Comparative study on the drying shrinkage and mechanical properties of geopolymer foam concrete incorporating different dosages of fiber, sand and foam agents

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ABSTRACT

A recent innovation, geopolymer foam concrete (GFC), combines the advantages of geopolymer technology and foam concrete , and provides the opportunity to reduce the environmental footprint of construction materials in terms of raw materials, embodied CO_2 and operational energy in service. Foam concrete is generally defined as a type of lightweight concrete that consists of a cementitious binder with a high degree of void space, with or without the addition of fine aggregate. One of the main drawbacks of these materials is high drying shrinkage. This paper presents an extensive experimental study to reduce the drying shrinkage in foam geopolymer concrete. Moreover, mechanical properties of foam geopolymer concrete were characterized by compressive and flexural strengths. To reduce the drying shrinkage in foam geopolymer concretes different strategies used, including foam content (0.2%, 0.5%, 0.8%), sand/binder content (0.30, 0.35, 0.40, 0.45, 0.50, 0.75, 1.00, 1.25, 1.50), and using polypropylene (PP) fibers with different lengths (6 mm and 20 mm) and fiber volume fractions (0.2%, 0.6%, 1%, and 1.4%). The obtained results showed that increasing sand content up to 50% reduced the drying shrinkage, while the drying shrinkage increased above this sand content. Additionally, increasing foam content intensified the increase of drying shrinkage. This increase was proportional to foam content. In general, regardless of fiber type and content, reinforcement of foam geopolymer concrete reduced the drying shrinkage and enhanced mechanical properties.

Keywords: Drying shrinkage, Compressive strength, Flexural strength, Porosity, Foam geopolymer concrete

INTRODUCTION

A recent innovation, geopolymer foam concrete (GFC), combines the advantages of geopolymer technology and foam concrete , and provides the opportunity to reduce the environmental footprint of construction materials in terms of raw materials, embodied CO_2 and operational energy in service. Shrinkage is one of the main drawbacks of this type of new materials. Introducing high amount of porosity due to adding foam agent in the geopolymer concretes intensify the shrinkage problem, when compared to concrete without foam. Some micro-cracks formed due to high shrinkage, which these cracks can significantly degrade mechanical and durability properties of foam geopolymer concrete. These cracks are caused by high capillarity pressure between wet and dry areas of microspore network. Concerning the importance of the formed cracks due to dry shrinkage, most implemented studies on the reduction of shrinkage have been assigned to control the micro-crack widths.

To the best of the author's knowledge, an extensive experimental study has not been reported yet on the effective parameters on the drying shrinkage in the foam geopolymer concretes.

Although, some studies have been reported the effects of sand and fibers on the drying shrinkage of geopolymers. Yet, no study has included an extensive experimental study on reduction of drying shrinkage and characterization of mechanical properties.

Thus, this study established to assess the effects of different parameters on the drying shrinkage of foam geopolymer concrete, and then the effects of these parameters on mechanical properties were also addressed by compressive and flexural strengths. Moreover, effects of these parameters on the porosity of GFCs were obtained. The investigated parameters were included by variations of foam agent content (0.2%, 0.5%, 0.8%), sand/binder content (0.30, 0.35, 0.40, 0.45, 0.50, 0.75, 1.00, 1.25, 1.50), and using PP fibers with different lengths (6 mm and 20 mm) and fiber volume fractions (0.2%, 0.6%, 1%, and 1.4%).

EXPERIMENTAL PROGRAM

Materials and mix designs. The GFCs were prepared by mixing fly ash, slag, sand, alkali activator and mechanicaly prepared foam. According to ASTM C618 recommendation, the used fly ash could be categorized as class F. The mixing proportions of each material in the geopolymer foam concrete are listed in Table 1.

Table 1. Mix proportions of used materials for GFCs (In weight %).

Fly ash/Binder	*Slag/Binder*	*Alkali Activator/Powder*	*Sand/Binder*	*Foam/Binder (%)*	*Fiber (Vol %)*
0.85	0.15	0.3	0.30-1.5	0-0.8	0-1.4

Powder: fly ash + slag + sand
Binder: slag + fly ash

The GFCs were cast into cubic molds (50 × 50 × 50 mm), and prismatic beams (40 × 40 × 160 mm) to assess compressive and flexural strengths, respectively. Moreover, the prismatic beams with copper nails installed at both end sides were used to measure the drying shrinkage.
After casting, the specimens were kept at temperature of 28°C and 80% relative humidity for 24 hours. Then, all specimens were demolded and cured at the ambient conditions. The relative humidity and temperature were recorded during the measurement of the drying shrinkage of specimens.

RESULTS AMD DISCUSSIONS

Effect of sand/binder ratio on drying shrinkage

The drying shrinkage of GFCs was measured up to 90 days. Stabilization of the length variations was taken into account to stop shrinkage test. The obtained results are depicted in Figure 1, which the curves represent the average of three replicated prismatic beams.
Different efficiencies were detected in controlling drying shrinkage of GFCs. With respect to the results indicated in Figure 1a, increasing the sand/binder content from 0.30 to 0.35 increased about 20% the strain recorded for drying shrinkage, while increasing the sand/binder content from 0.35 up to 0.50 reduced about 60% the drying shrinkage strain. According to the results, using higher amount of sand not only reduced the drying shrinkage, but also increased it. The minimum drying shrinkage was obtained about 60% in the mix composition with 0.50 sand/binder, when compared to the reference mix composition with 0.40 sand/binder. The increase of drying shrinkage results from considering constant value for the alkali activator to binder ratio. Accordingly, increasing sand content increases the alkali activator content, which caused to increase the drying shrinkage in GFCs with sand/binder content higher that 0.50.
By comparing the attained results in Figure 1b, it is revealed that increasing the foam content up to 0.8% consistently increased the drying shrinkage with respect to mix composition without foam. The drying shrinkage in geopolymer concrete (0% foam) was about 4 times less than the drying shrinkage in compare to mix composition containing 0.8% foam agent. The findings in [1-2] indicated that the drying shrinkage in the foam concrete varied in range of 0.1%-0.36% after 1 year, which is 5–10 times higher than the typical shrinkage of dense mortar and concrete specimens.
Based on Figure 1c, reinforcing GFCs with PP fibers of 6 mm length reduced the drying shrinkage up to 60% in the mix composition reinforced with 1.4% of fiber content. The microscopic images showed that shape of PP fibers at both ends provides good mechanical anchorage and subsequently increases the interaction between fiber and geopolymer matrix. This mechanism results in reducing the dry shrinkage in mix composition reinforced with PP fiber. *Zhang* et al. in 2009 found that addition of 0.75% of PP fiber with length of 3 mm reduced about 50% shrinkage in geoplymer concrete [3]. As indicated in Figure 1d, using beyond 0.6% PP fiber with length of 20 mm not only reduced the dry shrinkage, but also increased it up to 70% in compare to the mix without fiber. This reduction maybe results from unfavorable effects of long

fiber length such as balling. *Ranjbar* et al. showed that using beyond 3% PP fiber with 12 mm length resulted in poor workability and adverse effect of PP fiber in controlling drying shrinkage [4].

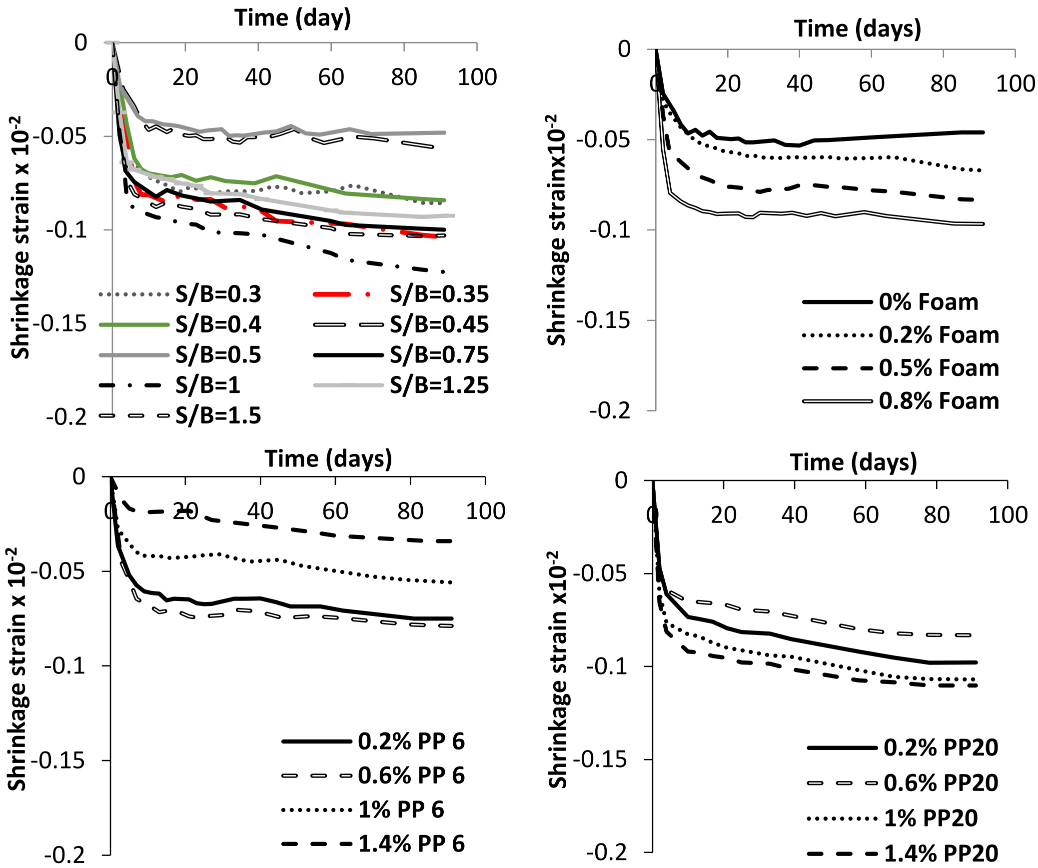

Figure 1. The drying shrinkage for GFCs with: a) different sand/binder contents; b) different foam contents; c) different PP fiber with 6 mm length; d) different PP fiber with 20 mm length.

Compressive strength

Figure 2a depicts the compressive strength for GFCs with different sand/binder contents. With respect to the results obtained, adding sand reduced the compressive strength in all specimens, which it can be caused by an increase of alkali activator content. The minimum compressive strength was detected around 2.00 MPa for the mix composition containing 75% sand.
Concerning the results indicated in Figure 2b, increasing foam dosage resulted in increasing the porosity of GFCs, which causes reduction in compressive strength. Thus, the lowest compressive strength was recorded around 3.50 MPa in mix composition containing 0.8% of foam. Adding fiber to the plain geopolymer concrete can increase porosity and consequently, reduces the compressive strength. On the contrary, reinforcement of the plain geopolymer concrete can effectively limit crack

propagation. Thus, adding fiber to the plain geopolymer concrete has two opposite effects on the compressive strength, which can either increase or decrease compressive strength.

Based on the results shown in Figure 2c, a descending trend was detected for the reinforced mix composition with 0.2% due to adding PP fiber with 6 mm length.

Increasing fiber content from 0.2% to 1% showed an increasing trend, while exceeding fiber dosage than 1% reduced the compressive strength around 10% in compare to the reference mix without fiber. Due to addition of PP fiber with 6 mm length, the maximum increase and decrease of compressive strength were obtained about 40% and 35% in the reinforced GFCs with 1% and 0.2% fiber dosages, respectively.

An increasing trend for the compressive strength of the GFCs reinforced with PP fiber of 20 mm length. The maximum increase was obtained more than 2 times in the mix composition reinforced with 1.4% of PP fiber. Increasing the compressive strength due to addition of PP fibers was intensified by increasing the fiber content from 1% to 1.4%. This finding may be justified by increasing number of fiber bridging in arresting the crack opening.

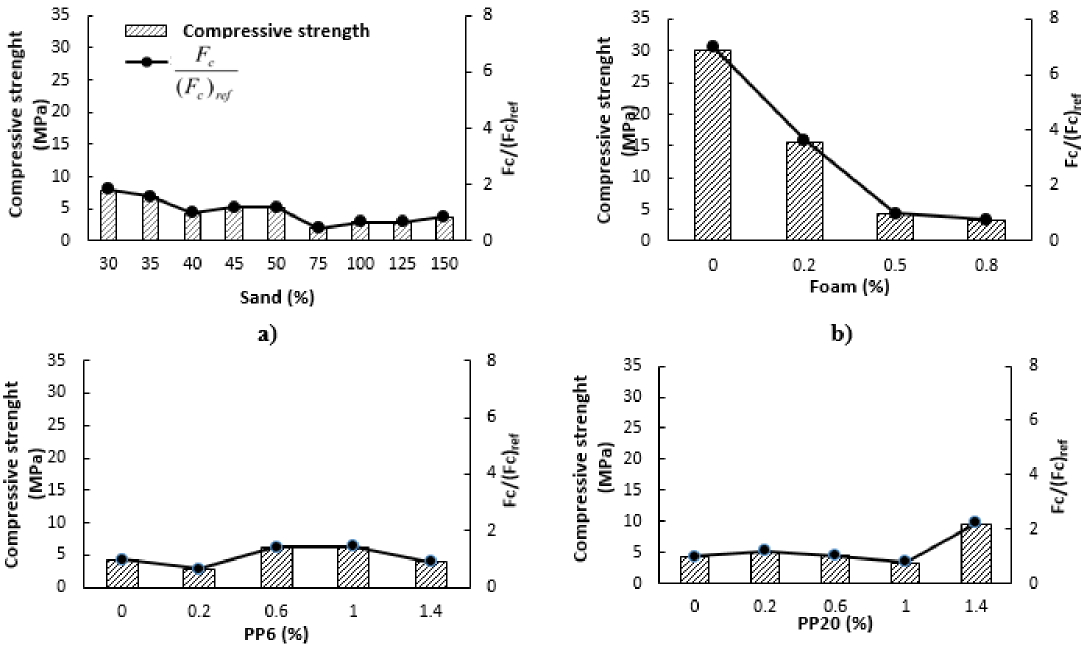

Figure 2. Compressive strength of GFCs with: a) different sand content; b) different foam contents; c) PP fiber with 6 mm length; d) PP fiber with length 20 mm.

Flexural strength

The flexural strength of geopolymer foam concrete obtained under TPB test and the results indicated in Figure 3. The flexural strength concerns to GFCs incorporating different sand contents depicted Figure 3a. The results showed that there is no general trend in the flexural strengths for different sand/binder contents. The maximum flexural strength was recorded about 2.0 MPa in the mix composition containing 35% of sand. Moreover, the lowest flexural strength was measured about 1.0 MPa for the mix composition with sand content of 125%. In compare to the referenced mix composition (40% sand), the maximum increase and the minimum decrease were around 10% and 45% in GFCs containing 35% and 150% of sand, respectively.
As shown in Figure 3b, a decreasing trend was registered for the flexural strengths of GFCs containing higher foam agent content. By increasing the foam content, the porosity of geopolymer concrete increases and subsequently the flexural strength reduces. According to the obtained results, the maximum decrease was recorded more than 3 times in a mix composition with foam content of 0.8%, when compared to geopolymer concrete without foam.
As depicted in Figure 3c, no specific trend in the flexural strength of the reinforced GFCs was detected due to addition of PP fiber with 6 mm length.
Furthermore, Figure 3d exhibited the effects of reinforcing the GFCs with PP fiber of 20 mm length on the flexural strength. A decreasing trend in the flexural strength was registered for the reinforced specimens with fiber content up to 1%. Beyond this content (V_f: 1%), the flexural strength was increased. The maximum flexural strength was registered around 2.0 MPa for the specimens reinforced with 1.4% of PP fiber, when compared to reference mix composition.
The efficiency of fibers in improving mechanical properties of the reinforced GFCs are significantly governed by the fiber bridging action.

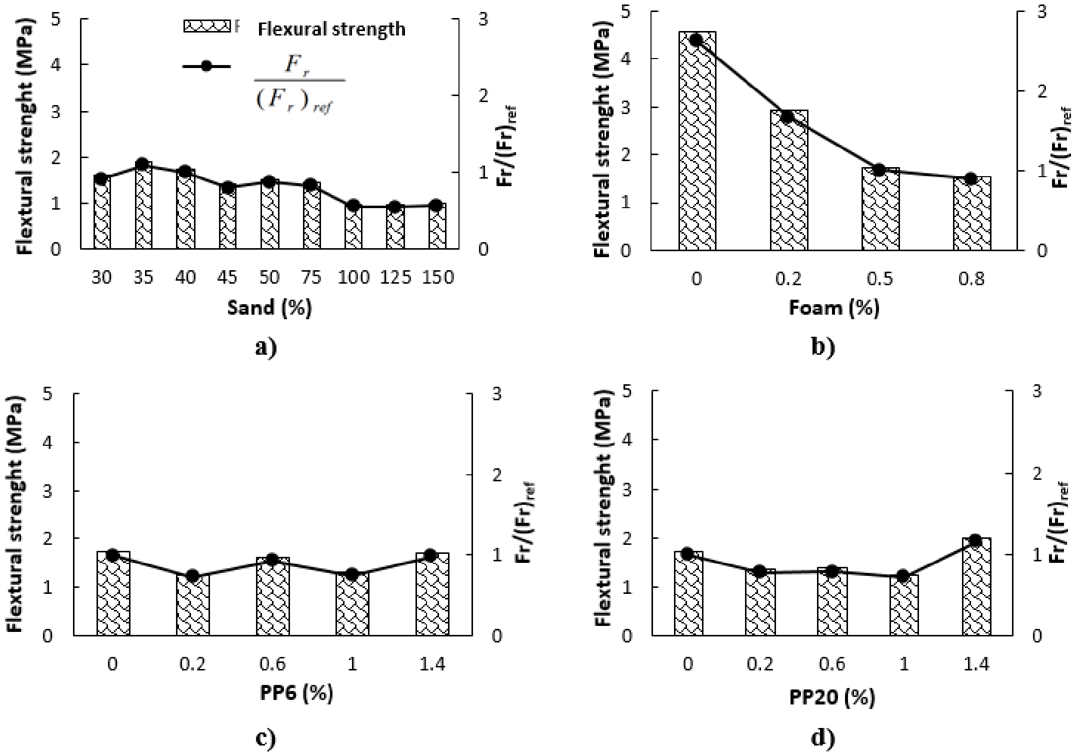

Figure 3. Flexural strength of GFCs with: a) different dosage of sand; b) different foam contents; c) PP fiber with length 6 mm; d) PP fiber with length 20 mm.

CONCLUSION

This paper presents the effects of some parameters on the drying shrinkage and mechanical properties of geopolymer foam concretes. These parameters include sand content, foam agent dosage and addition of PP fibres with different lengths and dosages. Two hundred and seven specimens were cast and assessed experimentally to obtain compressive strength, flexural strength and drying shrinkage. Then, the obtained experimental results were comprehensively interpreted and the following results were highlighted:

The maximum reduction in the drying shrinkage was registered about 35% in mix composition containing 50% sand content with respect to the reference mixture.

Increasing foam content up to 0.8% increased the drying shrinkage up to 50%.

Increasing sand and foam contents degraded mechanical properties.

Adding PP fiber reduced the drying shrinkage up to 45%, when compared to the reference mix composition without fiber. Moreover, addition of PP fiber with 6 mm length improved mechanical properties, so that the maximum compressive strength and flexural strength were recorded for specimen reinforced with 1.4% fiber.

Reinforcing specimens with PP fiber with 20 mm did not reduce the drying shrinkage with respect to the reference mix composition. Additionally, increasing fiber dosage up to 1.4% had no significant impact on improving mechanical properties.

The maximum reduction in the drying shrinkage of the reinforced specimens was obtained about 30% in the reinforced geopolymer foam concrete containing 1.4% PP fiber with 6 mm length.

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