EFFECT OF BENTONITE & POLYPROPYLENE FIBERS ON FRESH AND HARDENED PROPERTIES OF FLY ASH BASED GEOPOLYMER CONCRETE

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Abstract- Geopolymer concrete is developed by alkaline activation of waste materials and industrial byproducts rich in silica and alumina. Bentonite is one such pozzolanic clay material that is rich in SiO_2 content. It has been extensively used as a supplementary cementitious material in conventional Ordinary Portland cement (OPC) concrete resulting more cheaper, environment friendly and durable concrete. However, a little research is reported so far to assess the performance of bentonite modified geopolymer concrete. This study investigates the individual and combined incorporation of bentonite and polypropylene (PP) fibers on the workability and mechanical properties of fly ash based geopolymer concrete. Fly ash (FA) was used as precursor to develop geopolymer concrete (GPC) mixtures. FA was replaced with bentonite at 10% wt content and PP fibers were added at three different proportions i.e., 0.5%, 0.75% and 1%. Both raw (untreated) and heat-treated (up to 200 degrees Celsius) forms of bentonite were used. The intention was to ascertain whether heat-treated bentonite can perform better than untreated bentonite when combined with various PP fibers concentrations. The mechanical properties of bentonite modified, and PP fiber reinforced GPC mixtures were evaluated. The findings showed that addition of bentonite and PP fibers significantly increased the mechanical properties of GPC mixtures. However, the contribution of heat-treated bentonite in combination with PP fibers to mechanical properties of GPC mixtures is more significant.

Keywords- geopolymer concrete, bentonite, polypropylene fibers, mechanical properties

1 Introduction

Our planet's climate is rapidly changing as a result of increased pollution and excessive CO2 emissions into the atmosphere. All researchers are concentrating on environmentally friendly methods to protect the environment by encouraging sustainable living practices and the creation of eco-friendly technologies. In addition, the construction sector is on the lookout for eco-friendly, low-CO2 emitting green materials. Approximately 4 billion tons of ordinary Portland cement (OPC) are used annually as a binding material in construction activities worldwide [1-2]. OPC adds 1 tons of CO2 emission into the environment for every 1 ton it produces, which results in significant CO2 emissions into the atmosphere. Additionally, the production of OPC requires a significant amount of raw materials. To fulfil the rising demand for infrastructure, OPC concrete manufacturing is constantly growing. The building industry is under pressure to develop OPC-based material substitutes that have similar qualities to OPC and satisfy sustainability and green material requirements [2].

The use of geopolymer concrete (GPC), which totally replaces the use of OPC and is entirely made of industrial wastes/by-products that are activated with the use of an alkaline solution, is the most efficient option to promote sustainable construction practices [3–4]. Geopolymer concrete can be considered as one emerging category of green cement adhesives

With the potential to reduce the harmful environmental effects of traditional Portland cement (OPC), such as carbon footprint and energy usage, geopolymers have recently been offered as a more environmentally friendly substitute [5–6]. Fly ash (residue of coal power plants) has been proposed as suitable precursor material to produce GPC mixtures due to its chemical composition and adequate SiO2 and Al2O3 content [7-8]. It is reported that curing of GPC mixtures at elevated temperatures further improves the engineering properties. Due to the low reactivity of FA at ambient temperature, heat curing of FA-based GPC is typically carried out at a temperature of 80°C to 100°C for activation [9–10]. Furthermore, it has been established that geopolymers subjected to elevated temperature curing outperforms traditional OPC mixtures in most of the engineering properties [11–13].

There are several research available that show Class F FA has higher mechanical qualities after 24- to 48-hour heat curing. However, ambient curing of FA-based GPC does not yield the desired results because FA is not very reactive at low temperatures. Additionally, FA does not begin to geopolymerize at low temperatures. According to reports, using heat curing for GPC in worksite and field applications is not realistically viable.

The production of GPC has made considerable use of the waste products FA from coal power plants and slag from the steel and iron sectors, both of which have established high performance [14–18]. However, concerns continue to exist over the reliability of the delivery of high-quality FA, and some regions of the world have experienced FA shortages as a result of tighter regulation around coal-fired power plants. Comparatively speaking, the yearly demand for concrete for global building activities is rather high compared to the global supply of SG. In order to pursue a sustainable alternative to traditional concrete building, all available alternative raw material possibilities should be thoroughly investigated [19].
One of these ingredients is low calcium bentonite, a silica and alumina-rich naturally formed pozzolana that has been employed widely to enhance the different aspects of concrete [20]. It is an alumino-phyllosilicate clay, frequently produced when volcanic ash is chemically decomposed in the presence of water. It is mostly composed of the mineral montmorillonite. Numerous studies have shown that the engineering characteristics of conventional concrete are improved when bentonite is used in replace of cement [20–28]. The sodium or calcium varieties of bentonites are typically used in industrial settings.

The swelling capacity of calcium bentonite is significantly lower than that of other forms of bentonites [20]. Attock, Jhelum, Nowshera, and Karak are just a few of the areas in Pakistan where bentonite may be found. Low calcium bentonite has been reported to be used as a partial substitute for OPC by different researchers [26 -27]. It was reported that mixes with bentonite addition do better than traditional cement concrete at different ages by using bentonite as a 0 to 21% mass replacement of OPC [26]. It was also discovered that mixtures with bentonite addition had enhanced resistance to acid assault. Bentonite's pozzolanic behaviour in the presence of the OPC has been shown by Mirza et al [27].

Low calcium bentonite has positive influences on the engineering characteristics of traditional OPC concrete, according to a review of the recent literature [21, 26, 27, 29–32]. There isn't much research, nevertheless, available on the use of bentonite to enhance the performance of GPC mixtures. Concrete is a brittle substance by nature; hence, research scholars have utilized fiber as reinforcements for concrete to increase its ductility [33-34]. PPF are great polymer fibers because they are inexpensive, light, have low thermal conductivity, and have a high elastic modulus [35]. PPF may be added to concrete to help decrease drying shrinkage and boost tensile, compressive, and flexural strength [36-37]. Researchers looked at the mechanical properties of mortars that included PPF and found that ductility was significantly improved. Until the concrete reached the optimal concentration of 1% PPF, its strength remained unchanged [38].

However, no studies have yet looked at the combined effect of heat-treated bentonite and polypropylene fibers on the performance of concrete. Previous studies have examined the effects of utilizing bentonite and polypropylene fibers independently on the qualities of concrete. In this work, we sought to examine the fresh and hardened properties of concrete when both heat-treated and untreated bentonite, as well as polypropylene fibers, were added.

2 Experimental Procedures

2.1 Materials Descriptions

FA was used as the raw ingredients for the development of the geopolymer binder. FA was replaced with bentonite at 10 wt% to develop the bentonite blended GPC mixtures. The physical and chemical composition of OPC, FA and bentonite is shown in Table 1. Other than the coarse aggregates and sand as used in conventional concrete, the precursors and alkaline solution are the main components of GPC. The most frequently used alkaline solution in the production of GPC is a mixture of sodium hydroxide (SH) and sodium silicate (SS). The required molarity of SH was achieved by adding water and 98–99% pure SH pellets. SS solution with a SiO2 to Na2O ratio of 2.0 was bought from a local vendor. Bentonite clay (low calcium type) was obtained locally from Jehangir, Pakistan. Moreover, scanning electron microscopic (SEM) image of bentonite revealed spherical and thick-flake shaped particles as shown in Figure 1. Bentonite particles were found to be flaky and spherical in form. LawrancePur and Margalla, respectively, provided the fine and coarse aggregates. PPF with a 19 mm length was utilized. The properties PP fibers are presented in Table 2.

Table 1: Physical and Chemical properties of OPC, Bentonite and Fly ash

Oxides	**Ordinary Portland cement**	**Bentonite**		**Fly ash**
		Memon et al. work [26]	**The present study**	
SiO2	53.96	54.5	52.8	35.8
Al2O3	32.21	20.2	16.4	20.2
Fe2O3	2.98	8.6	5.8	11.4
MgO	1.51	4.5	1.4	1.80
CaO	4.72	7.3	4.6	14.3
Na2O	0.3	1.3	0.62	1.20
K2O	1.3	3.6	0.7	2.2
General properties				
Relative density (g/cm3)	2.10	2.81	2.64	1.8
Specific surface area (cm2/gm)	3207	4800	4900	3250
Loss on ignition (%)	1.30	5.4	9.6	0.57

Table 2: Properties of Polypropylene Fibers

Properties	**Values**
Tensile strength at breaking (MPa)	31 - 41
Flexural strength (MPa)	41 - 55
Elongation at break (%)	100 - 600
Tensile modulus (MPa)	1137 - 1551
Specific gravity	0.9 – 0.91

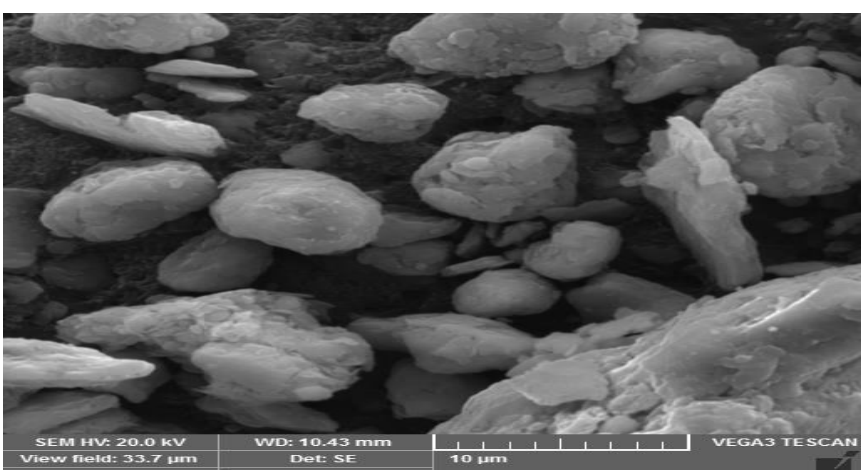

Figure 1 SEM of bentonite used in this study.

2.2 Mixture Proportions

A total of 9 mixture proportions as shown in Table 9 were prepared in this study with the aim of study the influence of untreated (raw bentonite) and treated bentonite, and PP fibers on the workability and mechanical properties of GPC mixtures. Fly ash was utilized as the precursor to develop the GPC mixes. The bentonite clay was used as substitution of FA at 10% by weight in both treated and untreated form to study the effect of bentonite clay. The optimum dosage of bentonite (10% by weight of binder) used in the present study was achieved from the literature review. GPC mixtures with 0% replacement level of bentonite were taken as the control mixes. PP fibers were added at three different proportions i.e., 0.5%, 0.75% and 1%.

Table 3: Mixture proportions used in this study.

Mix	**Mix proportions (%)**					**Mix quantities (kg/m3)**							
ID	**FA**	**Treated Bentonite**	**Un-treated Bentonite**	**Fibers**		**Sand**	**CA**	**FA**	**Bentonite**	**Alkaline solution**	**NaOH**	**Na2SiO3**	**SP**
M1	100	-	-	-		640	1201	400	-	160	53	107	6
M2	90	-	10%	-		643	1206	360	40	160	53	107	6
M3	90	-	10%	0.5		646	1212	360	40	160	53	107	6
M4	90	-	10%	0.75		652	1220	360	40	160	53	107	6
M5	90	-	10%	1		643	1206	360	40	160	53	107	6
M6	90	10%	-			646	1212	360	40	160	53	107	6
M7	90	10%	0.5			644	1208	360	40	160	53	107	6
M8	90	10%	0.75			647	1214	360	40	160	53	107	6
M9	90	10%	1			655	1225	360	40	140	53	107	6

2.3 Testing Procedures

The workability of the freshly mixed concrete mixtures was assessed by performing the slump cone test conforming ASTM C143 procedure [40]. The compressive strength of GPC mixtures was measured by testing cubes of 150mm at the age of days according to BS standard EN-12390 [41]. Concrete cylinder samples measuring 150 mm by 300 mm were tested for split tensile strength in line with ASTM C496 standards after 28 days of cure [42]. Flexural strength tests on beam specimens with dimensions of 100mm, 100mm, and 500mm were performed in accordance with ASTM C78 guidelines [43].

3 Results and Discussions

3.1 Workability

Fig. 1 displays the slump cone test results of all GPC mixes. The workability of both raw bentonite and heat-treated bentonite blended mixtures is negatively influenced by the addition of bentonite, as can be shown in Figure. As a result of the flaky shaped particles and higher specifics surface area of bentonite clay as compared to fly ash round particles, the slump values of bentonite blended GPC mixes has decreased. Because bentonite clay particles have a greater specific surface area, more water or solution is needed in the mixture to thoroughly wet the particle surfaces, which makes the mixture difficult to deal with. Although adding bentonite reduces the mix's workability, the mixture is still cohesive. The earlier investigations [34, 40] have found a similar declining tendency in slump values due to bentonite addition in concrete mixes. It is significant to note that the decrease in workability in is more apparent in raw bentonite blended mixes than treated blended mixes. The similar phenomenon is also reported in the previous studies [34, 40]. The decreasing trend of workability with bentonite inclusion was more pronounced for raw bentonite blended mixes. It can also be observed that workability of fiber reinforced mixes is lower as compared to their counterparts (without fiber). Since the concentration of fibers increased internal friction in the blends with constant water to binder, the addition of PPF significantly decreased the workability.

3.2 Compressive Strength

The compressive strength of control mix and bentonite blended mixes was evaluated at the age of 28 days. Three identical specimens measuring 150x150x150 mm were tested to determine the strength of each mix. The results of compressive strength tests are shown in Figure. It can be seen that a 10% bentonite replacement led to an improvement in compressive strength for all the specimens than control mix. However, the performance of GPC mix blended with heat treated bentonite was better than un-treated bentonite blended mix. The compressive strength was improved by an extent of 10% and 18% for raw bentonite blended mix and treated bentonite blended mix respectively when compared to the control mix without bentonite. This increase in strength may be attributed to the bentonite filler and pozzolana reaction properties, which has improved the strength and led to a more compacted and refined microstructure in the concrete [25].

Furthermore, the addition of PP fibers resulted in increasing the compressive strength for all the mixes by an amount of 5-18%. The maximum increase in strength was observed for the mix with 1% addition of fibers for both untreated and treated bentonite blended mix when compared to the mix without fibers. The compressive strength of M3, M4 and M5 with 0.5%, 0.75% and 1% fibres were increased by an amount of 8%, 13% and 14% respectively when compared to control mix M2 (without fibers) for untreated bentonite blended mixes. Similarly, the compressive strength of M7, M8 and M9 mixes with 0.5%, 0.75% and 1% fibres were increased by an amount of 5%, 13% and 15% respectively when compared to control mix M6 (without fibers) for treated bentonite blended mixes. The influence of fibers was more significant for mixes with 0.5% and 0.75% fraction of fibers for both untreated and treated bentonite blended mixes.

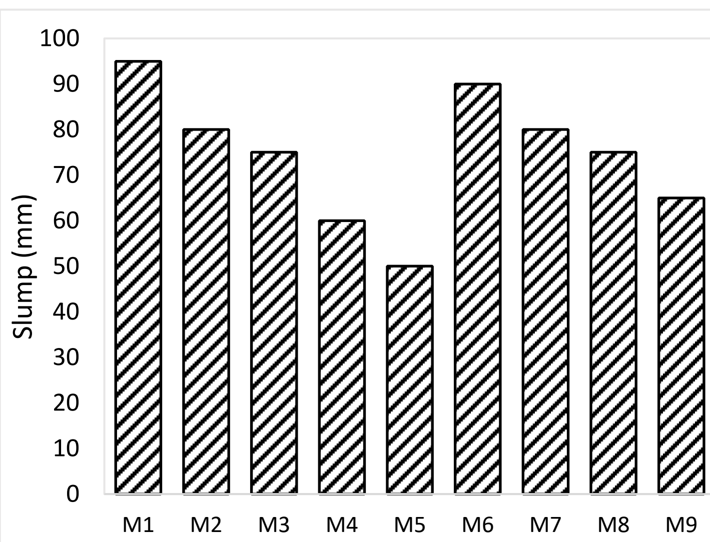

Figure 2 slump cone test results of all GPC mixes

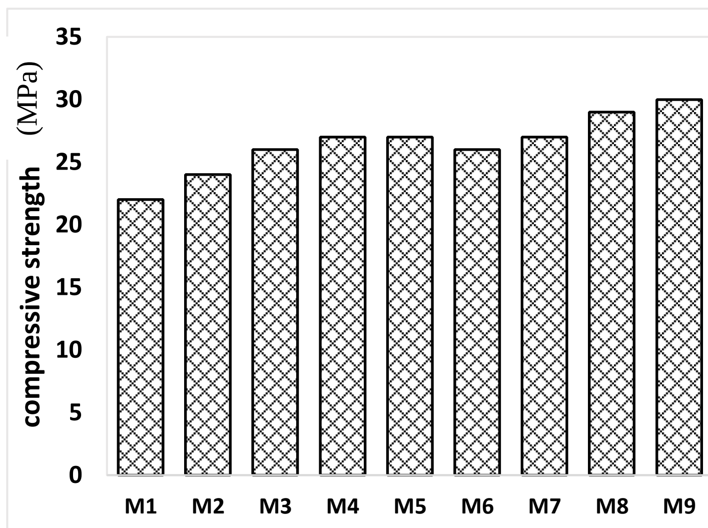

Figure 3 compressive strength of all GPC mixes

3.3 Tensile Strength

The splitting tensile strength tests on 150x300mm cylinders were carried out after 28 days of casting. Figure 8 displays the tensile strength results for the all the mixes. An increase in the tensile strength of all GPC mixes was observed with 10% bentonite (treated and raw) replacement level for all the specimens when compared to the control mix. However, the influence of bentonite on the tensile strength of GPC mixes is evident, though not huge. The tensile strength of M2 and M6 mixes containing 10% raw bentonite and treated bentonite respectively was 4% and 10% higher than the control mix (without bentonite). Furthermore, the inclusion of fibers caused a considerable increase in the tensile strength of all GPC mixes. The tensile strength of M3, M4 and M5 mixes with 0.5%, 0.75% and 1% fibres were increased by an amount of 9%, 20% and 32% respectively when compared to control mix M2 (without fibers) for untreated bentonite blended mixes.

Similarly, the tensile strength of M7, M8 and M9 mixes with 0.5%, 0.75% and 1% fibres were increased by an amount of 7%, 19% and 33% respectively when compared to control mix M6 (without fibers) for treated bentonite blended mixes.

3.4 Flexural Strength

Figure 7 shows the flexural strength value of all GPC mixes. The comparison between flexural strength values of control mix and bentonite blended mixes showed that bentonite has a positive effect on the flexural strength of all GPC mixes. It is also evident from Figure that heat treated bentonite blended specimens performed better than raw bentonite blended specimens. Additionally, the inclusion of PP fibers increased the flexural for all of the mixtures by a range of 6 to 29%. When comparing the blend of untreated and treated bentonite to the blend without fibers, the mix with a 1% addition of fibers showed the greatest gain in strength. When compared to the control mix M2 (without fibers), the compressive strength of M3, M4, and M5 (untreated bentonite blended mixes) with 0.5%, 0.75%, and 1% fibers was raised by 8%, 17%, and 27%, respectively. Similarly, as compared to control mix M6 (without fibers), the tensile strength of M7, M8, and M9 mixes (treated bentonite blended mixes) containing 0.5%, 0.75%, and 1% fibers increases by amounts of 6%, 18%, and 29%, respectively. The rough surface of the fibers, which results in a strong connection and bond in the concrete, may be to attribute for this increase in flexural strength [32, 35]. Due to their bridging influence, the fibers start to stop the crack from spreading as soon as concrete starts to cracks. This reduces the concrete's brittleness and improves its post-cracking behaviour [32, 35].

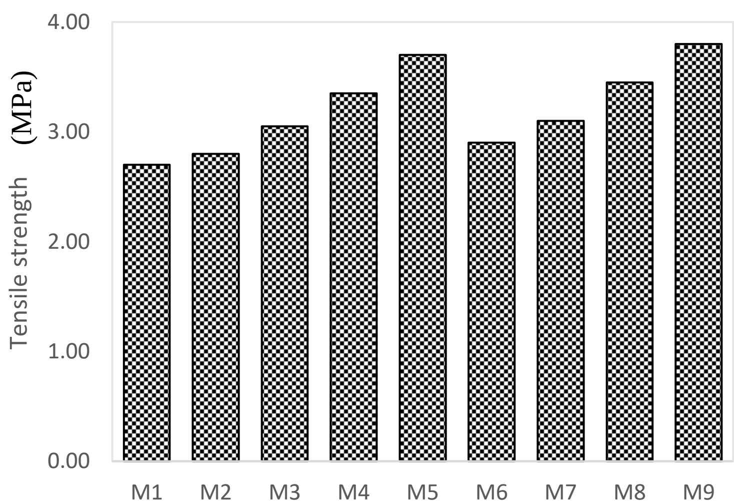

Figure 4 Tensile strength of all GPC mixes

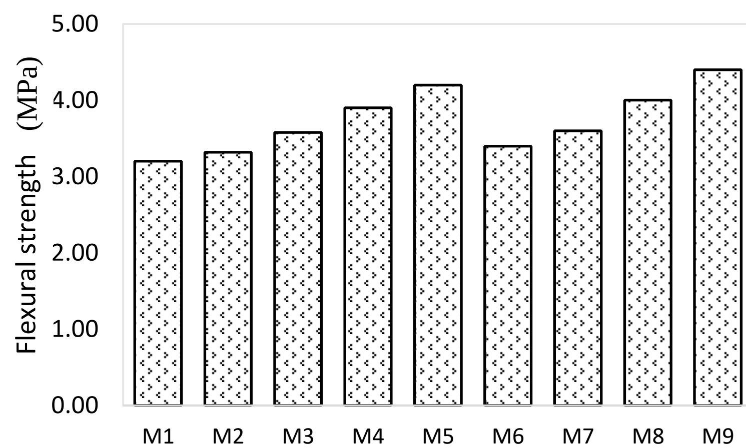

Figure 5 Flexural strength of all GPC mixes

4 Conclusions

This paper has presented the results of an experimental study conducted to evaluate the influence of bentonite and PP fibers on fresh and hardened properties. Following key conclusions have been drawn from this study:

1. The workability of both raw bentonite and heat-treated bentonite blended mixtures is negatively influenced by the addition of bentonite.
2. The decreasing trend of workability with bentonite inclusion was more pronounced for raw bentonite blended mixes.
3. Incorporation of Polypropylene fibres results in in further decrease of workability.
4. A 10% bentonite replacement resulted in an improvement in compressive strength for all the specimens when compared to the control mix (without bentonite).
5. However, the performance of GPC mix blended with heat treated bentonite was superior to un-treated bentonite blended mix.
6. Furthermore, the addition of PP fibers resulted in increasing the compressive strength for all the mixes by an

amount of 5-18% as compared to mix without fiber.

7. The maximum increase in strength was observed for the mix with 1% addition of fibers for both untreated and treated bentonite blended mix when compared to the mix without fibers.
8. The influence of fibres on mechanical properties was more significant for mixes with 0.5% and 0.75% fraction of fibers for both untreated and treated bentonite blended mixes.
9. For each mix, the outcomes of the tensile and flexural strengths show trends that are identical to those of the compressive results. The addition of 10% bentonite improves the flexural strength and tensile strength of all GPC mixes.
10. The incorporation of PP fibres significantly increases the flexural strength and tensile strength. The inclusion of PP fibers increased the flexural and tensile strength for all the mixtures by a range of 6 to 29%. When comparing the blend of untreated and treated bentonite to the mixes without fibers, the mix with a 1% addition of fibers showed the greatest gain in strength.

5 Future Recommendations

The use of GPC in field applications is very limited. A very few practical applications of GPC in the field are reported. There is a need to develop broader and more reliable statistics on the practicality of utilizing GPC in structural applications. Further It is recommended to conduct an extensive experimental study to evaluate the long-term durability performance of PP fibres incorporated bentonite blended GPC mixes in aggressive environments, such as acidic and sulphatic environments. The behavior of GPC in extreme conditions (Fire and Corrosion environment) needs to be ascertained.

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