SIGNIFICANCE OF INCORPORATING STEEL FIBER AND POLYVINYL ALCOHOL FIBER IN CEMENT BASED COMPOSITES UNDER STATIC AND DYNAMIC LOAD

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Abstract- The single fiber reinforced concrete had improved mechanical properties than plain concrete. However, the addition of different fibers together resulted in better crack arresting performance at different scale that of individual fibers. Therefore, the steel fibers and polyvinyl alcohol (PVA) fibers are blended together to achieve the fiber bridging performance at multi scale. The inclusion of these two fibers will contribute together at their particular level and will contribute in the improvement of mechanical and dynamic properties. In this paper, the properties of steel fibers and polyvinyl alcohol fibers are studied with different length and contents to study the static and dynamic behavior of cementitious composites. For static properties, compressive strength and peak micro strain are determined; and to evaluate the dynamic behavior the curves of column top acceleration-time are considered. The addition of multi-scale fibers resulted in enhanced peak micro strain and showed longer time period under dynamic load. This indicate the positive synergy of steel and PVA fibers blend designed for improved static and dynamic properties of cementitious composites.

Keywords- Crack arresting performance, Steel fibers, Polyvinyl alcohol fibers, Static properties, Dynamic properties.

1 INTRODUCTION

The performance of fiber reinforced cementitious composites (FRCC) are influenced by many factors like base matrix characteristics, fibre size, length and mix proportion [1-3]. FRCC are developed to reduce the brittleness of plain composites and improves its crack resistance performance [4]. The dynamic behavior of cementitious composites are necessary parameter to assess the safety performance [5]. The FRCC showed improved performance in earthquake resistant structures as compared to that of plain composites (PC) [6]. Steel fibers are generally used as a basic material for improvement in toughness of FRCC [7, 8]. Also, the PVA fiber are used in FRCC because of its high strength, large elongation, higher elastic modulus and bond strength [6, 9]. The improvement in toughness as well as crack arresting mechanism of composites is observed with use of PVA fiber [6]. The fiber composite should be design for enhanced energy absorption capability under dynamic load [1]. The addition of hybrid fibers result in reducing the crack propagation and delay the crack growth in cementitious composites. Thus, the combination of steel and PVA fibers may reduce the crack growth by controlling the displacement and acceleration of composites under dynamic load. During service life of composites structure it experiences a lot of dynamic loads like seismic load, hydrodynamic pressure and wind load [10, 11]. It was found that the behaviour of composite structure under dynamic load are relatively changed than under static loading [12]. The strong dynamic load due to earthquake can damage the structures and cause a huge loss in earthquake prone areas. The PC are susceptible to failure under the dynamic load due to its brittle behavior [6]. Hence, it is essential to make a FRCC with superior characteristic to resist dynamic load that may be suitable for area susceptible to earthquake.

Hybrid fiber reinforced composite is a compound material and many parameters effect its cracking mechanism like mixing regime, mix composition and basic raw material etc [13]. There are three basic stages during crack process in cement based material, i.e. initial cracking stage, crack extension stage and final stage when crack open. It is obvious that there are always some pre-existing crack available in cementitious composites. When the load is applied, the existence of these cracks will cause the stress redistribution in cementitious composites and will result in development of cracks in CSH and cement paste layer. By further increment in applied load, the crack will start to extend and step into crack extension stage in cement based material. At this stage, the PVA fiber will come across the crack and provide the bridging law in fiber composites. The bridging law of PVA fiber will result in fiber pull out or fiber fracture ultimately consume more energy. In the meanwhile, further addition of load will expand the crack and at the same time, the steel fiber start to act as bridge between the cracks and does not allow the crack to propagate in cementitious material. This bridging law will delay the crack growth and increase the crack propagation pathway eventually result in improved performance of hybrid fiber cementitious composites under dynamic load. The addition of single type fiber in composites will provide crack resistance at one scale, but the inclusion of hybrid fibers will provide the bridging law at different scale as per their size limitations. Therefore, to achieve the better performance under static and dynamic load the use of hybrid fiber are more effective than that of single fiber in cement based composites.

To the best of author's knowledge no study is reported on dynamic mechanical properties of single degree of freedom specimen prepared by steel fiber-PVA fiber reinforced composites under hydraulic shaking table. However, researchers focused the dynamic behavior of hybrid fiber reinforced composites with steel bars; but this study is an initiative to study the behavior of hybrid fiber reinforced composites without steel bars. Therefore, this study explore the effectiveness of dynamic response of single degree of freedom steel fiber-PVA fiber reinforced composites. The cube compressive strength and peak strain are evaluated for static parameters; and for dynamic behavior, the column top-acceleration time curves are recorded.

2 EXPERIMENTAL PROCEDURES

The cement, quartz sand, super plasticizer, steel fiber and PVA fiber are used. The physical parameters of quartz sand, steel fiber and PVA fiber are presented in Table 1.A total of four mix proportion was considered and named as 2SF/13mm, 1.5SF/13mm + 0.5PVA/6mm, 2SF/35mm and 1.5SF/35mm + 0.5PVA/12mm. The SF and PVA represents the steel and PVA fiber, respectively; and 2, 1.5 and 0.5 denotes the percentage of fibers. The short-steel fibers (13mm), short-PVA fibers (6mm), long steel fibers (35mm) and long PVA fibers (12 mm) were used. The mixing procedure is shown in Figure 1, respectively. After uniform mixing, the moulds of cubes and columns with fresh matrix were filled and vibrating table was used for compaction. Finally, the cubes and columns were demoulded and kept at 20℃ for 28 days.

Table 1- Physical parameters of raw materials

Raw materials	Density (g / cm^3)	Physical Parameters	Mechanical Properties
Quartz sand	2.65	Fineness modulus (2.51)	Moh's hardness = 7.0
Steel fiber	7.8	Length (13 mm and 35 mm)	Tensile strength ≥ 2 GPa
PVA fiber	1.29	Length (6 and 12 mm)	Tensile strength ≥ 1.1 GPa

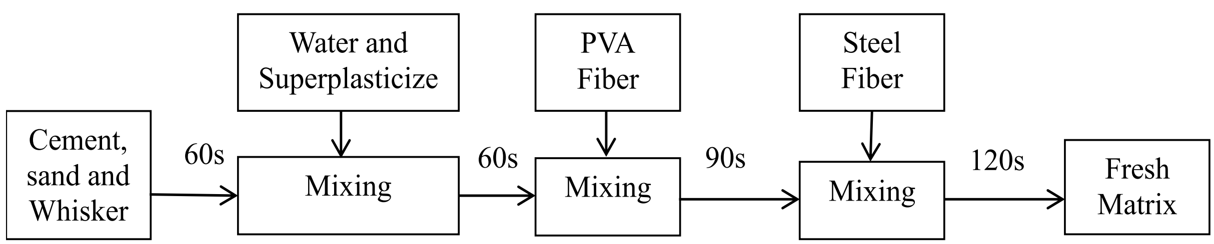


Figure 1: Mixing procedure

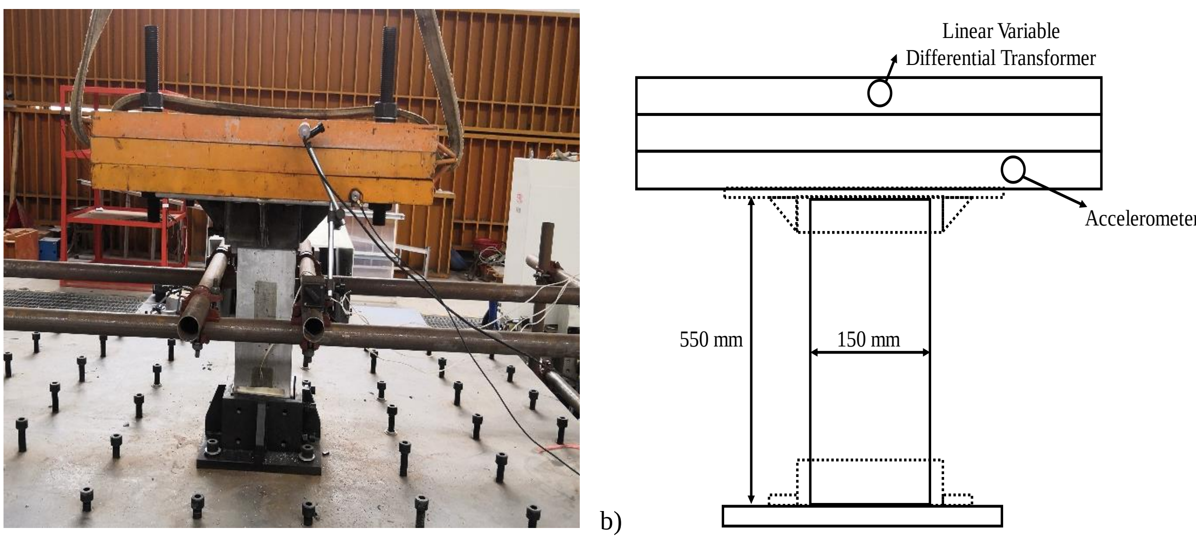
3 RESEARCH METHODOLOGY

The WAW / 600D universal testing machine (UTM) was used to test the FRCC cube specimen under for compressive load as per ASTM standard C39 [14]. The single degree of freedom SST-100 hydraulic shaker as shown in Figure 2 (a) was used to evaluate the dynamic behavior of FRCC. The dynamic signal acquisition system was used to calculate the dynamic signal measurement and analysis. The maximum force and acceleration was 100 KN and 1 g, respectively. The size of shaking table was 2000 mm × 2000 mm × 200 mm. The real time test data was determined, which include column top acceleration obtained from acceleration sensor as shown in Figure 2 (b).

4 RESULTS AND DISCUSSION

4.1 Static properties

The compressive strength and strain at peak are shown in Figure 3. The compressive strength for short length fiber composites of SF/13mm and 1.5SF/13mm were 81.75 MPa and 62.15 MPa, respectively. However, the long length fiber addition in composites of 2SF/35mm and 1.5SF/35mm + 0.5PVA/12mm were 79.55 MPa and 70.70 MPa, respectively. The incorporation of PVA fibers resulted in decrease trend for both groups, i.e. short length fibers composites and long length fiber composites. It is obvious that addition of fibers may reduce the compressive strength but it result in increased strain capacity of composites as evident from Figure 3 (b). The peak strain of hybrid fibers composites was increased with addition of steel and PVA fibers together than that of single length steel fiber. However, the better improvement was observed in peak strain with addition of long hybrid fibers as compared to that of short length hybrid fibers. The higher stiffness and higher modulus of steel fibers with 2% content resulted in greater compressive strength. On the other hand, the hybrid fiber composites with steel and PVA fibers resulted in low compressive strength. This is because inclusion of PVA fibers in composites produced new interfaces, which are the basis for low compressive strength. Similar results are also stated by Cao, et al. [15]. In addition, the blend of steel and PVA fibers together showed positive synergy and increased the peak micro strain of hybrid fiber composites that that of single fiber composites.

a)


b)

Figure 2: Test setup, a. (a) column under dynamic load, and b. schematic diagram

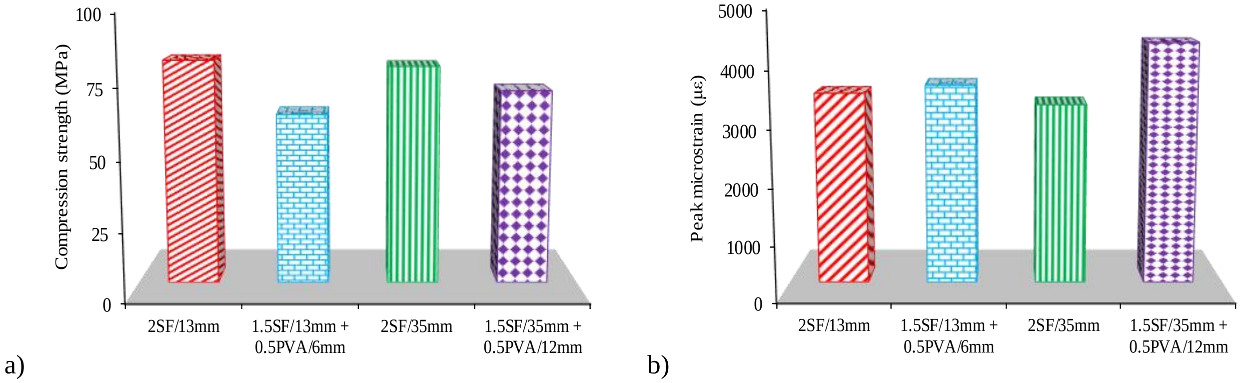


Figure 3: Static properties, a. compressive strength, and b. strain at peak

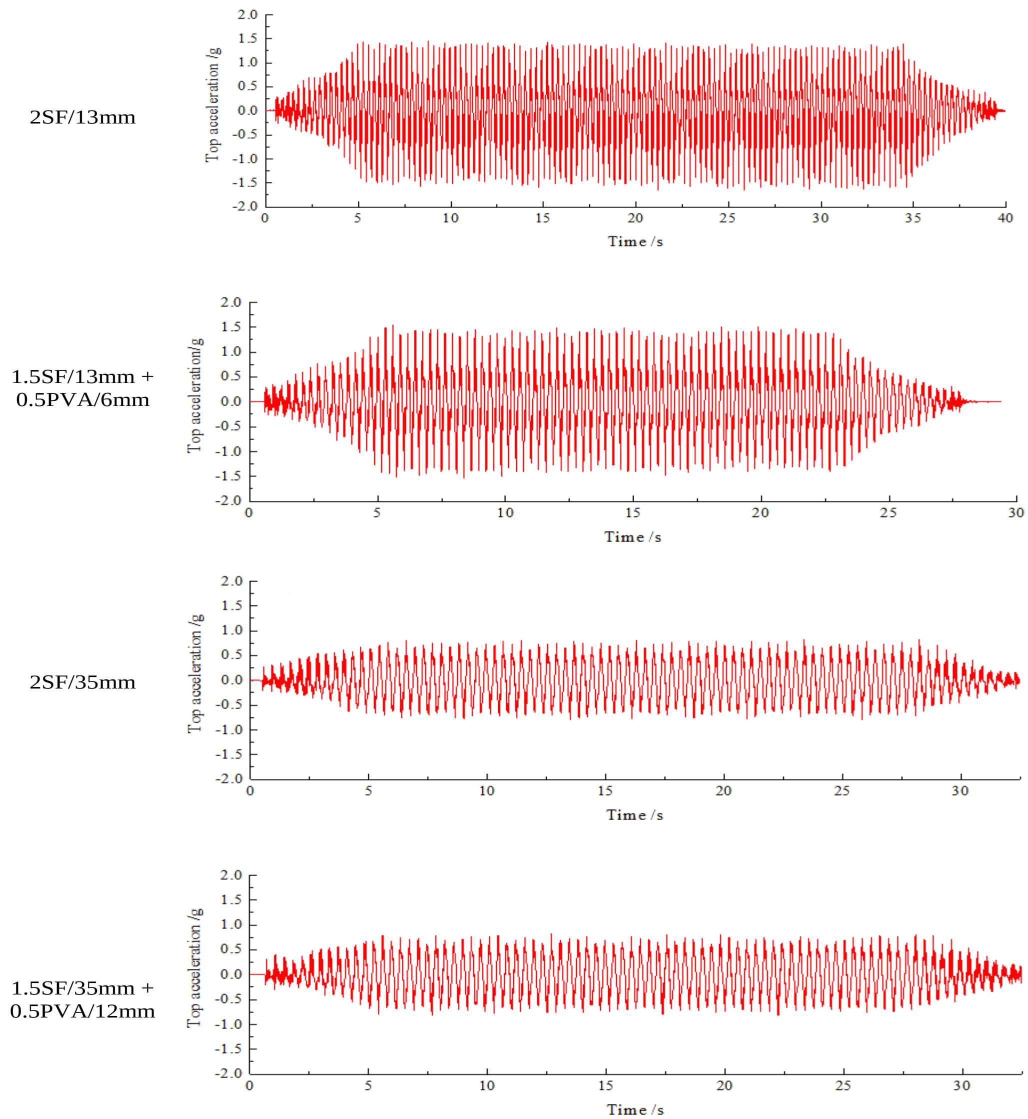


Figure 4: Column top acceleration versus time curves

4.2 Dynamic properties

Figure 4 illustrates the curves of column top-acceleration versus time for all composites. The 2SF/13mm and 1.5SF/13mm + 0.5PVA/6mm had presented better acceleration than those of 2SF/35mm and 1.5SF/35mm + 0.5PVA/12mm cementitious composites. In case of short-steel PVA fiber, the partial substitution of PVA lead to in reduced top-acceleration time curve of cementitious composite. However, the substitution of long PVA fibers in 1.5SF/35mm + 0.5PVA/12mm cementitious composite almost showed the stable performance. This short length of PVA fibers caused the reduction in acceleration due to shorter development length ultimately had low bond strength with cementious composites. In addition, the inclusion of PVA fibers produce new interfaces in composites that could result in low strength performance. Same conclusion is also reported in the literature [15]. In contrast, the long PVA fiber replacement in 1.5SF/35mm + 0.5PVA/12mm composite had proper development length and showed proper bond. This resulted in increased acceleration by fiber bridging and eventually restricted the crack growth in composites. The steel fiber and PVA fiber will result in fiber pull out or fiber fracture ultimately consume more energy and improved the performance under dynamic load. These fibers does not allow the crack to propagate and act as bridge between the cracks in composites.

5 CONCLUSION

The current study presents the compressive and dynamic response of hybrid fibers (steel and PVA fiber) in cementitious composites. The compressive strength and peak strain are determined under static load. The dynamic test is performed on hydraulic shaker with single degree of freedom condition and the curves of column top-acceleration verses time are studied. The following conclusions are made:

- The degree of decrement in compressive strength is more in short length hybrid fibers cementitious composites than those of long length hybrid fiber cementitious composites.
- The addition of long length hybrid fibers in composites improved the peak micro strain than that of short length hybrid fiber reinforced cementitious composites.
- The long PVA fiber replacement in 1.5SF/35mm + 0.5PVA/12mm composite indicated better acceleration performance because of fiber bridging that provides crack arresting mechanism.
- The steel fibers and PVA fibers offers the resistance against cracking by bridging across it at their particular scale ultimately caused the improvement in static and dynamic properties of hybrid fiber reinforced cementitious composites.

Further study is necessary with different lengths, contents, types and sizes of hybrid fiber in cementitious composites for enhanced performance under dynamic loading. Future work is to perform the SEM and XRD analysis for understanding the mechanism of hybrid fibers with matrix under dynamic load.

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