When the findings for compressive strength, split tensile strength, and flexural strength are compared to those of regular portland concrete, the results for geopolymer concrete with ground granulated blast furnace slag and micronized biomass silica are found to be greater.
5) For all specimens, the concrete's ability to absorb water is below the limit, indicating high concrete quality. By adding micronized biomass silica, the chloride ion penetration is also successfully resisted.
6) In conclusion, this developed GPC mix has been proven to be promising for use in a variety of constructions, including load-bearing, concrete highway, and non-load bearing structures.

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