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ORIGINAL ARTICLE

Effect of fabric types on the impact behavior of cement based composites in flexure

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Abstract Two different fabric types were used to investigate the effect of the fabric types on the static and impact behavior of fabric reinforced cement based composites by using three point bending tests for various drop heights of hammer and position of the specimens on the supports. For each fabric type, 18 specimens with dimensions of 50 mm × 150 mm × 12 mm were produced with the pultrusion process. The vertical specimens have more stiffness, less ultimate deflection and higher load carrying capacity than the horizontal specimens for same drop heights. However, the horizontal specimens subjected to impact loads have higher stresses than the vertical specimens due to the section properties. The tests showed that polyvinyl alcohol (PVA) fabric reinforced cement based composites carried higher impact loads, were stiffer and had less deflection than other composites. At the drop heights over 100 mm, the impact strength of the horizontal specimens sharply decreased, while that of the vertical specimens was remained same.

Keywords Impact · Flexure · Fabric · Pultrusion · Drop height · Cement-based · Composite

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1 Introduction

Fibers are added into concrete mix to improve the ductility, tension, impact and flexural strength. Such cement based composites are used around the world in all fields of construction primarily due to their ability limited crack growth. The tensile strength, toughness, and ductility of fiber reinforced cement-based composites increase as the fiber contents in the mix increases. The fiber content cannot exceed a certain volume fraction to prevent the balling of fibers and to provide workability to the cement-based materials. Instead of fibers, woven fabrics have recently been used to develop the similar mechanical properties in thin cement-based composites. Thin precast cement-based materials have been preferred due to their lower costs of production, transportation, and installation compared to the cast-in-place concrete. Areas of application include retrofit projects, exterior panels, and roofing components, cladding members, impact resisting structures and high pressured pipes. Peled et al. [1] expressed that the pultrusion process was effective in doing so, resulting in a much better bond and better utilization of the filaments to maximize their efficiency and led to improve flexural and tensile performance. Fabric reinforced cement-based composites (FRCC) can be used together with structural elements as overlay of floors, and walls, retrofit components of beams and columns. Some concrete structures or structural elements such as piles, hydraulic structures, airport pavements, military structures, and industrial floors overlays may be subjected to severe impact loads. During such dynamic loads, very high stress rates occur, and a large amount of energy is suddenly transmitted to the structure or structural elements. Structural elements subjected to dynamic loads such as severe strike and explosion should have enough strength, toughness and ductility to maintain integrity without collapse. Low-velocity impact on fiber-reinforced plastics has been the subject of many experimental and analytical investigations performed by Bogdanovich and Friedrich [2], Naik and Sekher [3], Shen [4], and Liu et al. [5]. Lok and Zhao [6] showed that the post-peak ductility of steel fiber reinforced concrete (SFRC) is clearly absent at strain rates exceeding 50 s^{-1}, because fragments can no longer bond onto the steel fibers. Bindiganavile et al. [7] revealed that compact reinforced composites under impact were capable of dissipating much higher energy compared to conventional fiber reinforced concrete with polymeric or steel fiber. Alhozaimy et al. [8] expressed that polypropylene fibers increase the first and failure impact resistance of concrete and the positive interactions between polypropylene fibers and pozzolans leads to enhanced impact resistance of fibrous concrete having pozzolans. Bindiganavile and Bantia [9, 10] illustrated that the flexural strength of fiber reinforced concrete is higher under impact loading than under quasi-static loading. Furthermore they showed that polymeric fibers (with suitable length, geometry and deformations) reinforced concrete may absorb fracture energy very close to that of steel fiber reinforced concrete under impact loading. Choi and Lim [11] showed that the impact response of composite laminates could be easily analyzed by the linearized contact law approach without developing new finite elements method. Banthia et al. [12] expressed that at a given fiber volume fraction, macro-fibers of steel are far more effective in improving the toughness than micro-fibers, but composites with a hybrid combination of macro and micro fibers were the toughest and also fiber reinforced composites were marginally more impact resistant at a higher hammer velocity, but absorbed somewhat diminished amounts of impact energy at a subnormal temperature. Wang et al. [13] reported an increase in the fracture energy of the beams increased depending on the volume of the hooked steel fibres in concrete mixture. Manolis et al. [14] expressed that fibrillated polypropylene fibers significantly improves the impact resistance of concrete slabs without affecting the natural frequency while the static compression and flexural strength decrease with increasing fiber content. Tang and Saadatmanesh [15] revealed that composite laminates significantly increase the capacity of concrete beams to resist impact loading and reduce the maximum deflection and also the shear strength of the beam by preventing widening of cracks. Li et al. [16] investigated static and impact behavior of extruded sheets with short fibers by using polyvinyl alcohol (PVA) and glass fibers. The results of these investigations indicate that glass fibers are more effective in improving the tensile strength and impact properties of specimens, while PVA fibers can greatly increase the tensile strain and toughness of specimens.

Peled and Mobasher [17] studied tensile performances of the pultruded fabric cement based composites using a closed loop control direct tensile tests performed on a MTS testing machine. In this study, the static and impact flexural behavior of polyethylene (PE), and PVA fabric reinforced cement based composites is investigated. The two of them were both woven fabrics.

2 Experimental program

2.1 Material properties and mix design

The mechanical and technical characteristics of PE and PVA fabric are presented in Table 1 and are shown in Fig. 1. The mix design of cement paste for fabric reinforced cement-based composites produced in this study is given in Table 2. The flexural and impact test specimens presented in this paper have

Table 1 Mechanic and technical characteristics of the reinforcing fabrics

Fabric type	Yarn nature	E (MPa)	σ_u (MPa)	Filament size (mm)	Bundle diameter, γ (mm)
PE	Monofilament	1,760	260	0.25	0.25
PVA	Bundle	2,900	1,400	0.025	0.93

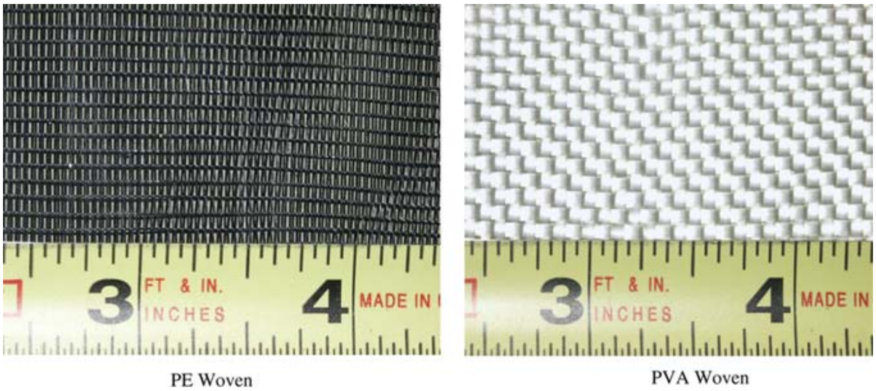


Fig. 1 Fabric types

Table 2 Mix design of cement paste

Material	Weight
Cement	8,159 g
Water	3,263 g
Silica fume	677 g
Super plasticiser	12 ml

same material properties and fabric layers as the composites in [17].

2.2 Pultrusion process

Specimens were produced with the pultrusion process. The fabrics were immersed in a slurry infiltration chamber, and then pulled through a set of rollers to squeeze the paste in the openings of the fabric, and remove excessive paste. Composite laminates were formed on a rotating mandrel. Fabric-cement sheets with width of 200 mm, length of 330 mm and thickness of 10–12 mm were produced. The impact and flexural tests specimens were made of six layers of fabrics, resulting in a reinforcement content of about 6% by volume for the PE and PVA fabrics. Note that the volume fractions reported here were calculated based on the bundle diameter assuming no penetration of the cement matrix between the filaments of the bundle. After forming the sample, pressure was applied on top of the laminates to improve interlaminar bonding and penetration of the matrix in fabric openings. A constant pressure of 15.3 kPa was applied on the surface of the fabric-cement sheet. Most of this pressure was removed 1 h after casting, with only a stress of 1.7 kPa maintained up to 24 h from the pultrusion process and then stored in room environment until testing at the age of 28 days. The panels produced by using PE and PVA fabric were cut to dimensions of 50 × 150 mm and the thickness of these panels was between 10 and 12 mm. The pultrusion process is shown in Fig. 2.

2.3 Experimental test set up and instrumentations

Impact tests were performed to determine the dynamic characteristics of FRCC in Structural Laboratory of Civil Engineering Department at Arizona State University. The schematic of the impact test set up system is presented in Fig. 3a. The proposed test system is based on a free-fall drop of an instrumented hammer on a three point bending specimen. The cement based composite specimens in this study were tested in both vertical and horizontal positions with respect to the directions of applied impact load. The fabrics of composites in the vertical orientation (beam type) were parallel to the direction of load, while in the horizontal specimens the fabrics were perpendicular to the direction of load application (plate type).

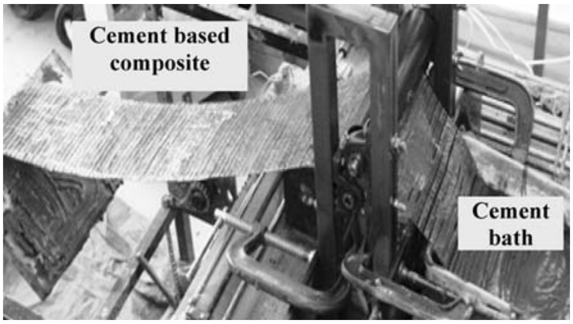
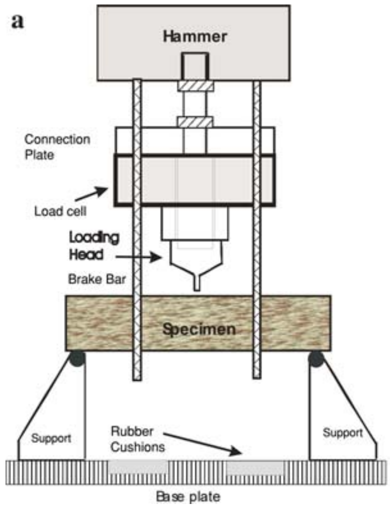


Fig. 2 The view of pultrusion process



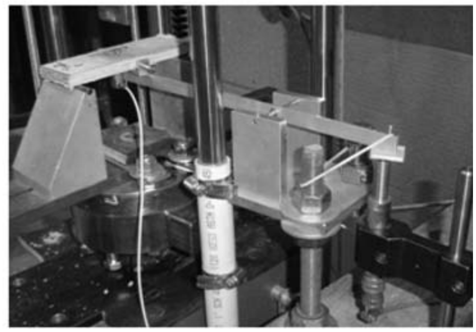


Fig. 3 (**a**) Schematics of the impact test set up. (**b**) Impact test set up with a specimen after the test. The displacement measuring anchor is also shown

The current experimental set-up includes several components listed below. The entire moving part that applies impact to the specimen is referred as the hammer and includes the free weight, frictionless bearing assembly, load cell, connection plate, and the threaded rods all weighing 137 N. The span of FRCC beams was 127 mm for three point flexural impact tests. The impact force was induced by the free fall weight of the hammer assembly that was released by means of an electronic brake-release mechanism from a predetermined drop height varying from 10 to 1,600 mm. After impact, an anti-rebound system held the striker to avoid multiple hits on the specimen. A pneumatic brake system triggered by a contact type switch is used to stop the hammer after the duration of impact is completed. This feature allows sensitive instrumentation to be placed on the specimen with a much reduced chance of damage. The hammer force was measured by means of a load cell with range of 90 kN mounted between hammer and blunt head of the impact head. A linear variable displacement transducer (LVDT) with a range of ±3.17 mm was connected to the tensile fiber of the specimen by means of a lever system.

During the preliminary tests two accelerometers were used to document the acceleration-time histories of the hammer and specimen in the impact test system. One of two accelerometers has a range of ±100*g* and was mounted at the bottom of the specimen; other accelerometer with the range of ±10*g* was placed on the hammer. The data acquisition system consists of an IBM computer, National Instruments PCI acquisition card and LABVIEW VI's with trigger function which can record signals from load cell, accelerometers and the LVDT, simultaneously at a sampling rate up to 100,000 Hz which is fast enough to acquire the whole test, typically lasting for less than 0.2 s. For data processing purpose several Matlab programs have been used to smooth and plot the data and calculate the parameters such as initial stiffness, toughness etc.

Rapid variation of the kinematical quantities excites vibrations depending on the stiffness and mass of both the specimen and the hammer. The interpretation of these signals is complex and often questionable. It is thus mandatory to filter the data.

Several preliminarily simplified experimental modal analysis allowed us to identify the first axial predominant frequency of the hammer and the base plate and consequently to select a low-pass filter with cut-off frequency of 3,000 Hz. All the test data were filtered in order to eliminate various disturbing effects. Figure 4a gives the Fourier amplitude spectra of the hammer by using Fast Fourier Transform (FFT) which shows the frequency content of the acceleration data of a test specimen. The predominant frequency of the hammer is about 5,000 Hz. The predominant frequency of test specimens was also calculated by using the same method. It was found that the predominant frequencies of all specimens were less than 1,000 Hz both in horizontal and in vertical direction.

By varying, the hammer weight and the drop height, a range of loading conditions can be simulated

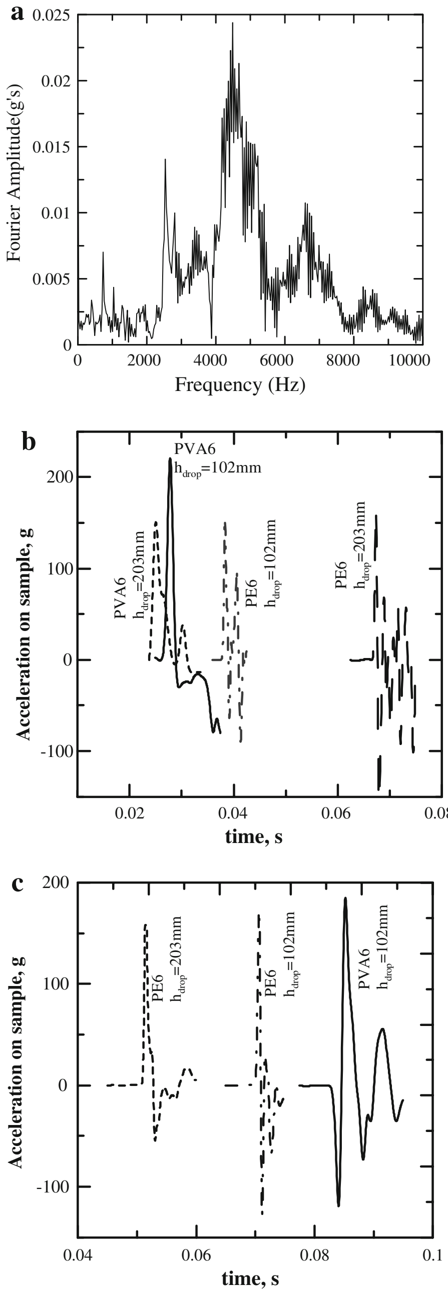


Fig. 4 (**a**) Fourier amplitude spectra of hammer. (**b**) The variations between time and the accelerations measured on horizontal specimens around impact effects. (**c**) The variations between time and the accelerations measured on vertical specimens around impact effects

and by changing the hammer weight and the drop height a range of input energy/impact velocity parameters can be explored. Force versus time variation can be calculated by using the following equation:

$$F(t) = ma(t) = m\frac{\Delta v}{\Delta t} \qquad (1)$$

where $F(t)$ is the force measured by load cell, m is the mass of the hammer and $a(t)$ is the acceleration time history of the hammer and also v is the drop velocity of hammer.

On the other hand, also the force versus time variation is measured by the load cell. The deflections $d(t)$ at the middle of span will be measured by LVDT and also can be calculated by double integrating of accelerations of the specimens. Thus, the absorbed total energy E can be evaluated by using $d(t)$ and $F(t)$ for each specimen, as follows:

$$E = \sum F(t)\Delta d(t) \qquad (2)$$

The absorbed total energy varies the area under load–deflection curve. The total impact energy applied to the specimen is varied depending on the drop height of the hammer, since the mass of the hammer was kept constant during the preliminary tests. The system can be idealized by a single degree of freedom model, the damping of the specimen can be neglected, and then the equation of dynamic equilibrium is

$$ma(t) + F_{\text{specimen}}(t) = F(t) \qquad (3)$$

where $F_{\text{specimen}}(t)$ is the impact force on the specimen.

When the specimen is broken by a single dropping, the measured acceleration is always downward direction (positive), thus the true impact force is always less than the force measured by load cell. If the mass of the specimen is small, it can be assumed that the force measured by the load cell during the impact tests is approximately equal to the impact force ($F_{\text{specimen}}(t)$) on the specimen. Moreover, for horizontal and vertical specimens, Fig. 4b and c indicate that the transient peak accelerations measured on the FRCC specimens vary between -145 and $225g$ during impact according to the different drop heights of hammer. The weights of specimens are around 0.2 kg, according to Newton's second law of motion, when the drop height is 102 mm, the inertial forces of horizontal FRCCs made of PE and PVA fabrics with six layers are about 30 and 45 N, respectively. The inertial forces of specimens made from PE and PVA fabrics are only about 4 and 3.5% of the impact forces

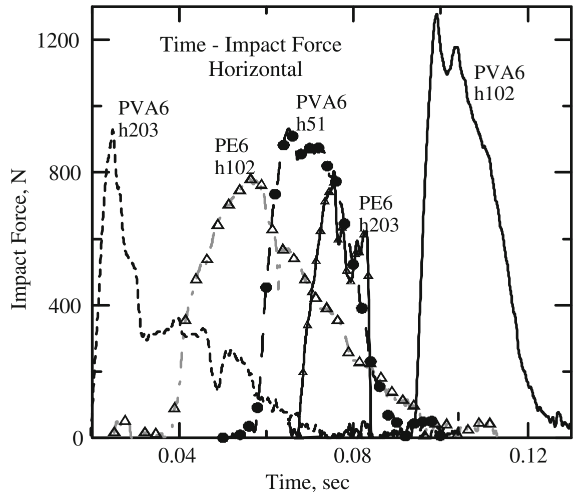


Fig. 5 Time–impact force variation for horizontal fabric-cement paste composites for various drop heights (the number right next to the h)

shown in Fig. 5 and measured by load cell. The inertial forces for vertical FRCCs with PE and PVA fabrics are about 35 and 38 N, respectively. The inertial forces of vertical FRCCs are almost 1% of the impact forces measured by load cell. Because of these results, the inertial forces on the specimens during impact are neglected in this study. If the specimen is broken by the single impact, the flexural energy absorbed by the specimen (defined as the area under the impact load versus deflection curve) is less than the total energy released by the hammer during its fall. The difference between the total energy and the flexural energy absorbed represents the sum of the inertial energy and the kinetic energy of the broken pieces of the specimen. That is, the impact load on the specimen versus the deflection curve should be similar to the load measured by load cell versus the deflection curve. This is because the inertial and kinetic energies transferred to the specimen while it was being accelerated were gradually released back to the system as the specimen returned to be stable.

3 Discussion of test results

The experimental parameters of the study and their effects on the experimental results are explained in the sub-headlines. The test results of the cement based composites with PE and PVA fabrics are presented on the evaluations of the horizontal FRCC specimens (the variations of maximum stress and absorbed energy amounts, initial stiffness versus the drop heights of the hammer).

3.1 Effects of drop heights

The impact force was directly induced by dropping weight (138 N) from a certain drop height and was measured by means of load cell having a range of 90 kN. At the same drop heights of hammer, the FRCC with PVA fabrics withstood higher impact loads than the composites made of PE fabrics. It was seen that the impact forces carried by FRCC specimens increased as the drop height of hammer increased until the drop height of 102 mm (see Figs. 5a, b and 6a, b). For the drop height of 203 mm, FRCC specimens had wider cracks and carried less impact loads than the specimens at the drop height of 102 mm. It can be assumed that FRCC specimens subjected to impact loads begin to display plastic behavior at the drop heights over 102 mm. The impact loads that the horizontal composites with PE fabrics carried at the drop heights of 102 and 203 mm were pretty close to each other (see Fig. 5b). The impact load that FRCC specimens with PVA fabric carried at the drop height of 203 mm was 25% less than impact load at the drop height of 102 mm. According to these results, the hammer drop height of 102 mm can be defined as the critical drop height for all of specimens in this study. Evaluation of the test results show that vertical FRCC specimens are similar to the former evaluations presented for horizontal specimens (see Fig. 6a and b).

The deflection–stress variations are shown for both horizontal and vertical specimens in Figs. 7 and 8, respectively. It shows that the horizontal FRCC specimens have higher deflections and flexural impact stress than vertical ones. These figures indicate that FRCC for each fabric type has the highest stress at the hammer drop height of 102 mm. After this critical drop height of the hammer, both the flexural impact stress of the vertical FRCC specimens and flexural impact stress in the horizontal FRCC specimens sharply decrease gradually.

3.2 Effect of fabric type

The effect of the fabric type on the impact behavior of FRCCs under impact and static loads has been

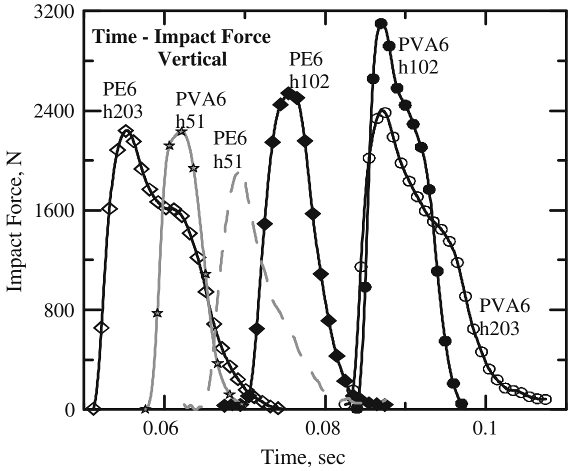


Fig. 6 Time–impact force variation for vertical fabric-cement paste composites for various drop heights (the number right next to the h)

studied from view point of strength and ductility. For each drop height levels of the hammer, Figs. 7–10 together with Tables 3–5 indicate that the FRCCs having PVA fabric withstand higher stress levels. Moreover, it is seen that the composites made of PE fabric display more ductile behavior than the composites with PVA fabrics. In other words, the ultimate deflection capacity of FRCCs produced using PE is larger than the one of the FRCCs with PVA fabric at the same category (i.e. drop height levels of the hammer and orientation of specimens). FRCCs made from PVA fabrics have the highest impact flexural stress responses to impact loads among the all test specimens for the same drop heights of hammer. In additional to these results, the initial stiffness of the composites with PVA fabrics under impact loads sharply increase as the drop height of hammer increase until the drop height of 102 mm and are

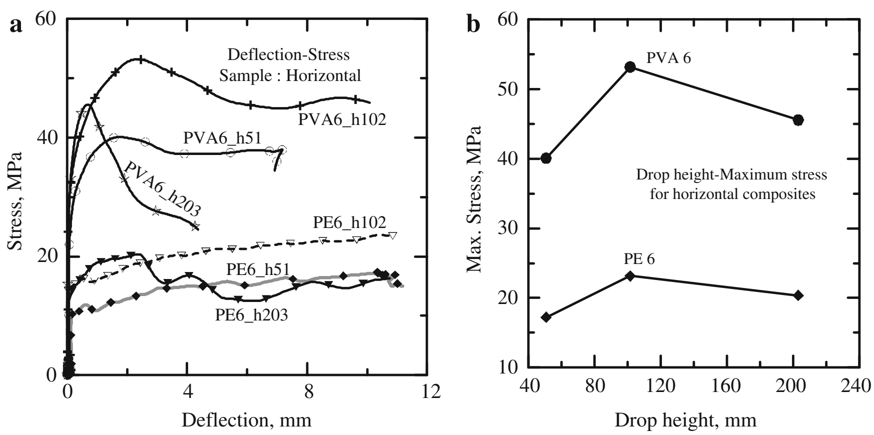


Fig. 7 (**a**) Deflection–stress variation for horizontal fabric-cement paste composites for various drop heights. (**b**) Drop height–maximum stress variation of horizontal fabric-cement paste composites under impact loads

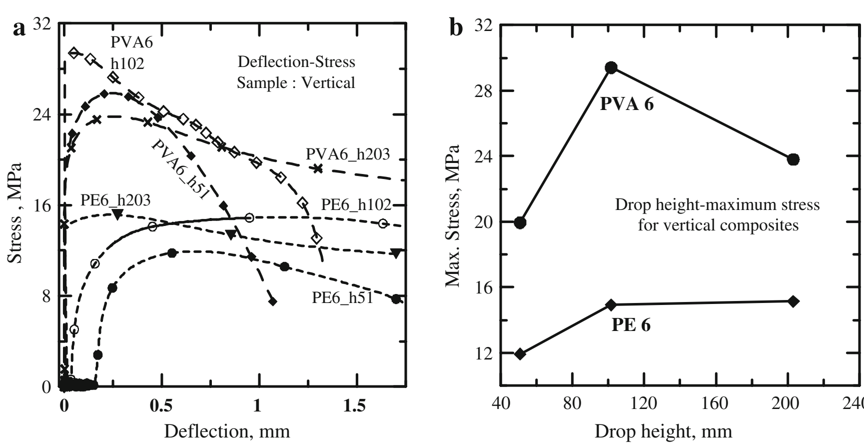


Fig. 8 (**a**) Deflection–stress variation for vertical fabric-cement paste composites for various drop heights. (**b**) Drop height–maximum stress variation of vertical fabric-cement paste composites under impact loads

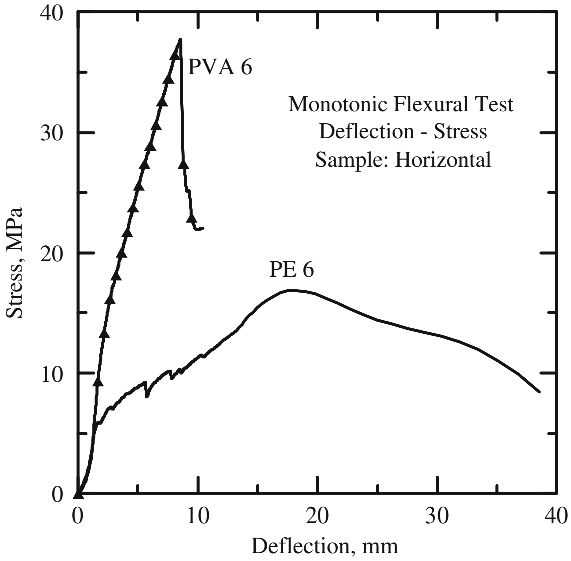


Fig. 9 Deflection–stress variation of horizontal fabric-cement paste composites under monotonic flexural loads applied in three point bending tests

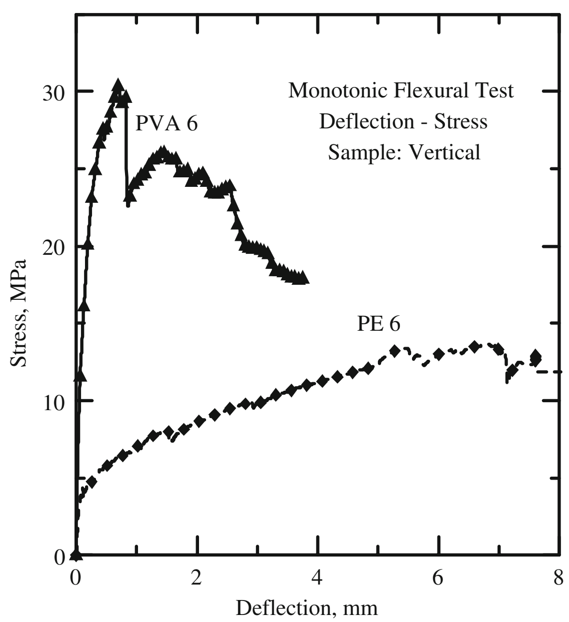


Fig. 10 Deflection–stress variation of vertical fabric-cement paste composites under monotonic flexural loads applied in three point bending tests

more larger than the ones of the composites with PE fabrics for all categories.

The results obtained in this study indicate that the PVA fabric had better bond with cement paste and also was more effective and than PE fabric on the impact behavior of FRCCs. Cement based composites with PVA fabrics had much higher impact strength than FRCCs with PE fabrics. Peled and Mobasher [17] suggest that the reasons of these differences in behavior between FRCCs made from the PE and the PVA specimens are associated with the differences in the structure of the yarns which make up the fabrics and the difference can be explained as follows:

- When a bundled knit fabric (PVA) is passed through a cement bath during the pultrusion process, the intensive impregnation process helps to fill the spaces between the filaments of the bundled yarns as well as the loops of the stitches, leading to improved bonding and enhanced mechanical performance.
- A PE woven fabric is made from monofilament yarn where the cement can only penetrate in between the openings of the fabric and does not have enough room to force the paste matrix in between the filaments and no improved penetration of the matrix is required. Therefore, the pultrusion process does not lead to significant influence on the mechanical performance of the PE.

3.3 Monotonic flexural tests for three point bending

The composite specimens of 10 mm × 50 mm × 150 mm and 10 mm × 25 mm × 150 mm were horizontally and vertically placed on the supports for three point bending tests, respectively. Three composite specimens were tested for each category. The displacement controlled vertical load was applied to the specimens at the mid-span by means of MTS Hydraulic Systems having a capacity of 90 kN. The deflections were measured using a LVDT with a range of ±2.54 mm. The deflection rate of monotonic flexural tests was 5 mm per minute. The deflection–stress variations of the composite specimens are presented in Figs. 9 and 10 for horizontal and vertical positions of specimens, respectively. For the horizontal positioned specimens, it is seen that the composites with PVA fabric have 1.26 and 2.70 times more flexural strength than ones with PE fabrics, respectively (Fig. 9 and Table 3). Figure 10 and Table 3 indicates that the

Table 3 The mechanical properties of FRCC specimens under the monotonic flexural loads

Fabric type in FRCC	Horizontal				Vertical			
	Toughness (N mm)	Stiff. (N/mm)	σ_{max} (Mpa)	δ_{max} (mm)	Toughness (N mm)	Stiff. (N/mm)	σ_{max} (Mpa)	δ_{max} (mm)
PVA	3,595	534	37.71	5.56	2,205	1677	32.34	3.06
PE	1,102	644	14.05	7.07	3,051	751	13.67	8.03

Table 4 The experimental results of horizontal FRCC specimens under impact loads

Fabric type in FRCC	H_{drop} = 51 mm			H_{drop} = 102 mm			H_{drop} = 203 mm		
	Stiff. (N/mm)	σ_{max} (MPa)	Absrb.En (N mm)	Stiff. (N/mm)	σ_{max} (MPa)	Absrb.En (N mm)	Stiff. (N/mm)	σ_{max} (MPa)	Absrb.En (N mm)
PVA	128,000	53.03	2,902	291,300	54.6	2,480	182,800	45.97	2,811
PE	24,000	22.79	2,441	34,400	30.04	5,833	90,500	30.77	10,200

Table 5 The experimental results of vertical FRCC specimens under impact loads

Fabric type in FRCC	H_{drop} = 51 mm			H_{drop} = 102 mm			H_{drop} = 203 mm		
	Stiff. (N/mm)	σ_{max} (MPa)	Absrb.En (N mm)	Stiff. (N/mm)	σ_{max} (MPa)	Absrb.En (N mm)	Stiff. (N/mm)	σ_{max} (MPa)	Absrb.En (N mm)
PVA	4,650	41.43	5,482	19,500	65.59	10,340	1,7800	40.09	6,005
PE	3,250	17.65	5,415	2,171	27.16	9,685	1,553	20.72	7,462

flexural strength of the vertical positioned FRCC with PVA fabric is 2.36 times larger than FRCC with PE fabric, respectively. These results yielded that PVA fabric is more effective than PE fabric on the flexural behavior of composites.

3.4 Energy amounts absorbed by the fabric-cement paste composites under impact loads

Absorbed energy amount is one of the important parameters to evaluate the mechanic properties of FRCC specimens under the impact loads. The energy amount absorbed by composite specimens subjected to impact loads was evaluated as area under impact load–deflection curve. The input energy is of prime importance and depends on the drop height of the hammer and the total mass of the hammer. The input energy amounts were varied as the drop height of hammer was changed by keeping the total mass of hammer to be constant for all tests. Some of the input energy is absorbed by the test specimen and the remaining input energy is transferred to the test set up by through the supports of specimen. The ratio of the absorbed energy amount to the initial energy was determined for each drop height of hammer, each type of fabric used in specimens, and positions of specimens. The variations of these ratios and the absorbed energy amounts of the specimens with respect to the drop height of hammer are shown in Figs. 11 and 12 for the horizontal and vertical specimens, respectively. Although the composites with PVA fabric carried higher impact loads than FRCC specimens with PE fabric, the absorbed energy amounts of the vertical FRCCs with PVA fabric are the lowest among the specimens for the same drop height levels of the hammer and have nearly same the value for all drop heights. The reason of this result can be denoted that the vertical FRCC specimens with PVA fabric display less deflection as well and exhibit stiffer behavior than the other composite specimens. Moreover, the vertical composites made of PE fabric absorbed more energy than the composites made from PVA fabrics, although the composites with PE fabrics carry less impact loads than composite specimens with PVA fabrics. These results indicate that the vertical FRCCs with PE fabric

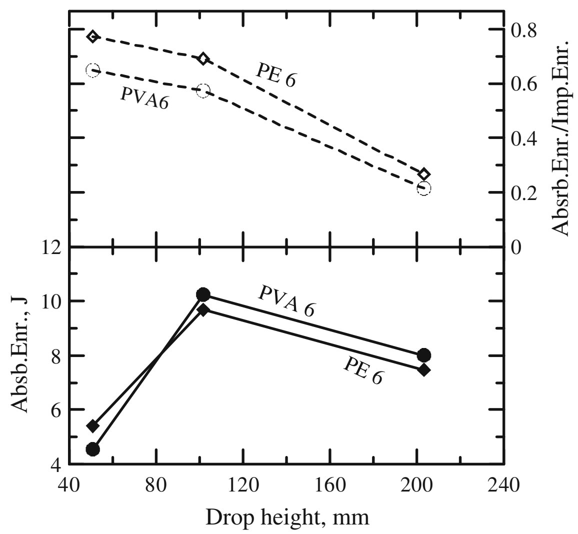


Fig. 11 Variation of drop height-ratio of the absorbed energy to the potential energy and absorbed energy amounts for horizontal composites specimens

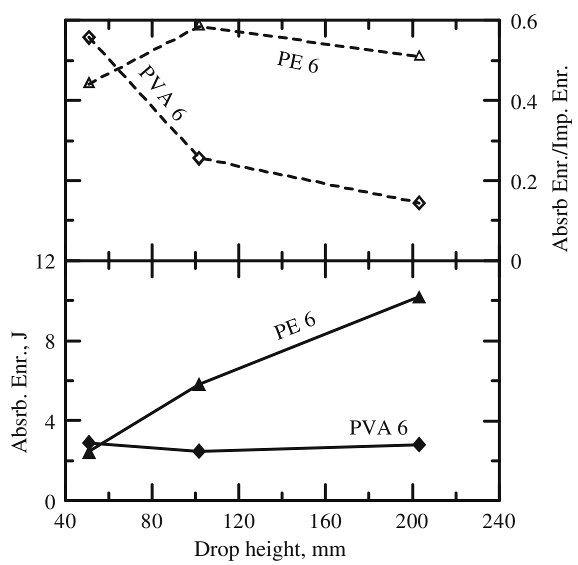


Fig. 12 Variation of drop height-ratio of the absorbed energy to the potential energy and absorbed energy amounts for vertical composites specimens

display more ductile behavior and have larger ultimate deflection capacity than the composites with PVA fabrics. The absorbed energy amounts of the horizontal FRCC with PE fabric are similar to the ones of the horizontal FRCC with PVA fabrics for various drop heights.

3.5 Initial stiffness of cement based composites under impact loads

The initial stiffness of cement based composites is obtained as the initial slope of the impact load-deflection curve under the impact loads for each drop height and positions of the specimens on the support. The variations of initial stiffness versus drop height are shown in Figs. 13 and 14 and Tables 4 and 5 for horizontal and vertical FRCCs, respectively. Figure 13 indicates that the initial stiffness of the horizontal FRCCs with PVA fabrics continuously increase as drop height increase contrary to the horizontal FRCCs with PE fabric. It shows a sharp increase at the drop height over 102 mm. It is seen that the vertical FRCCs with PVA fabric are far stiffer than ones with PE fabrics. These results yielded that the type of fabric is quite effective on the flexural impact behavior and the rigidity of FRCCs.

3.6 Positions of the specimens

The horizontal FRCCs with PVA and PE fabrics were tested for three different drop heights. For the impact loads, Figs. 7b and 8b indicate that the horizontal FRCCs have higher stress than vertical specimens. The difference of the cross sectional area between horizontal and vertical specimens is probably the main cause of the result above. Figures 9 and 10

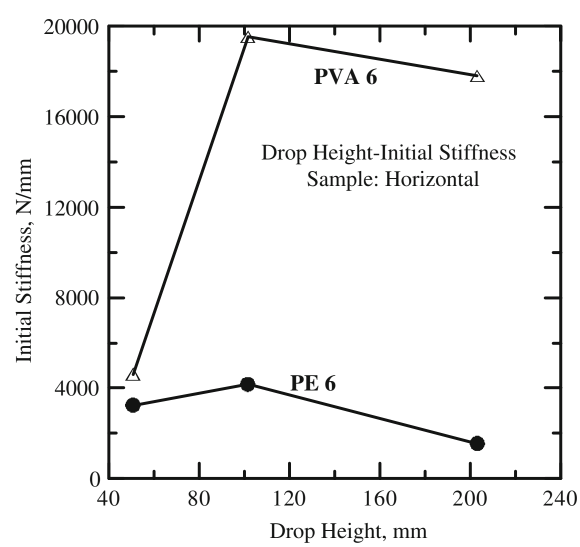


Fig. 13 Drop height–initial stiffness variation for horizontal fabric-cement paste composites

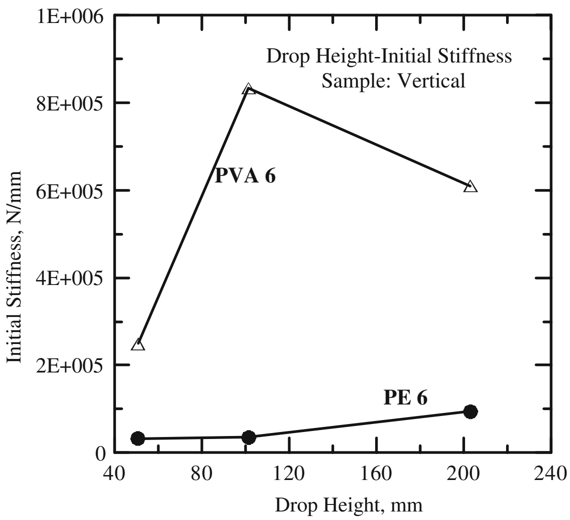


Fig. 14 Drop height–initial stiffness variation for vertical fabric-cement paste composites

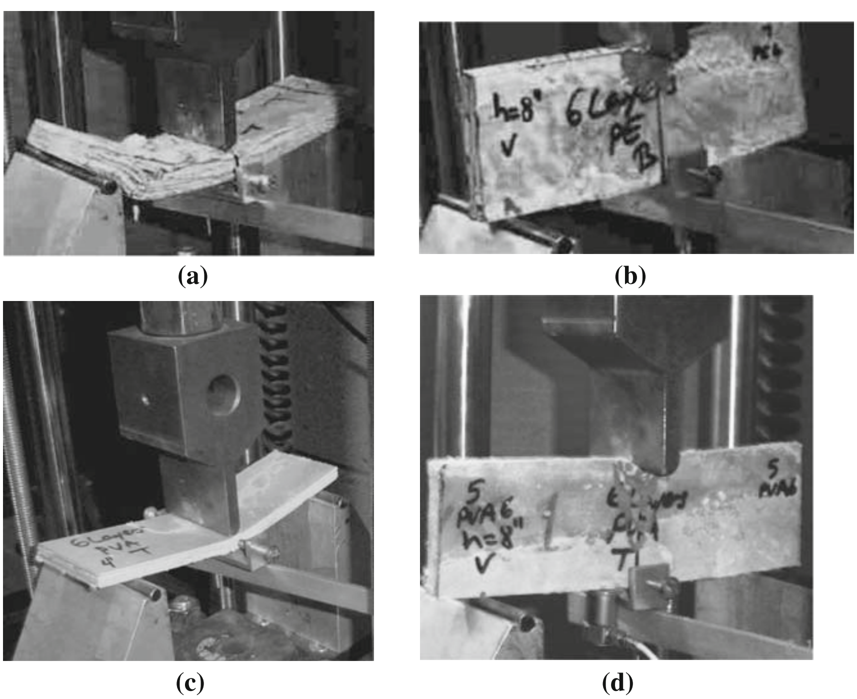
show that the effects of the positions of FRCC specimens subjected to the monotonic loads on the flexural strength are similar to the results obtained for the impact loadings. Figures 13 and 14 indicate that the initial stiffness of the vertical FRCC specimens is significantly higher than those of the horizontal specimens. The initial stiffness of vertical composites with PE fabrics continuously increases as the drop height increases. Whereas, the initial stiffness of the horizontal FRCC specimens with PE fabric decreases contrary to the vertical specimens as the drop heights of hammer increase. Moreover, the initial stiffness of the horizontal FRCC with PVA fabric more sharply increases than ones of vertical composites PVA fabrics until the drop height of 102 mm. These results show that the vertical FRCC specimens have larger impact loads capacity and less deflection. Consequently, the vertical FRCC specimens extremely higher initial stiffness than horizontal ones. All of the test results are summarized and given in Tables 3–5.

Furthermore, it was observed that the horizontal composites have flexural crack patterns while the vertical composites have crack patterns similar to ones of deep beams subjected to bending (see Fig. 15a–d).

4 Conclusions

The FRCC specimens produced with various fabric types were tested under the both impact loads (for three different drop heights) and static monotonic loads. The test results are evaluated to determine the

Fig. 15 (**a–d**) The views of damages on the FRCC specimens after impact loads. (**a**) Horizontal FRCC with PE 6 for drop height of 203 mm; (**b**) vertical FRCC with PE 6 for drop height of 203 mm; (**c**) horizontal FRCC with PVA 6 for drop height of 102 mm; (**d**) vertical FRCC with PVA 6 for drop height of 203 mm



effect of fabric type on the behavior of the specimens under dynamic and static loads by considering the impact and static flexural strength, the ultimate deflections, and the damage propagations of the specimens. The results can be summarized as follows:

a. It can be seen that the impact strengths in flexure for horizontal FRCC specimens made of PVA and PE fabric are almost 42 and 35% higher than their flexural strengths under the static loads, respectively, when the Fig. 7a and b are compared with the Fig. 9. However, for vertical FRCC specimens, the Figs. 8a–b and 10 indicate that the impact strengths in flexure are almost equal to their flexural strengths under static loads.
b. Although the vertical composite specimens with PVA fabric had much larger flexural strength and initial stiffness than ones with PE fabric under the impact flexural loads, the vertical composite specimens made of PE fabric could absorb higher energy than the composites with PVA fabric. These results indicate that the vertical FRCCs with PE fabric display more ductile behavior and have larger ultimate deflection capacity than the composites with PVA fabrics. However, these differences in behavior between the PE and PVA are associated with the differences in the structure of the yarns which make up the fabrics and in the bond force between cement paste and fabric.
c. The PE woven fabric is made from monofilament yarn where the cement can only penetrate in between the openings of the fabric, and no improved penetration of the matrix is required. Consequently, the FRCC specimens with PE fabric carry significantly less the impact and monotonic flexural loads than the ones with PVA fabrics and even the pultrusion process does not lead to a significant influence on the mechanical performance of the PE.
d. After the impact and monotonic flexural tests, the cement paste was easily seperated from PE fabric because the cement paste colud not sufficiently penetrate in between the openings of PE fabric. For this reason, it was seen that bond between PVA fabric and cement paste was stronger than bond force between PE fabric and cement paste. This property of FRCC specimens with PVA fabric yields a performance better than that of FRCC with PE fabrics.

In view of the above discussion, it can be concluded that the type and the structure of fabric used in the FRCCs is highly effective and these composites can increase the strength of structural elements subjected to flexural impact loads.

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