

# Microstructure and mechanical properties of carbon microfiber reinforced geopolymers at elevated temperatures

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## HIGHLIGHTS

- Mechanical surface activation of carbon microfibers (CMF) by ball milling.
- Studied microstructure and mechanical properties of CMF/geopolymer composites.
- Observed less pore area for high CMF loading at elevated temperature exposure.
- Minimum compression strength loss for 15 wt% CMF/geopolymer composites.

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## ABSTRACT

The present work deals with the effect of carbon microfiber addition on the development of microstructure and mechanical properties of geopolymers at elevated temperature. The carbon microfibers were prepared from recycled inexpensive carbon fibrous wastes by ball milling, and then subsequently incorporated under 5, 10 and 15 wt% loading into metakaoline based geopolymers. The addition of carbon microfibers was found to produce compact structure of geopolymers due to their pore filling characteristics and formation of additional calcium silicate or calcium aluminosilicate and sodium aluminosilicate hydrates. The geopolymer composite of 15 wt% carbon micro fiber was found to maintain the residual compressive strengths of 33.55 and 23.96 MPa at 400 °C and 800 °C, respectively and thus recording a minimum strength loss of 19 and 42%, respectively. This behavior was attributed to decreased thermal stresses and restricted swelling of unreacted geopolymer phases after addition of carbon microfibers.

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## 1. Introduction

Due to reduced energy consumption and less CO<sub>2</sub> emission during the manufacture, geopolymers received considerable attention over Portland cement in recent years [1–3]. The geopolymers are attractive as green concrete in construction industry because of cost efficiency, chemical stability, corrosion resistance, rapid strength gain rate, low density, low permeability, low shrinkage and freeze-thaw resistance [4,5]. The geopolymers are amorphous cementitious binders having cross-link chain of silica, oxygen and alumina (Si-O-Al) [6,7]. They are synthesized by reacting aluminosilicate source materials (i.e. metakaoline, fly ash, blast furnace slag, etc) with highly alkaline activators. Further, the chemical composition, mineralogical composition, morphology, fineness and glassy phase content present in aluminosilicate sources decide

the microstructures and mechanical properties of geopolymers [8]. The metakaoline based geopolymer offers better strength, permeability, etc. However, it has limitations of poor rheological properties due to plate shaped morphology, complex processing, higher water demand, accelerated hydration reactions and more heat evolved at early ages [9]. On the contrary, fly ash-based geopolymer is more durable and stronger than that of metakaolin-based geopolymer. But, it has also disadvantages such as extended setting times, slow strength development, low early-age strength, construction delay, difficulties to use in cold weather concreting, etc [10]. The advantages of slag-based geopolymer are high early strength and greater acid resistance than those of metakaolin and fly ash-based systems. However, the slag being byproduct of the ore refinement process, it is not easily available. Moreover, the harder nature of slag requires frequent maintenance of equipments and costly processing than metakaolin and fly ash [11,12].

Despite many benefits, geopolymers still have certain limitations over ordinary Portland cement. Due to their cross-linked

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structure, geopolymers tend to be more brittle, susceptible to crack formation and undergo catastrophic failure as compared to ordinary Portland cement [13,14]. Previous studies have reported their fracture energy about 40% of that of ordinary Portland cement [15]. Therefore, for further improvements of performance and durability, the improvement in fracture properties of geopolymers is extremely necessary. Although incorporation of different fibers (steel, polypropylene, polyvinyl chloride, and basalt fibers) have been found to be effective in controlling crack propagation and enhancing the fracture energy of geopolymers, the mechanical properties of geopolymers were found non-consistent and inadequate when exposed to elevated temperatures [16–18]. During fire accidents, many of these fibers fail in providing effective reinforcements due to lack of structural strength and durability at higher temperature [19]. Therefore, further research is required to identify alternative fibers which possess good thermal resistance and

maintain higher residual mechanical properties when exposed to elevated temperature.

More recently, carbon materials are considered as a potential candidate for reinforcement of geopolymers when exposed to higher temperature due to their extraordinary mechanical, thermal and electrical properties. To this aim, carbon nanotubes, carbon nanofibers, graphene, etc were investigated for improving the ductility and strength of geopolymer composites [20,21]. In fact, lower fiber-to-fiber spacing, relatively higher specific surface area and the extended (frictional) pullout are important factors to effectively control the micro-crack propagation [22]. For instance, carbon nanotubes possess exceptional physical and chemical properties at elevated temperature; however, successful transfer of these properties is challenging due to their difficulty in uniform dispersion within the matrix [22]. As a result, many studies have devoted their particular attention to the scale and distribution of

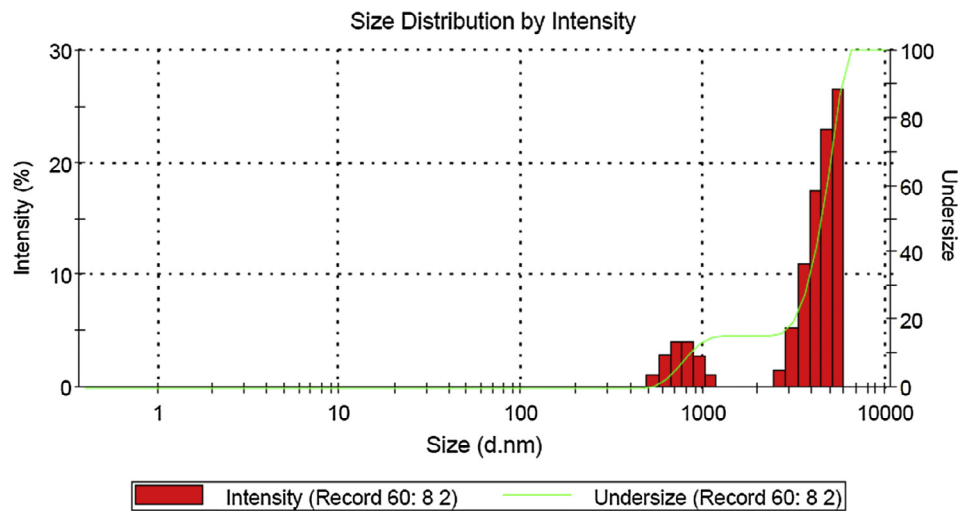


Fig. 1. Particle size distribution of carbiso mill particles after 30 min dry milling.

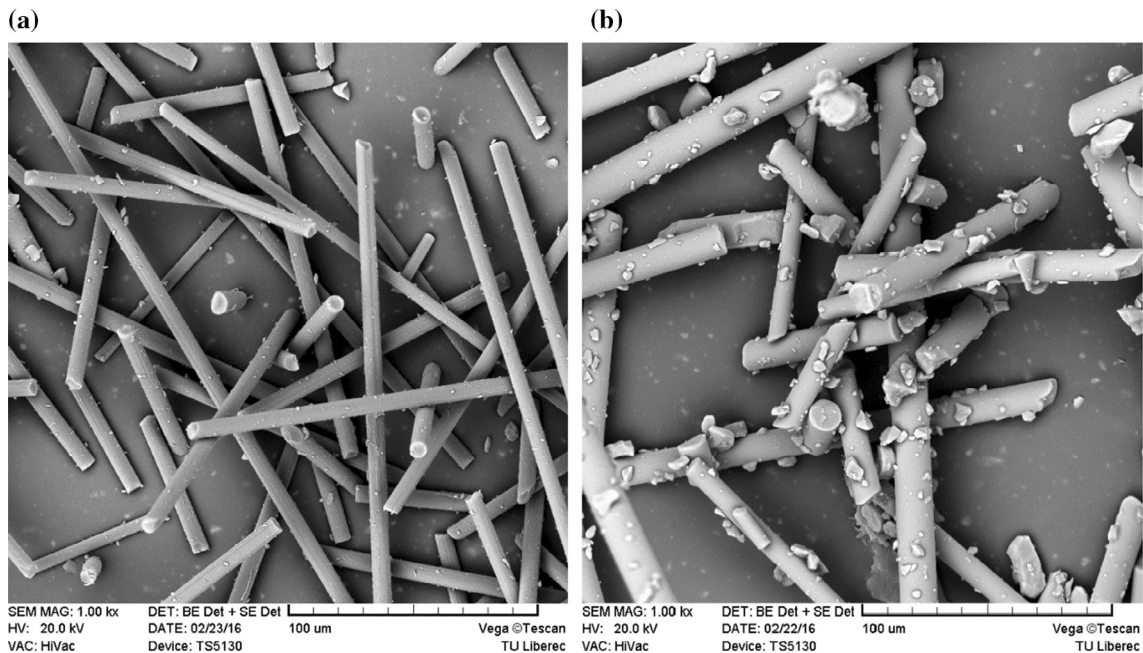


Fig. 2. Microstructure of carbiso mil (a) before milling (b) after milling.

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