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Mechanical behaviour of micro-fine steel fibre reinforced sulphoaluminate cement composite

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HIGHLIGHTS

- A new cement based composite (MSFRSC) with high early strength and toughness was developed.
- The mechanical behaviour of MSFRSC was experimentally investigated.
- The flexural and shear strength of MSFRSC were improved by the addition of MSF.
- The flexural toughness of MSFRSC was improved significantly by the addition of MSF.
- The flexural toughness of MSFRSC was evaluated based on different codes.

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ABSTRACT

In this study, a new cement-based composite with high early strength and toughness was developed by the addition of micro-fine steel fibre (MSF) in sulphoaluminate cement (SAC). The new composite is termed as MSF reinforced SAC composite (MSFRSC). The mechanical behaviour of MSFRSC was experimentally investigated, the flexural toughness and ductility of MSFRSC was evaluated. It was found that the compressive strength, flexural strength, shear strength, flexural toughness and ductility of MSFRSC were significantly influenced by the curing time and volume fraction of MSF. The compressive strength, flexural strength and shear strength of MSFRSC increased with the increase of curing time, especially during the first three days. The flexural strength and shear strength of MSFRSC improved significantly with the increase of the volume fraction of MSF. The flexural toughness of MSFRSC significantly improved and the ductility slightly improved with the increase of the volume fraction of MSF from 0.0% to 2.0%. The flexural toughness slightly increased and the ductility slightly decreased with the increase of the curing time from 1 day to 28 days. Also, the recommendations of different codes for the evaluation of the flexural toughness and ductility of MSFRSC were compared. The recommendations in ASTM C1609 fully reflected the flexural toughness and ductility of MSFRSC. The recommendations in JG/T 472-2015 distinguished the influence of MSF on the pre-peak and post-peak flexural load-deflection behaviours of MSFRSC. A simplified approach based on JG/T 472-2015 was proposed to evaluate the flexural ductility of MSFRSC.

1. Introduction

Sulphoaluminate cement (SAC) is well known for its high early strength, fast setting, and high frost and permeation resistance. The SAC has been widely used in the rapid construction and repair of existing structures [1,2], structures exposed to sub-zero temperature [3], as well as water retaining structures [4,5] in the last few decades. Compared to the ordinary Portland cement (OPC), SAC is green cement with lower CO_2 emissions [6–8]. It uses industrial waste materials during the manufacturing process [9,10]. Therefore, SAC is considered a suitable alternative to OPC and has the potential for wider applications in the environmentally sustainable construction industry [11].

Significant research attentions have been devoted in recent years on the SAC due to its superior mechanical properties. Ding et al. [12] developed high performance ultra-early strength SAC grout by using superplasticizer, early strength agent and

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anti-moisture dispersant. The test results showed that SAC grout achieved 8-h compressive strength of 40 MPa and 28-day compressive strength of 65 MPa. Ma et al. [13] mixed nano-SiO_2 into SAC based composite materials to investigate the flowability and the compressive and flexural strength of the paste. It was found that the compressive and flexural strength of specimens increased and the flowability of paste decreased with the increase of nano-SiO_2 content in the paste. The compressive strengths at 8 h and 28 days were 65.7 MPa and 92.1 MPa, respectively. The flexural strengths at 8 h and 28 days were 8.5 MPa and 9.4 MPa, respectively. Li et al. [14] blended magnesium potassium phosphate cement (MKPT) and calcium sulphoaluminate cement (CSA) to develop a blended system (CSA-MKPT), which was cured in various relative humidity and temperatures. Li et al. [14] investigated the mechanical properties of CSA-MKPT. It was found that the humidity hardly had any effect on the compressive strength of CSA-MKPT. The compressive strengths of CSA-MKPC cured for 7 days with SAC contents of 20%, 30% and 40% of the weight of the MgO were 78.05 MPa, 74.75 MPa and 65.73 MPa, respectively, at a curing temperature of −5 °C. Chen et al. [15] developed a new artificial reef concrete (NARC) with SAC, sea sand, sea water and other admixtures. The measured compressive strengths of NARC cured for 3 days, 7 days and 28 days were 55.3 MPa, 63.3 MPa and 71.3 MPa, respectively. The compressive strength at 3 days was nearly 80% of the compressive strength at 28 days.

Although a significant number of studies were carried out on the development of SAC, the SAC-based composites are typically brittle in nature. For the OPC concrete, the most effective way of reducing the brittleness and improving the toughness or ductility is the addition of steel fibre (SF) [16] in the concrete mix. Relatively low cost and high effectiveness of steel fibre, especially the micro-fine steel fibre (MSF), in enhancing the performance of concrete, make the MSF an attractive choice for the addition in OPC concrete. The MSF is made of drawn wire and coated with copper. The diameter of MSF usually varies between 0.2 mm and 0.3 mm. The tensile yield strength is usually more than 2000 MPa. Compared to ordinary SF, MSF has the advantages of having a larger number of fibres per kilo, higher tensile strength and easier dispersion. The MSF was used to prepare the reactive powder concretes with the ultra-high compressive strength of more than 100 MPa. The addition of MSF improves tensile strength, flexural strength and ductility of the reactive powder concrete [17–19]. The effect of MSF on high performance alkali-activated slag/silica fume mortars was investigated by Aydin and Baradan [20]. The test results indicated that the alkali activated matrices achieved higher bond to the MSFs compared to OPC matrices and increase in the fibre content reduced the shrinkage cracking associated with the alkaline activation of slag systems. When MSF was used in engineered cementitious composites with SAC, the cracking strength, tensile strength and maximum tensile strain at failure of the composites were increased. The individual crack width in the multiple-cracking stage was decreased with the addition of MSF [21]. Hence, MSF has the potential to improve the brittleness of SAC composite.

In this study, a new cement-based composite with high early strength and toughness was developed by adding MSF in SAC. The new composite is named as MSF reinforced SAC composite (MSFRSC). The compressive strength, shear strength, flexural strength and flexural performance tests were conducted to investigate the effect of MSF volume fraction, curing time and water-binder ratio on the mechanical behaviour of MSFRSC. Afterward, the flexural behaviour of MSFRSC has been evaluated based on the flexural load-midspan deflection curves and the flexural performance index calculated by the recommendations in different standards.

2. Experimental program

2.1. Materials

The SAC used for all the mixtures was Grade P.O 52.5R according to GB20472-2006 [22]. The properties of cement provided by the manufacturer [23] are reported in Table 1. The natural river sand with the fineness modulus of 2.0 was used as fine aggregate. Silica fume with SiO_2 content of 92% and apparent density of 150–250 kg/m^3 was used as an additional admixture. The Naphthalene sulfonate formaldehyde condensate (FDN) was used as a water reducing agent with a water reducing ratio of 0.18–0.25. Both ends of the micro-fine steel fibre (MSF) used in this study were deformed, as shown in Fig. 1. The properties of MSF provided by the manufacturer [24] are reported in Table 2.

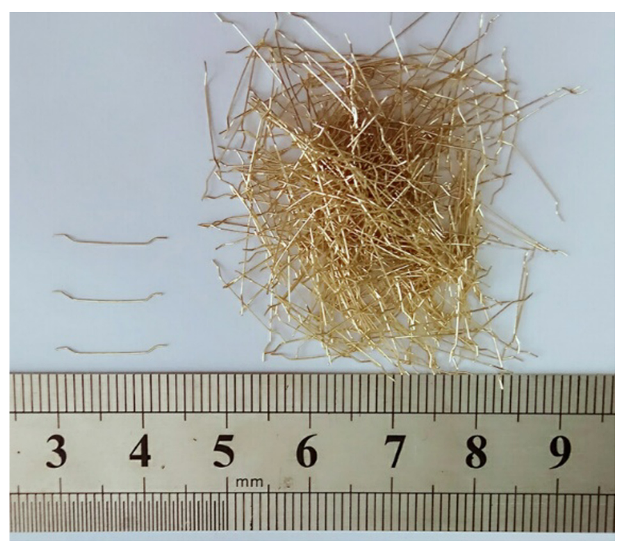

Fig. 1. Micro-fine steel fibres.

Table 1
Properties of SAC [24].

w/c	s/c	Compressive strength (MPa)		Flexural strength (MPa)		Setting time (min)		Surface area (m^2/kg)	Normal consistency	Free calcium oxide
		1 d	3 d	1 d	3 d	Initial setting	Final setting			
0.45	3.0	43.8	55.9	6.6	7.1	27	32	455	24%	0%

Note: w/c is the weight ratio of water to cement and s/c is the weight ratio of sand to cement.
Mechanical properties were determined according to GB/T 17671-1999 [23].