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Basalt Fiber Reinforced Geo-polymer Concrete (BFRGC)

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ABSTRACT: An experimental study was carried out to develop a metakaolin-based geopolymer concrete. Meta-kaolin clay was used as the source material in the study. The alkali activator solution was prepared with sodium-based compounds such as sodium silicate and sodium hydroxide solution. The molarity of sodium hydroxide solution was taken as 10,12,14 and 16M. The ratio of Sodium silicate to sodium hydroxide solution was kept as1,1.5,2 and 2.5. The optimum results of compressive strength for M30 geopolymer concrete were found at 14 Molar sodium hydroxide solution for the ratio of 2.5:1 of alkali-activated solution. This mix was used for further investigation in which the basalt fibers were added as a percentage replacement of meta-kaolin.

INTRODUCTION:

Production of cement-based products pollutes the environmental habitat in several ways, some of them may be listed as the release of emissions such as CO2 into the atmosphere resulting in the depletion of the ozone layer, giving rise to global issues such as pollution (air and water), decrease in the quantity of natural resources such as lime deposits [1]. Geopolymer concrete is a sustainable material when compared with cement compounds[2]. Its production requires very less usage or no usage of cement, resulting in environmental protection as energy is conserved which is almost half the energy required for conventional concrete [3]and it also provides mechanical properties which are relatively higher than that of conventional concrete[4].

Natural source materials such as metakaolin which is high in aluminia and silica content or industrial by-products such as fly ash, GGBS are reacted with alkali activators which are generally sodium and potassium compounds (silicates and hydroxides), to produce geopolymer concrete[5,6]. Most of the studies done by researchers in the past have used different alternatives in geopolymer production such as fly ash [7,8,9], rice husk ash [12,13], GGBS, or kaolin [14,15].

Metakaolin-based geopolymer studies are limited, most of them are on to study the method of geopolymerization [16,19], the effect of methods of curing on strength [20,23], and the effect of temperature. Researchers studied various parameters related to metakaolin-based geoplymer, some of which are noted below. Pires et al. used different source materials to prepare MK-based geopolymer and studied its fracture properties. Mohseni studied the effect of the alkaline solution ratio on the properties of GPC. Alanazi et al. studied the effect of freeze and thaw cycles on GPC. Xie et al. used recycled aggregates and varied proportions of slag and MK to study characteristics such as strength, toughness and Poisson's ratio. Pouhet and Cyr studied the effect of alkaline solution molar ratio on workability, strength, porosity and density.

By observing the above studies,it is understood that a study on MK-based GPC needs to be undertaken, as the literature is limited. The effect of various parameters needs to be studied. An attempt has been made in this study to understand the effect of mixed design parameters on GPC. Sixteen mix designs were prepared and cast to investigate the effect of the molarity of sodium hydroxide solution, and sodium silicate to sodium hydroxide ratio on workability, setting time and compressive strength at various ages. OPC mixes were also cast for comparison purposes. Basalt fibers were added in GPC to study mechanical properties. X-ray diffraction (XRD), scanning electron microscopy (SEM), and energy-dispersive X-ray spectroscopy (EDS) analysis were undertaken to study the microstructure of GPC on identified mixes.

2. Literature review

Geopolymer concrete (GPC) has emerged as a viable alternative to regular Portland cement (OPC) by the sustainable attention it deserves. GPC utilizes processed tailings rich in silica plus alumina or natural aluminosilicate as a replacement for OPC as the binder. By using this process, CO2 gas emissions that are usually tied to OPC production are reduced, making GPC more climate-friendly. One of the main producers that the geopolymer industry uses is Metakaolin which is made by calcining purified kaolin clay at 650-850°C. It is characterized by high reactivity [4].

Metakaolin is the main component of the geopolymerization process which produces an alkaline solution with rapid polymerization that creates a hardening matrix [5]. In the past, the effect of several parameters of metakaolin-based GPC has been researched in depth to evaluate its end properties. A curing regime – ambient curing, oven curing, or steam curing – would result in a much greater compressive strength. Curing in the oven and the steam autoclave shows improvement in strength by up to 2.5 times than the ambient curing condition [6]. The greater the molarity of the alkaline activator solution of NaOH results in faster setting and heating but it reduces the amount of workable time. The compressive strength of the corrosion data is linear up to 16 M NaOH [7]. The presence of sodium silicate acts as a retarder and improves the workability of concrete, also delaying the setting time, yet it might weaken the strength at higher ratios (>2.5-9\". Whereas researchers have managed to combine basalt fibers and plastic aggregates as reinforcements to improve mechanical properties [9, 10].

Experimental pieces of evidence about alkali-activated blast furnace slag cement have shown that milling the minerals before geopolymerization leads to the enhancement of the reaction intensity [11, 12]. The majority of work carried out on mechanical activation has commonly focused on fly ash-based geopolymers. Yet, we have not noticed much literature on mechanically operated MK GPC which focuses on how milling affects the geopolymer properties. According to Yao et al. [13], metakaolin was ball milled for 5-60 min then activated for 60 min and it was optimally effective for durability. The other important research would focus on the optimization of milling parameters (length, speed) too. Besides, a lot of researchers have employed SEM, EDX, XRD and NMR analyses to determine the microstructural modification of the metakaolin system [14, 15]. However, the influence of microstructural modification on the mechanical activation process is still poorly understood.

In addition, gainings should be made between MK-based GPC and OPC in terms of all fresh, hardened and durable properties using a standardized curing regime. Over the years many studies of the metakaolin geopolymer have shown that with heat curing they can match and even exceed OPC compressive strengths. [4, 16] However, not many studies are available on the action of the ambient temperature curing after which the infrastructure development-associated behavior is determined [3]. The absence of literature in this area requiring attention precludes the use of metakaolin GPC at the pilot scale. This review revealed that metakaolin has achieved its great promise in the field of geopolymer synthesis. What is more, valuable research may be needed to show how microstructure development and properties are affected by treatments like mechanical activation and bench curing. This may help in bringing such practices into common use.

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3. Experimental Program

3.1 Materials

3.1.1 Source material

Locally available metakaolin (MK) was used in the study as source material which is an alumiosilcate precursor. The chemical composition of MK is in Table 1. Alkali activators used in the study comprised of sodium silicate and sodium hydroxide solution. Sodium silicate solution was lab certified gel based solution whereas sodium hydroxide solution was prepared by mixing 98% pure NaOH pellets in tap water to solve the required molarity.

3.1.2 Aggregates

Coarse aggregates of size 20mm and fine aggregates of size less than 4.25mm are used in the study. The physical properties are listed in Table 2.

3.2 Test Matrix

An investigation was made to study the parameters like the molarity of prepared alkali-activated solution, sodium silicate to sodium hydroxide ratio, and workability on GPC. A reference mix was selected from a series of trials and was combined with basalt fiber to provide high strength. The design variables of MK-based GPC are listed in Table 3.

3.3 Casting and curing

Ingredients such as MK, coarse aggregate, and dry aggregate were mixed separately for about 2-4 minutes. Liquid ingredients such as sodium silicate solution, sodium hydroxide solution, and water were added to the dry compounds and mixed properly till a homogeneous mixture was formed. The concrete mixture thus formed is molded into standard specimens and vibrated using a vibrating table. Samples are cured at room temperature (air temperature).

4. Results obtained from the study

Table 1 includes the details of the chemical composition of meta-kaolin (MK) that is added to concrete as a supplement. The three most important components are appended - fine aggregate, coarse aggregate, and meta-kaolin clay. For fine aggregate the specific gravity is 2.70, the fineness modulus is 3.48 and the water absorption percentage is 0.5%. The aggregate has a lower specific gravity of 2.59 and a higher water absorption of 1.0%. Therefore, the coarse aggregate is composed of more material and contains less water. The fine aggregate gradation does not include the coarse aggregate nozzle. Lastly, kaolinite clay is the clay with the lowest specific gravity, 2.5. The fineness modulus for this material is at 1.11 which means it has a very fine distribution of the particles. Unfortunately, no water absorption percentage is shown for the meta-kaolin clay modifier.

Table 1. Chemical composition of MK

Property	Fine Aggregate	Coarse Aggregate	Meta-kaolin clay
Specific gravity	2.70	2.59	2.5
Fineness modulus	3.48	---	1.11
Water absorption (%)	0.5	1.0	--

Table 2 exemplifies the mix design which is for alkaline concrete, and it shows the proportion of the components that are required to get 1 cubic meter of concrete. Among other data, the Specification lists the target value of the MK ratio as 0.4, the coarse aggregate content as 405kg/m3, the fine aggregate ratio as 0.35, the fine aggregate amount range from 1255kg/m3 to 1252kg/m3 depending on activator ratios, the sodium silicate amount range from 8 Consequently the sodium silicate to sodium hydroxide grows from 1.0 to 2.5, resulting in increased amounts of sodium silicate and decreased amount of sodium hydroxide. Another more minute and less essential particle characteristic of the aggregate content is decreasing along with the increase of the activator ratio. This suggests mixed design modifications to consider the fact that greater water is created by a greater sodium silicate inclusion. In the end, the table presents a complete mix of alkali-activated concrete with a weight of coarse aggregate ranging from 405 to 405 kg/m3 and that of fine aggregate varying from 675 to 675 kg/m3. A variable amount of alkaline activators ranges from 125 to 160 kg/m3 together with additional water

Table 2. Mix Design physical properties of M30 Meta-kaolin based Geo-polymer concrete

The solution to the MK ratio	MK (Kg/ m^3)	Fine to Total agg. ratio	CA Kg/ m^3	FA Kg/ m^3	Sodium silicate to sodium hydroxide ratio	Sodium silicate Kg/ m^3	Sodium Hydroxide Kg/ m^3	Extra water Kg/ m^3
0.4	405	0.35	1255	675.77	1	81	81	30.22
0.4	405	0.35	1254	675.24	1.5	97.2	64.8	31.72
0.4	405	0.35	1253.38	674.89	2	108	54	32.71
0.4	405	0.35	1252.91	674.64	2.5	115.71	46.28	33.43

Table 3 shows the relationship between the molarity of aqueous sodium silicate (NaOH: Volumetric Concentration (EDTA) solutions and the mull diameter in mm for different volumetric ratios. With the increase of the molarity from 10M to 16M, a large flow diameter will be seen as opposed to a small flow diameter for a given mixing ratio. For example, at a 1:Varying the molarity from 10M to 16M (NaOH: SiO2 ratio) makes the diameter change from 35 mm at 10M to 24.8mm at 16 M. Along with this, the opposite behavior of the diameter with the varying content of SiO2 and NaOH occurs in the process. The most extreme example is 16M concentration - the diameter ranges from 24.8mm at a 1:SiO2 to NaOH ratio and has reduced from 1:23 to 1:2.5 at the same time, the NaOH (sodium hydroxide) component is not increased in any dramatic way. In summary, especially the high molarity and large silicon dioxide concentration compared to sodium hydroxide cause a small flowing diameter. The data shows that this trend holds for aqueous solutions of varying sodium silicate molarity and composition.

Table 3. Workability of meta-kaolin-based geo-polymer concrete

Molarity of AAS	Sodium silicate: sodium hydroxide	Flowing diameter (mm)
10 M	1:1	35
	1.5:1	33.33
	2:1	29.3
	2.5:1	26.8
12 M	1:1	29
	1.5:1	29
	2:1	28
	2.5:1	27
14 M	1:1	27
	1.5:1	27
	2:1	25
	2.5:1	25
16 M	1 :1	24.8
	1.5:1	23.6
	2:1	23
	2.5:1	23

After 10M, 12M, and 14M activators, respectively, at a higher SiO2/Na2O ratio, there is a positive trend of enhancing compressive strength of all curing ages in Table 4. For example at 14M, the 2.5. The compressive strength of the 1 binder sample was 50.4 MPa at 28 days, approximately 9% higher than the 1:1 binder, which had a compressive strength of 46.2 MPa at the same duration. Such presence means that soluble silicate renders to higher reaction with hydroxide and, therefore, generates more strength. However, at 16M concentration, the opposite trend is observed - the 1:1 element was employed, resulting in higher strength than higher silicate modulus binders. This means that in a high, hydroxide concentration regime the activation of adsorbent through the silicate species is reduced compared with that in high activator contents. In the silicates modulus ratios, a linear trend may be observed where compressive strength rises with increasing molarity from 10M to 14 M. Nevertheless, the strength of 16M slag was not observed to increase any further in the subsequent tests, and this most likely occurred due to the saturation of reactants at the 14M stage.

The greatest strength gains appear in 7 to 28 days conflicting with molarities and modulus of silicate. As the age increases up to the 90th day, only less significant extra increases in the compressive strength are found, which shows that the reactions are completed approximately as early as 28 days.

Table 4. Compressive strength of M30 Metakaolin-based Geopolymer concrete

Molarity	Sodium silicate: sodium hydroxide	7 days	14 days	28 days	90 days
10 M	1.0:1	21.2	33.7	45.8	47
	1.5:1	21.6	34.2	46.1	48.2
	2.0:1	22.4	34.8	46.7	48.9
	2.5:1	23.1	35.3	48	50.3
12 M	1.0:1	21.9	34.9	45.4	46.9
	1.5:1	22.3	35.7	47.1	49.2
	2.0:1	22.8	38.1	48.8	50.1
	2.5:1	23.5	38.8	49.2	51.6
14 M	1.0:1	22.7	35.5	46.2	49.3
	1.5:1	23.4	37.1	48.1	50.8
	2.0:1	23.9	39.4	49.3	51.2
	2.5:1	24.1	39.9	50.4	52.5
16 M	1.0:1	21.4	32.1	39.3	40
	1.5:1	21.7	32.6	39.8	40.2
	2.0:1	22.3	33.4	40.2	41.9
	2.5:1	23.5	33.7	40.7	42.3

Table 5 displays the compressive strength of the concrete in megapascals (MPa) after the varied curing times in the days below. In particular, the required compressive strength of the 7-day concrete was 5.3 MPa. Following 14 days of curing, the concrete resisted with a strength of 5.8 MPa. The strength of concrete increased more markedly at the 14-28-day interval, with the concrete being 7.4 MPa strong after 28 days were over. Concrete strength rose from 7.4 to 7.8 MPa for 28-90 days after the fermenting process. As a whole, the data points out that concrete achieves considerable strength in the first few days with the remainder of the gain to be done by the end of the 28th day. At the end of the 28 days, the gain in strength is much less than the previous comparable period and before the arrival at 90 days, it is unnoticeable. This shows that time of curing is essential in case of differential strengths between the given two concrete cubes.

Table 5. Split tensile strength of 14 M Metakaolin Geopolymer concrete.

Days	Strength (MPa)
7	5.3
14	5.8
28	7.4
90	7.8

Table 6 offshoots the correlation between the compressive strength of concrete and the number of days after it was cast. Compressive strength is given in the megapascals (MPa). At the end of the seventh day, the concrete was measured to have an unconfined compressive strength of 9.4 MPa. On the 14th day, the strength identified had a slight increase of 9.8 MPa. The reading for the concrete compressive strength was 10.3 MPa at 28 days. After 90 days, the concrete reached considerable strength with 11.3 MPa as opposed to 2.6 MPa recorded on the first day. This information indicates that the concrete continues to strengthen as the chemical hydration process works, which is the factor that causes the concrete to grow stronger. The vast amount of concrete strength is achieved after 28 days, though that process still gains tiny additional strength over time. Concretely, it has become clear that the analyzed concrete reached most of its strength potential after 90 days. Monitoring the power degree over time allows construction engineers to plan the removal of the forms and determine if the structure is ready for loading.

Table 6. Flexural strength of 14 M Metakaolin Geopolymer concrete

Days	Strength (MPa)
7	9.4
14	9.8
28	10.3
90	11.3

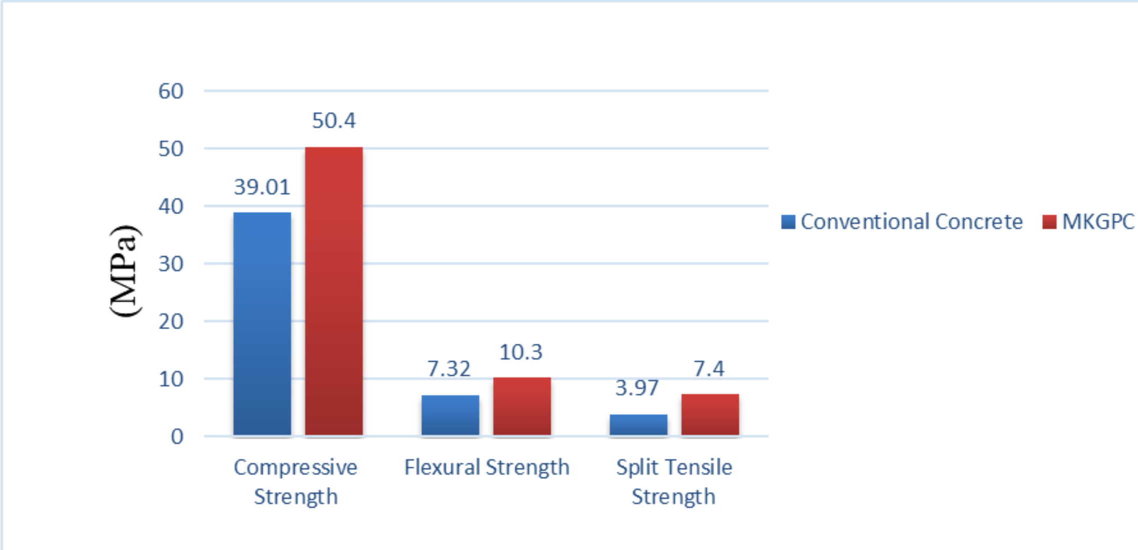
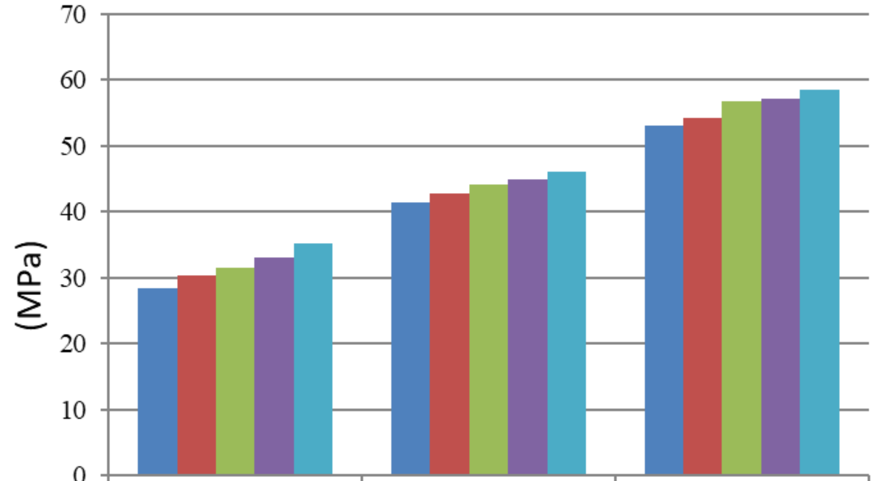


Figure 1. Comparison of 28 days strength of Metakaolin geopolymer concrete with Conventional concrete

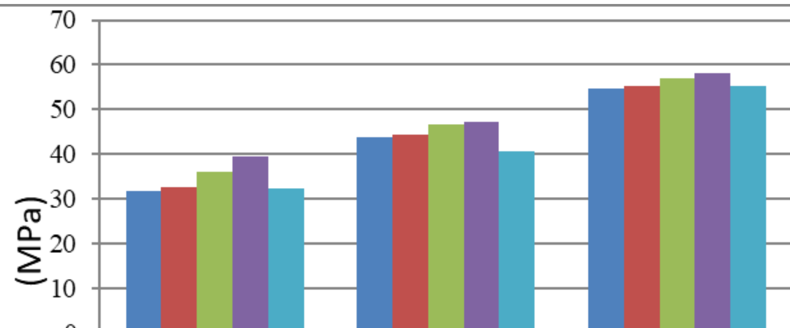
Figure 1 provides data on three key strength properties of two types of concrete: traditional concrete and a new concrete mix called multi-component granite powder concrete (MKGPC). For standard concrete, the compressive strength is 571.5 psi, the flexural strength is 104.4 psi, and the split tensile strength is 558.7 psi. The MKGPC has a compressive strength of 150.4 MPa, flexural strength of 10.3 MPa, and split tensile strength of 7.4 MPa in contrast to conventional glass. In specific, the results from the data analysis demonstrate that the inclusion of the granite powder in the total mixture of the MKGPC concrete causes a considerable increase in the compressive, flexural, and tensile strengths which are much higher than those of the conventional concrete. The compressive strength of MKGPC is about 3 times more than normal concrete, whereas the flexural and split tensile strengths of MKGPC are around 1.4 times higher as compared to conventional concrete. The high-performance concrete as such is considered by MKGPC to be a more powerful and stable kind of concrete.



	7days	14days	28days
0.5% BF	28.3	41.4	53.1
1% BF	30.4	42.7	54.3
1.5% BF	31.6	44.1	56.7
2% BF	33.1	44.9	57.1
2.5% BF	35.2	46	58.5

Figure 2. Compressive strength of BFRGC using 3 mm Basalt fiber length

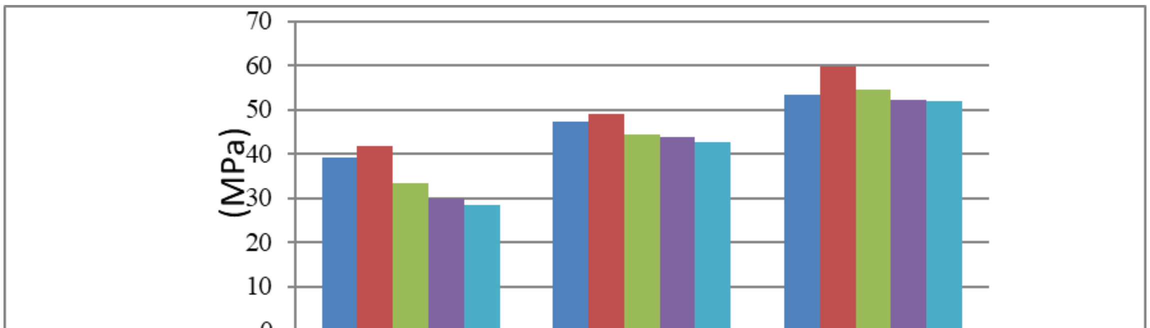
Figure 2 illustrates the response of concrete to various BF percentages by comparing its compressive strength at different times. Basalt fiber concentrations of 0.5%, 1%, 1.5%, 2% and 2.5% were adopted in preparing concrete mixtures. The compressive strength was evaluated for three representative times, 7, 14, and 28 days for each mixture. 2 days after the introduction of BF into concrete, the compressive strength varied from 28.3 MPa to 35.2 MPa, with 0.5% BF concrete giving a lower value and 2.5% BF concrete giving a higher value. It is apparent that there is a major boost in early strength coming with the addition of greater.



	7days	14days	28days
0.5% BF	31.7	43.7	54.8
1% BF	32.8	44.5	55.4
1.5% BF	36.2	46.8	57.1
2% BF	39.6	47.2	58
2.5% BF	32.3	40.8	55.4

Figure 3. Compressive strength of BFRGC using 6 mm Basalt fiber length

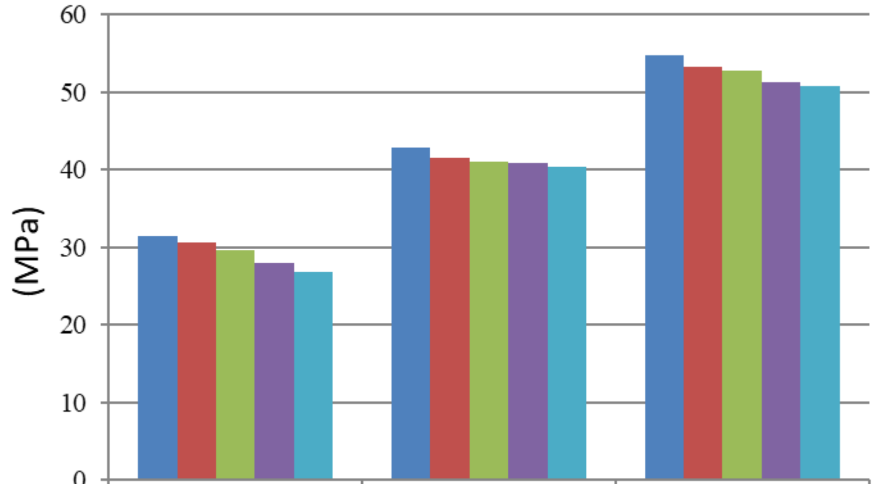
Figure 3 gives a picture of how final compressive strength relies on the BF concrete percentage which is taken at a different point of cure. On the seventh day after casting, by adding 0.5% basalt fibers to the concrete, the strength reached 3.4 MPa, while in plain concrete it did not. The most notable enhancement in the strength of 7-day cured-time was noticed at 1.5% basalt fibers which has approximately increased the compressive strength by 28.5% or 9 MPa, compared to plain concrete. After 28 days of curing, the strongest gain was observed to be either 1.5% or 2% basalt fiber, both demonstrating similar compressive strengths of about 57 MPa which marks a 4 MPa or 7% increase from the plain concrete. Unexpectedly, the compressive strength at 30% and 50% were lower than at 25% and 20% as diagnostic of all cure times. In summary, the highly compressive strength of basalt fiber is more manifested at early ages, but some of the benefits are still there around the 28th day. The targeted amount of basalt fiber for the best combination between 28-day strength and the minimizing of the fibers appears to be in the range of 1.5% to 2.0%.



	7days	14days	28days
0.5% BF	39.2	47.3	53.2
1% BF	41.8	48.9	59.7
1.5% BF	33.2	44.5	54.6
2% BF	30	43.8	52.1
2.5% BF	28.4	42.7	51.8

Figure 4. Compressive strength of BFRGC using 12 mm Basalt fiber length

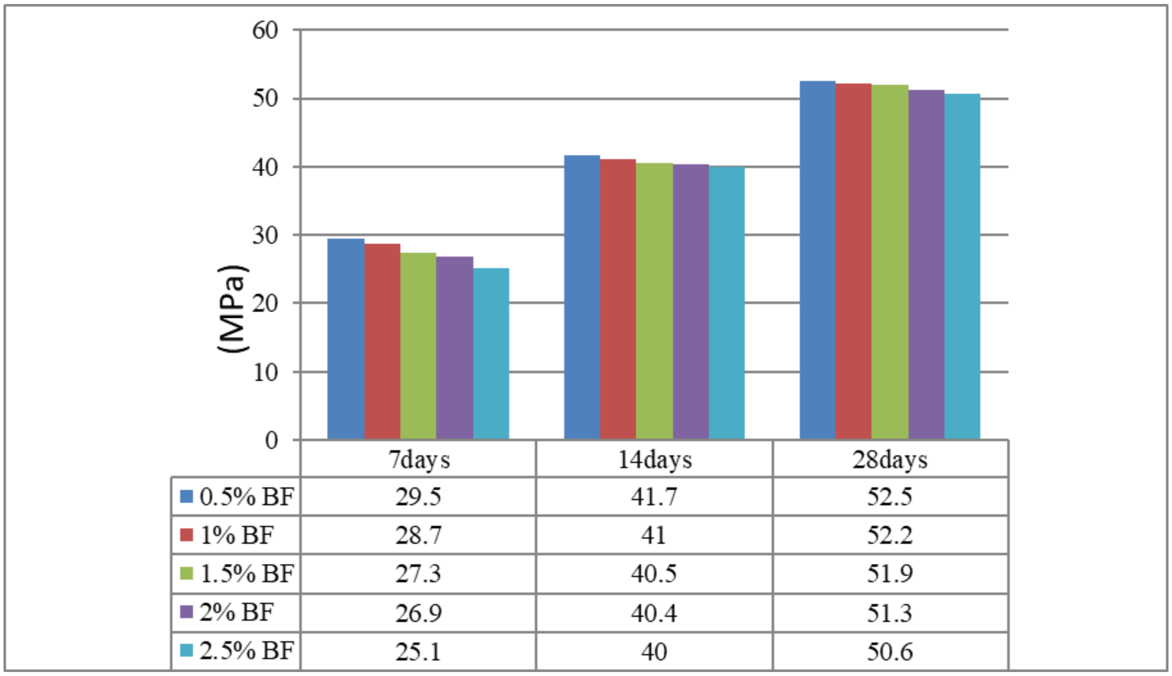
Figure 4 displays the number of days to reach the basalt fiber (BF) specific BF percentages at 0.5% increments starting from 1.5% up to 2.2% BF. This demands you to do a long term of 133 days to reach 1.5% BF. This implies that an additional 11 days would be needed to get to 2% BF if it were set as the target (i.e., 43.8 days, which is more than the 32.8 days needed for 1.5% BF as a target). And to reach 2% BF it would take 69.6 days, or about 8-9 days more than the 2.5% target. The day differentiation in targets between percentages of BF seems to decrease with increasing percent of BF. To illustrate: it needs 14 additional days to get from 1.5% to 2% BF, while only 8 days to achieve 2.5% from 2% BF. I hope to be 1.5% BF within 33 days, 51 for 2.5% BF. It is the longest period.



	7days	14days	28days
0.5% BF	31.4	42.9	54.7
1% BF	30.7	41.5	53.2
1.5% BF	29.7	41	52.8
2% BF	28	40.8	51.3
2.5% BF	26.9	40.3	50.7

Figure 5. Compressive strength of BFRGC using 18mm Basalt fiber length

Figure 5 presents the BF percentage variation in the material during the certain seven-, fourteen-, and twenty-eight-days periods. The BF% begins at 1.5% to start with. By the end of 7 days, the % reduced to 1.43% which suggests the fragmentation or depletion of some of the basalt fiber has occurred. However, the speed of decrease falls after 7 days, with the BF reduction only 1.4% after 14 days. In the last stage by the end of 28 days, the BF percentage has stabilized at 1.35%, which seems to be the best-case scenario. Thus, most of the short-lived and short-term basalt fibers have abraded and have not survived in the composite. The leading finding in this study is that the BF drops by about 10% from the initial baseline of 1.5% to the final number of 1.35% at 28 days. This, therefore, implies the core of the basalt fibers remains with no observable wear and tear, while the weakest edge parts wear away at first, leaving the longest and the strongest fibers in the material.



	7days	14days	28days
0.5% BF	29.5	41.7	52.5
1% BF	28.7	41	52.2
1.5% BF	27.3	40.5	51.9
2% BF	26.9	40.4	51.3
2.5% BF	25.1	40	50.6

Figure 6. Compressive strength of BFRGC using 24 mm Basalt fiber length

Figure 6 displays the effect of the compressive strength of concrete on concrete compressive strength, varying the percentage of basalt fiber (BF) added. In particular, the test result is the compressive strength in MPa after 7, 14, and 28 days for concrete mixtures for 0.5%, 1%, 1.5%, 2%, respectively. The most bending strength is found on day 7, where the 2% BF concrete compressor strength is 25.1 MPa and the 0.5% BF concrete compressor strength is 29.5 MPa. As the time increases, the range varies from 41.7 MPa (0.5% BF) to 40.4 MPa (2% BF) at day 14. On the 28th day, the 0.5% BF concrete had the highest strength at 52.5 MPa, as compared to 2% BF concrete with the least strength at 50.6 MPa.

The initial compressive strength appears to be decreased (after 7 days) with the increase of basalt fiber, conversely, a high percentage of basalt fiber brings about a strengthening effect (after 28 days). The 28-day peak compressive force is realized with 0.5% basalt fiber. Nevertheless, all the different concrete exhibits substantial strength credibility rise, thus proving the increasing strength feature of concrete material with such a percentage of added basalt fibers.

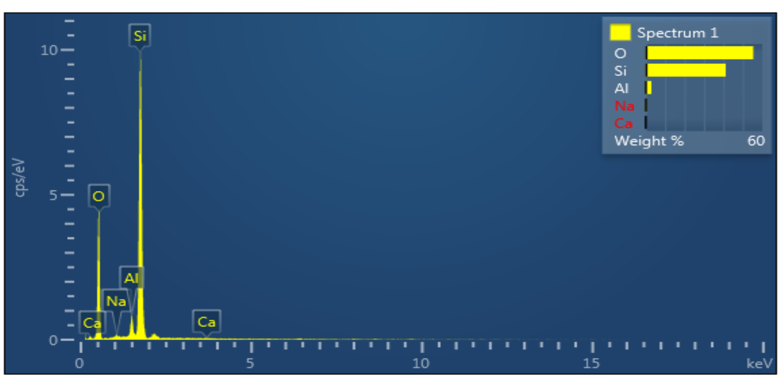


Figure 7. EDS results of 14 M Geo-Polymer concrete

Figure 7 shows that the geopolymer concrete contains a high amount of silica and provides insight into the constituent elements present in the geopolymer concrete. An EDS detector is used to separate the characteristic X-rays of different elements into an energy spectrum. A typical EDS spectrum is charted with X-ray wavelengths or counts vs. intensity or energy (in keV).

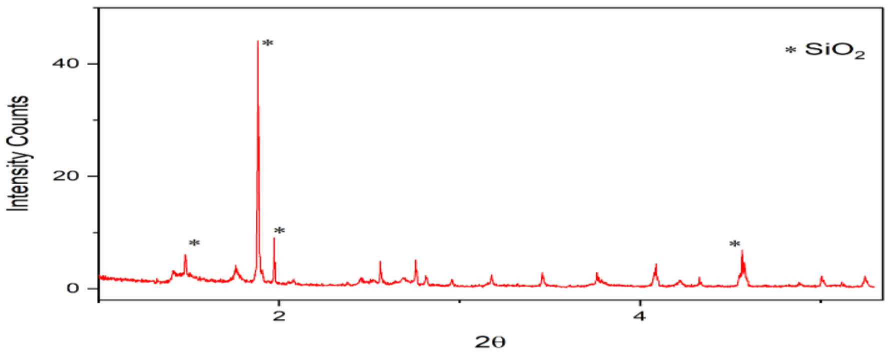


Figure 8. XRD graph of geo-polymer concrete

XRD is a technique employed to determine the underlying crystal structure of a material; it enables verification of the crystallinity and structure of a sample but gives no information of a chemical nature. The XRD characterization has been done to study the crystallinity of the nanostructured SiO_2-sensing film. Figure 8 exhibits that the changes responsible for the differences in compressive strength originate and take place within the amorphous part of the structure.

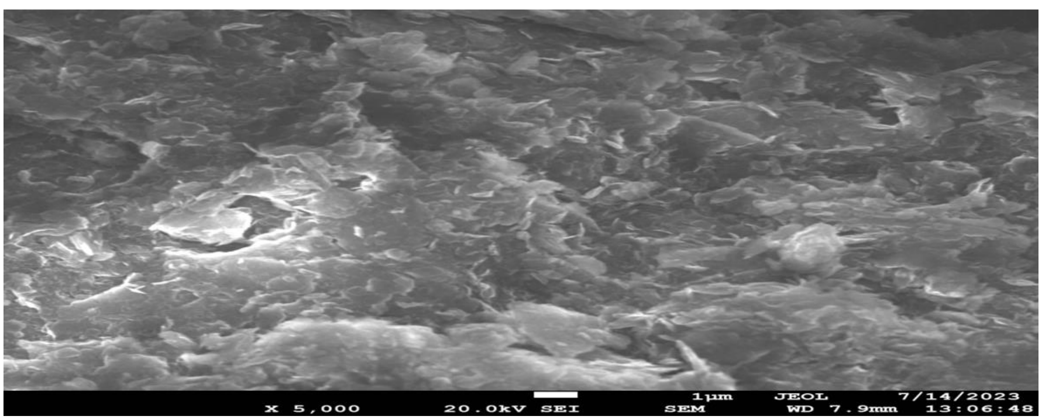


Figure 9. SEM image of geo-polymer concrete

SEM micrographs of the fracture surface of hardened GPC specimens were obtained and shown in Figure 9. This kind of microstructure without evidence of large pores is desirable for the better mechanical behavior of geo-polymer concrete (GPC). The microstructure of the GPC matrix that is visible in the micrographs is enormous with unrealized morphology, which indicates amorphous. Also, this micrograph shows minor cracks, which were probably formed to accommodate the stress fields associated with the main cracks responsible for the concrete specimen rupture under compression. It is reported that such minor cracks might contribute to keeping the integrity of the aggregate/matrix interface.

Discussion

Long-lasting, high-performance, and strong concrete is necessary for modern on-site construction. This research focused on the consequences of the incorporation of MK and variable lengths of BF into the beams of concrete specimens. Overall, it was demonstrated that the addition of MK as well as short BFs with optimal dosages increased the compressive strength.

The inclusion of this substance has received close attention among researchers as one of the most applied cementing materials. MK has high pozzolanic activity which is responsible for its reaction with calcium hydroxide that is produced from cement hydration to produce more calcium silicate hydrate (C-S-H) [16]. The C-S-H is formed in higher quantity which results in a gradual and careful pore structure evolution and better transition zone between aggregates and paste interface. In mix design, an MK replacement ratio of 0.4 was implicated as seen in Table 1. This degree addition even enhances the early and middle age compressive strengths.

Bosophate supply is being used widely as an additional component in concrete composites. In terms of strength, BFs are an inorganic material that has both a high tensile strength and a good resistance against acid, alkali, and salty solutions; they are also stable to high temperatures [17]. Surface activators, or BFs, can prevent early-age cracking and enhance the post-crack resistance of concrete (Wei & Meyer, 2016). This was accomplished by examining tables 4-6, which responded to BF treatments of different lengths and dosages. A survey of the literature, it can be concluded that shorter fibers at low volumes offer the best value of the firm compressive strength. The CPE value of 12 mm BF strength is 1% of addition, and that of 3mm BF strength is up to 2.5% of addition. A similar trend can be observed in the finding of Singha and Vinai (2020) as demonstrated by the reduction of the optical fiber volume with an increasing aspect ratio. The incorporation of BF into fresh concrete mixture modifies the mixture's workability and fiber distribution, and too high a volume of BF can cause fiber clumping, which results in uneven curing and low compressive strength [18].

The characterization techniques demonstrated in Figure 3 supply the details on the working principle delay in the mechanism of MK and BF acting in the improvement of the compressive strength. The high silica content of the geopolymer concrete provides for the formation of C-S-H which measures the pore sizes at lower values improving the strength of the concrete [16]. To make sure the concrete is mostly amorphous the XRD analysis is performed. From the SEM image, it is observed that this concrete has a dense microstructure and few large pores. In addition, microcracks are visible, which leads to the prevention of rupture using stress concentration reduction. Therefore, the microstructure phase transformation and the larger between-grains contact area are in line with the observed values of compressive strength in addition to the plain concrete.

The findings very much confirm the probability of the MK and BF routines for the strength benefit, but in-depth research is still required. The testing scope is supposed to include measurement of the effect on tensile strength, shrinkage, creep, and durability. This will help us to have better conclusions more completely and comprehensively. Moreover, the tests in field conditions can duplicate the complicated loading and the surrounding environmental exposure to some extent like the actual structures instead of the laboratory environment. On the other hand, alternative materials and production procedures could be considered to achieve multifaceted properties with lower expenditure.

In general, this study gives significant information concerning the increasing strength of concrete through MK and BF additives. By optimally choosing the additions, the microstructural and pore network refinements that followed increased the material's density and continuity leading to better strength. The results provide designers with new ways to improve the performance of concrete to apply them to the construction conditions that rule today. More trials on inclined and advanced fields can lead to the determination of the best mix proportions that would be within the cost-effective, durable, and high-strength range.

Conclusion

The data indicated that metakaolin (MK) has been a reliable additive when it comes to concrete mix solutions which increased the compressive strength and the tensile strength. Granite powder, together with the other cementitious minerals, is responsible for substantial strength gains in terms of compressive, flexural, and split tensile strengths compared with regular concrete. Basalt fibers are one of the various additives that are used to increase the compressive strength of MK geopolymer concrete up to a certain optimal level of content. Concerning the distance between the fibers (BF length of 3mm and 6mm), maximum strength was achieved at 2.5% addition and 2% addition, respectively. Increasing BF lengths in turn decreases the optimal percentage of strength increases, settling around 0.5% for 24mm diameter fiber. EDS, XRD, and SEM techniques aid the researcher in gaining a profound understanding of the amorphous microstructure and elemental composition behind the enhanced structural and mechanical performance of these concrete mixtures. Although the initial increase in strength is observed within the first 28 days, the further curing process, which unfortunately is going slow, contributes to the strength gain of concrete as well. Generally, the test results confirm the use of concrete mixes containing MK, granite powder, and basalt fibers which attain greater strengths, allowing for their application in high-performance concrete constructions.

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