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Investigating the performance of PVA and basalt fibre reinforced beams subjected to flexural action

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ABSTRACT

This paper presents the flexural test results of 21 fibre reinforced concrete (FRC) beams containing PVA and basalt fibres (1–3% by volume). Fibre reinforced concrete was made of three different binders; the first binder type was 100% cement, the other two types were blended cement system containing a part of 10% silica fume or metakaolin with 90% cement. For each the three binder system; 7 beams of the size $100 \times 200 \times 1500$ mm were cast, the first beam known as control beam contained no fibres. The remaining 6 beams were cast using FRC containing a volume fraction of 1%, 2% and 3% PVA and basalt fibres, respectively. All 21 beams were tested to failure under three-point flexural loading. Experimental results showed that the addition of PVA fibres significantly improved the post-cracking flexural response compared to that of the basalt fibres. Beams with 3% PVA fibre volume showed deflection-hardening behaviour with an improvement in post-cracking flexural strength. It means that the addition of high volume content of PVA fibres made the beams more tough and ductile. Whereas, deflection-softening behaviour was observed in case of beams containing higher volume of basalt fibres.

1. Introduction

Flexural behaviour of fibre reinforced concrete (FRC) is categorised as either deflection-hardening or deflection-softening, depending on its tensile response (Fig. 1).

From structure's point of view, deflection-hardening materials are very much useful in the structural applications where bending failure mode dominates. Deflection-softening composites cover an extensive variety of the practical applications starting from the use of controlling plastic shrinkage cracking of concrete to the higher end i.e. in concrete pavements and slabs on grades [2]. A general load–deflection response of unreinforced matrix and fibre reinforced concrete (FRC) is shown in Fig. 2, which shows that the addition of fibres significantly improves the toughness of concrete. Alongside, the volume of fibre is the major parameter that influences the load–deflection behaviour (refer to Fig. 3). This is also confirmed by Yoo et al. [3] who mentioned that the loading capacity, deflection corresponding to the peak load and the toughness of concrete significantly improves by the increase in the fibre volume content. Furthermore, there is negligible effect of the fibre volume on the first cracking strength of the concrete and fibre can only play an important role in the post-cracking response of concrete [3]. However, the opening of the crack in the presence of fibres is restrained and hence provide better performance.

A large amount of work has been done in the past to investigate the flexural behaviour of fibre reinforced concrete (FRC). In flexure, most of the studies on FRC are performed in the presence of longitudinal steel reinforcement and in almost all these studies, steel fibres were used together with longitudinal reinforcement [4–6] and showed significant improvement in the flexural behaviour. However, the use of steel fibres is not suitable in environmentally exposed infrastructures (e.g. bridge decks) and aggressive environment as they are susceptible to corrosion and fire [8]. Moreover, the higher volume of steel fibres added to a concrete mix complicates the uniform dispersal of the fibres (i.e. balling effect) and increases the density of concrete, which ultimately results in added structural weight [8]. Another problem is that the desired improvement in the structural response cannot be obtained unless the adequate quantity of steel fibres is used; while the optimum fibre volume recommended in ACI committee 544.1R-96 [4] is 2%. These limitations of steel fibres urge to investigate the other fibre types for the possible structural application.

Recently, polyvinyl alcohol (PVA) and basalt fibres have been investigated in the concrete and proved themselves a good candidate of the concrete due to excellent results of mechanical

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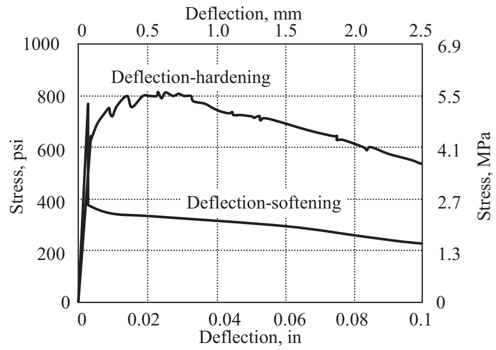

Fig. 1. Deflection-softening or deflection-hardening FRC [1].

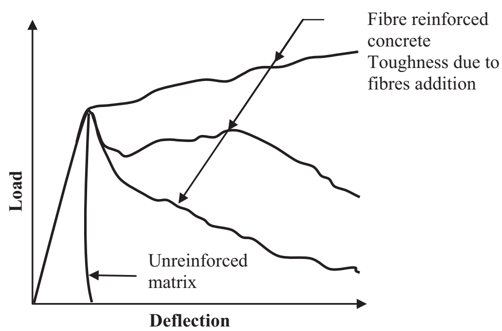

Fig. 2. Range of load–deflection curves for matrix and FRC (ACI committee 544.1R-96 [4]).

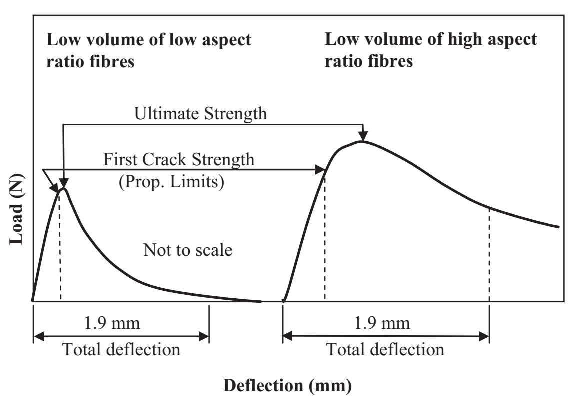

Fig. 3. Effect of fibre volume on the load vs. deflection behaviour of FRC [2].

properties [9]. PVA fibre is an essential component of "Engineered cementitious composites (ECC)", which achieved the tensile strain as 500 times higher than the normal concrete. The contributions of PVA fibres in ECC are well explored [9–11]; however, structural investigation of FRC using both PVA fibres and coarse aggregates is only investigated by Holschemacher and Höer [9] who stated that PVA fibres in FRC offer similar advantages as offered by steel fibre reinforced concrete (SFRC). There is another fibre, basalt fibre, which has recently been explored in several types of research [12–17]. From the structural point of view, basalt fibres possess many appreciable characteristics including high strength, high elastic modulus, high thermal and chemical stability [18], good sound insulation and electrical characteristics [12,15], corrosion and fire resistance [7,13] and durability [14]. Palmieri et al. [14] mentioned basalt fibres as high performance and low-cost fibre for structural application. According to Singha [16], basalt base composites have the ability to replace steel (1 kg of basalt reinforces equals 9.6 kg of steel) as lightweight concrete can be gotten from basalt fibres. Recently, this fibre was used in the concrete and exhibited excellent mechanical properties [8]. This fibre possesses a great potential to make a good alternative building material to metal reinforcements like steel and aluminium, as well as a worthy contender of concrete used in bridges and offshore structures due to high resistance to alkaline, acidic and salt attack.

On the basis of the deflection-hardening response of PVA fibres in ECC and the suitable characteristic of Basalt fibres from structural application's point of view (and especially corrosion and fire resistance), it seems that both fibres cab be used as an alternative of steel fibres. Therefore, a comprehensive experimental investigation on the flexural response of fibre reinforced concrete using both fibres is carried out.

In this study, the flexural response of PVA and basalt fibres has been studied in the three mixes of concrete. The first mix was prepared by utilising 100% cement and the other two mixes were prepared by replacing 10% cement content with silica fume and metakaolin. The main parameter of investigation is the volume of fibres, which has been varied from 0% to 3%.

2. FRC materials, mix composition, and preparation

The mixing materials along with their composition are given in Table 1. Total three series of FRC were prepared whose IDs are identified based on the concrete mix types. Each series was comprised of 7 mixes based on the fibre type and volume fraction. Each mix ID is distinguished based on the concrete type, fibre type, and fibre volume fraction.

The first series "P" was prepared by utilising 100% cement whereas, the other two series "S" and "M" were prepared by replacing 10% cement content with silica fume and metakaolin. Selection of the cement replacement content was based on the recently published review on mineral admixture [19]; according to which, use of 10% silica fume is the optimum cement replacement content and metakaolin can be used as a good and economical alternative of silica fume for the same cement replacement content. The physical and chemical properties of ordinary Portland cement (OPC) and mineral admixtures are given in Table 2.

Kuraray RF 4000 Polyvinyl alcohol (PVA) fibres and chopped basalt fibres were used in this research as reinforcements for concrete. The physical properties of both fibres are presented in Table 3; whereas the chemical composition of chopped basalt fibres is given in Table 4. Fibres were selected by considering their reinforcing properties as described in Table 3, which shows that PVA and chopped basalt fibres possess good tensile strength and young modulus and these fibres were added as 1%, 2%, and 3% by volume of concrete mix.

All mix ingredients given in Table 3 were mixed in a pan mixer of 0.1 m^3 capacity in compliance with ASTM C192/C192M standard [20]. In order to produce a workable concrete mix in the presence of fibres and to avoid difficulty in full compaction, as well as honeycombing, a water/cement (w/c) or water/binder (w/b) ratio of 0.4 was used in this research. This w/c (or w/b) ratio meets the optimum recommended water/cement ratio of 0.35 [21] and 0.5 [22] for full compaction. In order to improve the workability and fresh properties of FRC, Sika ViscoCrete®-1600 was used as superplasticizer. This superplasticizer is specially designed to meet the requirements of ASTM C 494-86 Type G standard [23] for the production of highly workable concrete and mortar. Variable dosages of superplasticizer were used, according to the increase in fibre volume, to increase the workability. The quantity of superplasticizer was mainly dependent on the target slump of 75 ± 10 mm (without fibres) and 50 ± 10 mm (with fibres).