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The effect of alkali–silica reaction on steel fiber–matrix bond characteristics of cement based mortars

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HIGHLIGHTS

- The effect of ASR on steel fiber–matrix bond characteristics has been investigated in this research.
- ASR gel congestion in fiber–matrix interface increased the pull-out load and debonding toughness significantly.
- Supplementary cementing materials reduced the ASR expansion and mechanical strength loss.
- SEM analysis revealed that the ASR products filled the fiber–matrix interface with different morphology.

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ABSTRACT

The effect of ASR on fiber–matrix bond behavior has been investigated in this research. The potentially reactive basaltic aggregate was chosen as a reactive material. Two series of specimens containing different amounts of supplementary cementing materials (SCMs) were prepared. One of them was cured in 1 M NaOH solution at 80 °C, other series were cured in 80 °C water up to 150 days to obtain similar maturity. ASR expansion, single fiber pull-out load, debonding toughness, flexural and compressive strength was determined. Test results indicate that the ASR gel congestion in fiber–matrix interface increased the bond strength significantly during alkali exposure. Furthermore, SCMs are effective to reduce ASR expansion and to prevent the mechanical properties loss due to ASR. Micro-structural investigations revealed the reaction products having different morphology (fibrous, rosette type, network appearance, etc.) in alkali exposed specimens.

1. Introduction

Brittle construction materials such as cement based plain mortars and concrete exhibit low ductility. Cracking and propagation of cracking are the most obvious disadvantages of these materials which have low toughness. It is known that the behavior of brittle materials can be improved by the addition of steel or various discontinuous fibers. Steel fiber reinforced concrete (SFRC) is one the most popular composites which resists tensile forces by its fiber and matrix phases. The stress transfer at the fiber–matrix is controlled by the bond between fiber–matrix phases. The fiber–matrix interface bond is the most essential factor to prevent crack propagation in the matrix. Therefore, tensile strength, tensile stress–strain curve, and toughness of SFRC are dramatically influenced by the bond characteristics at the fiber–matrix interface [1–7].

In recent years, bond characteristics of cement-based composites have been investigated by many researchers. However, there is a major lack of information about the effect of durability problems like alkali–silica reaction (ASR) on the pull-out behavior of steel fibers. Mechanical properties of matrix, curing conditions, fiber geometry, fiber orientation, and embedment length are some remarkable parameters that affect the fiber–matrix interface bond. Tuyan and Yazıcı [8] investigated the effect of these parameters on pull-out behavior of single steel fiber-SIFCON matrix. Kim et al. [9] reported that as sand to coarse aggregate ratio increased, twisted fiber showed a significant enhancement in bond strength while smooth and hooked fiber showed no clear difference. Cunha et al. [10] dealt with the fiber–matrix bond in self-compacting concrete by using experimental as well as analytical methods. Shannag et al. [11] indicated that the fiber–matrix interface bond increases with high strength matrix. Besides, debonding energy improves significantly by increasing the embedment length. Abu-Lebdeh et al. [12] evaluated the influence of loading rates on the pull-out behavior of very-high strength concrete (VHSC). They concluded that the increase in pull-out rate increases both peak load and debonding energy (toughness). Abu-Lebdeh et al. [13] reported that the pull-out behavior of steel fiber reinforced composites is influenced by the matrix strength and fiber end condition (smooth, hooked-end).

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Table 1
Physical, chemical and mechanical properties of cement, fly ash, slag, silica fume, and aggregate.

	Chemical composition (%)					Physical properties of cement	
	Cement	Silica fume	Slag	Fly Ash	Aggregate		
SiO_2	18.52	92.25	39.32	47.15	61.40	Specific gravity	3.15
Al_2O_3	4.70	0.88	9.36	20.42	15.80	Initial setting time (min)	110
Fe_2O_3	3.24	1.98	0.90	4.15	5.36	Final setting time (min)	166
CaO	64.25	0.51	36.61	20.47	5.65	Volume expansion (mm)	1.00
MgO	0.93	0.96	6.38	1.51	1.97		
Na_2O	0.35	0.45	–	0.59	3.05	*Specific surface*	
K_2O	0.80	0.12	–	1.36	2.37	Cement (m^2/kg) blaine	380
SO_3	3.03	0.33	0.16	2.08	0.06	FA (m^2/kg) blaine	292
Cl^-	0.006	–	0.013	0.0149	–	GGBS (m^2/kg) blaine	599
Loss on ignition	3.17	–	2.88	0.97	1.85	SF (m^2/kg) nitrogen Ab.	20000
						Compressive strength of cement (MPa)	
						2 days	27.1
						7 days	43.3
						28 days	56.0
						Pozzolanic activity index (%), ASTM C 311	
						FA (28 days)	83
						GGBS (28 days)	100
						SF (28 days)	115

Table 2
Properties of the hooked-end steel fiber.

Code	Length (L) (mm)	Diameter (d) (mm)	Aspect ratio (L/d)	Tensile strength (N/mm^2)
80.60	60	0.75	80	1050

Lee et al. [14] proposed an analytical pull-out behavior model considering fiber inclination.

The alkali–silica reaction is a chemical process involving alkali ions from cement and certain siliceous constituents in the aggregate. The product of this reaction is a complex silica gel, which swells by imbibing water [15–17]. The resulting volumetric expansion causes cracking and can lead to loss of strength, elasticity, stiffness, and durability of concrete [18–20].

Different methods have been suggested to mitigate or prevent ASR including the use of low alkali cement, using non-reactive aggregate, controlling the moisture content, using mineral or chemical admixtures [1–3,21,22], and the incorporation of various fibers (steel, brass-coated steel Polypropylene, etc.) to physically mitigate crack propagation and to restrain expansion. The latter method has been previously the focus of some researches [23–27].

The aim of this research is to investigate the effect of ASR on matrix-steel fiber bond characteristics. Also the role of the mineral admixtures to mitigate the ASR expansion and its deleterious effects on mechanical performance were also determined. Pull-out load vs. fiber debonding, pull-out peak load, debonding toughness, compressive strength, and flexural strength values before and after ASR exposure were determined and compared with the control specimens that are similar maturity.

2. Experimental

2.1. Materials

CEM I 42.5 R type high alkali cement was used during this research as binding material. Silica fume (SF), ground granulated blast furnace slag (GGBS) and fly ash (FA) was used as supplementary cementing materials (SCMs) to compare with plain mortar. Reactive basalt from western Anatolia, Turkey was used as aggregate (1–4 mm). The alkali–silica reaction behavior and characteristics of this aggregate (a basaltic rock from western Anatolia, Turkey) was also studied by Çopuroğlu et al. [28]. The main source of expansion is explained by the reactive glassy phase of the basalt matrix having approximately 70% of SiO_2 in this research [28]. The

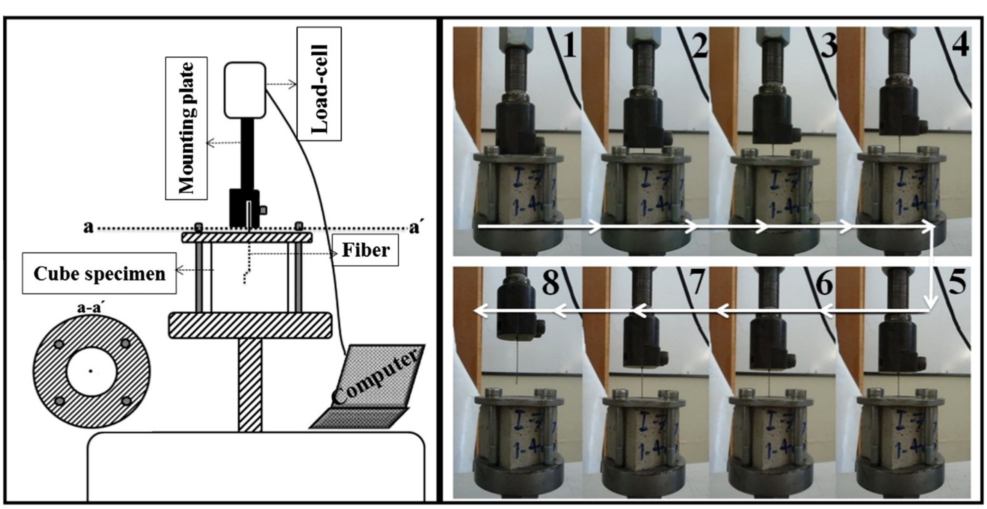

Fig. 1. Pull-out test setup and procedure.