

Carbon fiber waste incorporation in blast furnace slag geopolymer-composites

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Abstract

This work evaluates the properties of geopolymer-composites based on blast furnace slag with additions of a carbon fiber waste coming from the aircraft industry. Two parameters were considered: slag/waste ratio (100/0, 80/20 and 60/40) and nature of activating solution (8M NaOH and sodium silicate). Open porosity and compressive strength were analysed.

Geopolymers were also subjected to a sulphuric attack and thermal resistance test (compressive strength after 105, 300, 500 and 700°C was assessed). Porosities increased and compressive strengths decreased as the slag was replaced by the carbon fiber waste. A positive effect of the carbon fiber waste on the acid attack was observed mainly due to the created porosity which could generate space to calcium-sulphate products precipitation. CFW incorporation improved the thermal resistance since higher porosity could provide channel to increase heat dissipation.

Keywords: Blast furnace slag, geopolymer, carbon fiber waste, acid attack, compressive strength, thermal resistance

1. Introduction

Geopolymers are ecofriendly inorganic polymers with comparable performance to Portland cement (1). They are considered amorphous or semi-crystalline binders, which are the product of the alkaline activation of aluminosilicate materials at room or slightly more elevated temperature (2). Geopolymers synthesis may also be a successful alternative for reusing industrial by products or wastes (3). Research on geopolymer-composites using different

organic substances (carbon fiber, epoxy resins) were reported, where the effect of these substances on microstructure, mechanical properties, durability and thermal development have been evaluated (1, 4, 5). As aircraft industry generates high amounts of waste composite materials, this work aims to investigate the effects of this waste, based on carbon fibers and epoxy resin, on physical and mechanical properties, sulphuric attack and thermal resistance of geopolymer-composites.

2. Materials and methods

Blast furnace slag (BFS) was used as aluminosilicate source. SiO₂, CaO and Al₂O₃ percentages in BFS were 15.9, 38.2 and 5.97 wt%, respectively. Carbon fiber waste (CFW) from a composite material used by the aircraft industry was also used. Loss of ignition was 83 wt % and SiO₂, CaO and Al₂O₃ percentages were 5.6, 5.07 and 1.44 wt%, respectively. This waste contains sulfur (3.03 wt% in form of SO₃). Two activating solutions were used: 8M NaOH solution and sodium silicate solution with NaOH pellets in order to increase the Na₂O/SiO₂ molar ratio up to 0.98. BFS and activating solution were mixed in a ratio of 0.33 g BFS/mL activating solution. Then, CFW was added to the mixture. Water to obtain a workable paste was added. Water demand increased with CFW content (0.1 g water/g CFW). Cylindrical plastic moulds (30 mm-diameter and 41 mm-height) were filled and vibrated for 5 minutes to release entrapped gas bubbles. Samples were cured at room temperature (RT). BFS/CFW relative proportions by weight were 100/0 (geopolymer-paste (GP)), 80/20 and 60/40 (geopolymer-composites (GC)). Some samples were activated with sodium silicate (NaS) and other with 8M NaOH (NaH). After 1, 7, and 28 days, samples were subjected to compressive strength test (EN 196-1) (6). After 28 curing days geopolymer were submitted to other tests: open porosity (EN 1936) (7); acid attack resistance (submerging specimens in sulphuric acid at pH 1 and in water for 14 days); thermal resistance (heating specimens at different temperatures (100, 300, 500 and 700°C) for 3 hours).

3. Results and discussion

3.1. Open porosity

Table 1 shows open porosity (OP) results. Porosity increased as CFW proportion increased. This effect could be due to two reasons. The first reason could be related to the generated pores by the increasing water additions to keep a reasonable workability. Water was eliminated during curing and pores were generated. The second reason could be associated to voids generated between the geopolymeric gel and the CFW particles which behave as an inert material. Porosities also depend on activating solution. Silicate-geopolymers showed lower porosities than hydroxide-geopolymers. This behavior has also been noticed in other research work (2), hydroxide-geopolymers showed a poor developed geopolymeric gel with high porosity and silicate-geopolymers showed a high developed gel with a low porous microstructure.

Table 1. Open porosity and compressive strength along the time

3.1. Compressive strength

Table 1 shows the evolution of compressive strength (CS) of geopolymer along the time. CS worsened as the CFW content in the mixtures increased from 0 to 40% due to the porosity increment. Higher porosities always cause a CS decrease in any material because of the reduction of the volume/resistant mass ratio influence (3). This behavior was also observed in carbon fiber reinforced-concretes (8). The influence of activating solution on CS is deeply related to solids porosity. Hydroxide-geopolymers are more porous and less resistant than silicate-geopolymers, as it is well documented (2).

3.2. Acid attack resistance

Figure 1 presents the CS at 28 days of curing and the CS after the acid and water immersion.

Figure 1. Compressive strength after immersion in acid or water

CS was reduced after the immersion in acid or water, but samples were more mechanically resistant after acid than water attack. During water immersion, the absorbed water could weaken forces between gel-particles producing a cracks increase and a structure weakening (9). Sulphuric acid attack produces a depolymerization and dealumination of the geopolymeric matrix (10), which could explain the CS reduction regarding the CS at 28 days. In addition, sulfate ions penetrate into the pore structure and react with calcium ions generating calcium-sulphate products (1), which precipitate into the pores. Depending on porosities, pore size distributions and amount of formed products, these products can fill the pore structure (1), producing a more compacted material (more resisted) or an excessive expansion, leading stress (cracks and more pores) (less resisted). There was a visual evidence of calcium-sulphate precipitation in the geopolymer surface when they are immersed in acid (Figure 1-GP100/0 NaH Acid and GP100/0 NaH Water), which could explain the best results in acid by the production of a more compacted structure. To replace BFS by CFW produced less CS reduction after the attack. GP100/0 had more calcium to form calcium-sulphate products, but as this composition showed low porosity, the space where precipitation could occur was low and expansion stress could happen, causing a higher CS reduction. GC60/40, with a less BFS proportion, generated less calcium-sulphate (see Figure 1-GC60/40 NaH Acid) in a more porous structure, thus the precipitated products could fill the pores, causing a material compaction and a high resistant structure. As silicate-geopolymers were less porous than hydroxide-geopolymers, acid or water infiltrations in the silicate-geopolymer structure were lower, reducing the geopolymer deterioration (11). Silicate-geopolymers have a more developed gel (2) with a more cross-linked structure (10), which better resisted the attack.

3.3. Thermal resistance

Figure 2 represents the evolution of the relative residual CS ($CS(T)/CS(RT)$) (where $CS(RT) = CS(28 \text{ days})$) of the NaS-geopolymer submitted to different temperatures.

Figure 2. Relative residual compressive strength at different temperatures

GP100/0 showed a drop of CS after exposure to high temperatures (3). However, GC80/20 practically maintained a constant CS in the range 20-300°C (GC60/40 even showed a slight CS increase in this temperature range) and after that a big drop between 300-500°C. CS loss at elevated temperature is related to the mass loss (3) produced due to water evaporation (11). As geopolymers are heated at high temperatures, water evaporates increasing the system pressure and producing thermal stress in the structure (12). Porous matrices are more capable to support the thermal stress than denser matrices since they could provide channels to vapor release. Figure 3 displays the evolution of the relative residual mass ($m(T)/m(RT)$) at different temperatures of the NaS-geopolymers and CFW.

Figure 3. Relative residual mass at different temperatures

GP100/0 showed a permanent mass loss from 20 to 500°C due to water loss. Free water (11) was evaporated in the range 20-100°C, chemically bonded water between 100-300°C and finally the hydroxyl groups OH (11) were eliminated after dehydration and dehydroxilation above 300°C (13). However, CFW was thermally stable up to about 300 °C. After that, a high weight loss (60%) was produced between 300 and 500°C and finally a mass stabilization was observed. As CFW comes from a carbon fiber-epoxy resin composite, mass loss between 300-500°C was mainly caused by some organic compounds decomposition (5). GC80/20 and GC60/40 showed an intermediate behaviour between the GC100/0 and CFW curves, taking into account their FA and CFW proportions. Mass loss curves could therefore explain the CS evolution. CFW incorporation improved the performance of geopolymer-composites at elevated temperature. Firstly, carbon fibers present a high heat conductivity helping for heat dissipation (14) and reducing the thermal stress. Secondly, CFW geopolymer-composites were more porous than the geopolymer-paste. This higher porosity could provide channels to improve the vapor removal from the structure (11). NaH-geopolymers were subjected to these tests showing similar curves.

4. Conclusions

The organic waste addition in a geopolymer matrix increased the porosity, which in turn affected compressive strength, sulphuric acid attack and thermal resistance. The worsening of compressive strength seemed to point an incompatibility between the geopolymeric matrix and the organic waste due to a poor chemical interaction. The best acid attack resistances were observed as BFS was replaced by CFW since the high porosity could give the space required to calcium-sulphates precipitation. Thermal resistance was improved as well, probably also as a result of high porosity which could provide channels to enhance vapor and heat dissipation.

4. References

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