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Chemical durability and performance of modified basalt fiber in concrete medium

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HIGHLIGHTS

- The purpose of this study is to evaluate the chemical durability of modified and non-modified basalt fibers.
- Mechanical performance of modified basalt fiber reinforced HVFA and OPC concrete was also investigated.
- Modified fiber confirms better properties compared to non-modified based on physicochemical analysis.
- Modified fiber can significantly enhance the indirect tensile and flexural strength of HVFA concrete even after 56 days.

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ABSTRACT

Due to the concern about mechanical properties, thermal resistance, ecological friendliness and chemical resistance, basalt fibers have become intriguing now a days for infrastructural and civil engineering applications. In the present work, chemical durability of modified and non-modified basalt fibers is studied. The fibers were immersed into twelve solutions for 62 days considering the concrete medium. The failure pattern and damage features of the fibers were sorted with the observation of surface by scanning electron microscope (SEM) and their compositions were identified using energy dispersive X-ray spectroscopy (EDX). Long term mass retention capacity was also summarized. Efforts were also made to determine the strength maintenance rate of modified fibers in high performance ordinary portland cement (OPC) and high volume fly Ash (HVFA) concrete. The result revealed that the modified fiber exhibits superior properties compared to the non-modified fibers based on morphological and chemical analysis. Mechanical test results also showed that the modified basalt fiber can significantly improve the indirect tensile and flexural properties of HVFA concrete even after 56 days.

1. Introduction

Basalt fibers show several advantages including modulus of elasticity, specific strength and nontoxic [1], low cost [2], non-combustible [3] and high thermal insulating properties [4]. It has the feature of wider application temperature range of −270 °C to +750 °C [5,6]. The chemical and mechanical properties depend on the composition of the raw material. Different fiber composition and concentration give difference in thermal and chemical stability and also showed variance in mechanical and physical properties [4].

Chemical structure of basalt fiber is nearly related to glass. The most important components of basalt fibers are SiO_2, Al_2O_3, CaO, MgO, Fe_2O_3 and FeO. The different oxides compose a large cross linked molecule with primary bonds [7,8]. Basalt fibers are chemically composed of pyroxene, clinopyroxene, olivine and plagioclase minerals [9]. Basalt materials are classified according to their SiO_2 content. If the basalt has scarcity in silica, it is categorized as alkaline basalt. Further, if the basalt is rich in silica, it is called acidic basalt [7,9]. Compared to the other natural fibers (Table 1), it has excellent mechanical properties; lightweight, easily affordable and ecofriendly makes it an ideal material for civil engineering application. The addition of basalt fibers can improve the deformation and energy absorption capacity, toughness index, flexural strength, abrasion resistance and reduce dry shrinkage of fiber reinforced concrete (FRC) significantly [10–13]. SEM images of microstructure have shown a good bond between basalt fiber surface and hydrated cement matrix which is obtained in the early age, whereas a debonding phenomenon between cement matrix and basalt fiber is observed at 28 days [14].

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Table 1
Mechanical properties of some natural fibers [2,15].

Fiber	Density (gm/cm^3)	Tensile strength (GPa)	Elastic modulus (GPa)	Elongation at break (%)
E-glass	2.56	1.4–2.5	76	1.8–3.2
Carbon	1.4	4.0	230–240	1.4–1.8
Basalt	2.8	2.8	89	3.15
Jute	1.3	0.3–0.7	26.5	1.5–1.8
Flax	1.5	0.5–1.5	27.6	2.7–3.2

There is a prevalent literature on the manufacture and uses of basalt fibers, but little attempt have been made to use basalt fibers in concrete environment for long term specific applications. At early age, however it appeared that basalt has an excellent imperviousness to alkaline attack both at room and at elevated temperatures [16]. However it was stated by Wang et al. that basalt has better acid resistance than alkaline solutions [17]. Moreover, basalt fiber has strong resistance to corrosion in ocean water and especially in tap water solutions [18]. In alkaline solutions, the hydroxyl ions react with Si–O–Si group which leads to the breakdown of silicon linkage. The rate of this corrosion depends on the chemical composition of the fiber and the alkalinity of the solution as well as on time and temperature [19]. In saturated $Ca(OH)_2$ solution, while basalt fiber shows very low weight loss and high stability however may reduce 60% strength after 3 months of immersion of fibers [20,21]. Studies also indicate basalt fibers instability following 28 days in concrete medium [22,23]. The basalt fibers lost 80% strength at 28 days if it was immersed in a 1 M NaOH solution [24]. However, studies are also available by using different surface coating agents in basalt fibers [25–27] but particularly in concrete, it is not adequate.

From the available literature, it appears that the investigation on chemical stability of basalt fibers in alkaline as well as in chloride and sulphate medium is not sufficient, which generally happens in building and construction involving concrete material. In most cases, the approaches were on short term basis and are inadequate to explain the long term variance of modified and non-modified fibers. The objective of this study consists of investigating the capacity of two types of commercially available basalt fibers to retain in alkaline medium and the effect of pH and long term (62 days) mass retention at room temperature. Moreover, physico-chemical characterization of basalt fibers is investigated before and after the immersion in alkaline using SEM and EDX analysis. Efforts are also being made on the development of high performance HVFA concrete with modified basalt fiber for compressive, indirect tensile and flexural strength. For comparison, high performance OPC was also used.

2. Materials

Two different types of basalt fibers were used in this experiment. One was supplied by Kamenny Vek Ltd, Dubna, Moscow, Russia (Group A) and the other one was imported from Jiuxin basalt fiber industry Co. Ltd, Jilin Province, China (Group B). Group A fiber was modified by silane (SiH_4) surface coating agent. The organofunctional group of silane is epoxy functional. The nominal length and thickness of Russian fibers were 25 mm and about 15 μm respectively. Chinese fibers have 3 mm nominal length and similar thickness as Russian fibers. Chemical compositions of both fibers are shown in Table 2.

Fibers were investigated under various chemical solutions considering concrete medium. Twelve solutions were prepared using NaOH, NaCl, Na_2SO_4, $Ca(OH)_2$, $CaCl_2$ and $CaSO_4$. Chemical solutions were prepared in view of three different conditions of alkaline, chloride and sulphate medium. Mixtures of these ions were also considered to explore the combined effects.

The cement was ordinary portland cement (OPC) which corresponds to the Australian Standard AS 3972 type GP [28]. The fly ash was class F fly ash according to AS 3582.1–1998 [29]. The physical properties and chemical analysis of cement and fly ash are given in Table 3.

Table 2
Chemical components of two different basalt fibers (supplied).

Component	Content (% wt)	
	Group A	Group B
SiO_2	54.5–55.5	48–60
MgO	4.0–4.6	3–6
CaO	7.5–8.5	5–9
Fe_2O_3 + FeO	10.0–11.5	9–14
Al_2O_3	16.5–18	14–19
TiO_2	0.9–1.25	0.5–2.5
R_2O	4–5	–
Li_2O	0.1–0.3	–
$Na_2O + K_2O$	–	3–6
Others	–	0.09–0.13

Table 3
Physical properties and chemical compositions of cementitious materials.

Properties	OPC	Fly ash
Physical properties		
Specific gravity	3.16	2.35
Chemical analysis		
SiO_2	19.9	49.45
Al_2O_3	4.62	29.61
Fe_2O_3	3.97	10.72
CaO	64.27	3.47
MgO	1.73	1.3
K_2O	0.57	0.54
Na_2O	0.15	0.31
TiO_2	0.23	1.76
P_2O_5	–	0.53
Mn_2O_3	0.06	0.17
SO_3	2.56	0.27
S^{2-}	–	0.21
Cl	–	0.001

Coarse aggregate with a maximum particle size of 10 mm with 1.1% water absorption and relative specific gravity of 2.99 at saturated surface dry (SSD) condition was used. River sand with specific gravity 2.65 was used as fine aggregate in this research project. HVFA concrete was prepared by 40% fly ash as partial replacement of cement. Poly-naphthalene based high range water reducer agent with the commercial name of Sikament NN supplied from SIKA, Australia was used to adjust the workability of the concrete mixtures. The water reducer had a specific gravity of 1.21 and a solid contents of 40%. After several trials, mix proportions were selected (Table 4) taking into account slump value 15–20 cm. Considering previous study, volume fraction of basalt fiber was selected as 0.5% [30].

3. Methodology

Concrete is alkaline because of the portland cement hydration product calcium hydroxide. Besides, the common deterioration of concrete emerges due to the attack of chloride and sulphate ions from ocean, de-icing salts, soil and groundwater. In this project, strong base 1 M NaOH and 1 M $Ca(OH)_2$ solutions were applied to represent the contamination of alkaline ion. Therefore, 3% NaCl and $CaCl_2$ and 10% Na_2SO_4 and $CaSO_4$ solutions were prepared to determine the effect of chloride and sulphate ions.