Wave velocity characteristic for Kenaf natural fibre under impact damage

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Abstract. This paper aims to determining the wave velocity characteristics for kenaf fibre reinforced composite (KFC) and it includes both experimental and simulation results. Lead zirconate titanate (PZT) sensor were proposed to be positioned to corresponding locations on the panel. In order to demonstrate the wave velocity, an impacts was introduced onto the panel. It is based on a classical sensor triangulation methodology, combines with experimental strain wave velocity analysis. Then the simulation was designed to replicate panel used in the experimental impacts test. This simulation was carried out using ABAQUS. It was shown that the wave velocity propagates faster in the finite element simulation. Although the experimental strain wave velocity and finite element simulation results do not match exactly, the shape of both waves is similar.

1. Introduction

In recent years, there has been an environmental awareness focused the attention to use the natural fibres as reinforcements for the polymeric matrix due to the environmental advantages. Global warming have initiated a considerable interest in using natural materials to produce green products and reduce carbon dioxide emissions. So far studies on the properties of natural fibres based composites have been the subject of a large number of papers and reviews, especially during the last decade [1-3]. The use of composite materials in structural components has increased significantly in recent years by offering potential benefits to the aerospace, automotive and marine industry. Despite the potential of natural fibres, a special consideration is required on impact problems of natural fibre composites since these material are brittle under dynamic loading particularly impact loading. The presence of this sort of problem can severely degrade the mechanical properties of composite structures, and if it is not detected in the incipient stage, it may result in a catastrophic failure of the structure. Therefore, numerous experiments and simulation have been developed to better understand the mechanisms and mechanics of impact damage in composite materials [4-8].

Recent investigation has demonstrated the use of sensor technologies in impact damage detection. Here, sensors are employed to monitor the impact strain data. The energy of impacts is estimated, which could provide substantial information related to impact severity. When these natural excitations are used instead of active excitations, the complexity of a deployed system decreases substantially by using passive only sensors and data systems that listening to the structure during operation. The data collected can be the processed using a number of methods.

Wildy et al. [9] investigated the the development of a new passive technique of on-line damage detection based on the most fundamental concept which is called strain compatibility. The development of this technique are implemented for a few typical situations of the development of crack damage in plates such as notch, edge crack and point force. It was found that, the techniques can determine a violation of these equations for a localized area, indicating the presence of cracks, voids and other types of damage in the vicinity of the cluster.

Nemat et al. [10], performed an experimental and numerical studied to characterize the acoustic wave propagation in thin glass/epoxy composites plates. Signal processing algorithms and a passive damage diagnosis system based on AE techniques were proposed for continuously monitoring and assessing the structural health of composite laminates. It can be concluded that the measured velocity agrees well with the theoretical calculation as well as the experimental measurements.

Staszewski et al. [11] and Mahzan et al. [12], have demonstrated the feasibility of manipulating the stress wave for passive damage detection approach. The results indicated that different materials produced different wave propagations depending on the configuration of the composites. Tippman et al. [13] demonstrated the ability of damage detection and localization using passively reconstructed impulse response function. The results from experiments conducted on an aluminium plate and wind turbine blade were validated with simulated damage results. It was found that the results show a promising method that can detect damage by monitoring the reciprocity of the impulse response functions.

Although a lot of researcher have investigated about the natural fibre and damage detection, however, very limited findings have been reported available for information and data dealing with the impact damage for natural fibre reinforced composite. Hence the aim of this paper is to investigate the behaviour of wave velocity characteristic in kenaf fibre composite during impact events. The impact events on the KFC eventually initiate the strain data, substantial for wave velocity characteristic. Then the simulation is developed and implemented into finite element (FE) package ABAQUS/Explicit. The impact process is simulated by FE and the wave velocity characteristic results are compared with the experiments.

2. Wave Velocity Characteristics

Theoretically, during an impact event, the structure is deflected and produced strain waves that propagate outwards in all possible directions. For an isotropic material, it is expected that the wave propagation is identical in all possible direction. However, for a natural fibre reinforced composite, that categorized as an anisotropic material, the wave propagation is unknown. However, the wave velocity characteristics can be estimated a priori for monitored composite structures using experimental analysis for all possible angles of wave propagation.

Figure 1 demonstrates the schematic arrangement for modified multilateration procedure, as reviewed in Staszewski et al. [11] and Mahzan et al. [12]. Three different sensors, e.g. P_1, P_2 and P_3 were used to ‘sense’ the strain wave resulted from an impact event. Three different angles, e.g. α_1, α_2 and α_3 have been randomly selected for wave propagation directions. For every transducer P_i and assumed wave propagation angle, the distance d_i between the transducer and impact position can be calculated as

$$d_i = v_i t_i \quad (i = 1, 2, 3) \tag{1}$$

Where t_i and v_i are arrival times and velocities of the propagating strain waves, respectively. The arrival times can be estimated from the experimental strain data for all transducers.

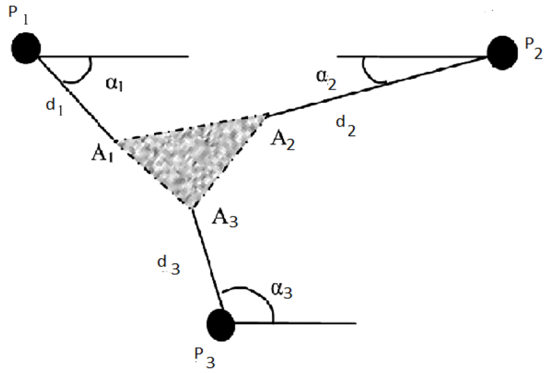


Figure 1. Schematic sensor arrangement of modified triangulation for wave propagation direction procedure [11]

3. Methodology

3.1 Sample preparation

The investigation employs the chopped kenaf fibres as the natural fibre and the epoxy as the resin matrix. The dimensions of the KFC panel were 300 mm (L) ×300 mm (W) and 3 mm thickness. The composites with fibre loading 10% of volume fraction were fabricated using compression technique. The internal surfaces of the mould were sprayed by a release agent in order to facilitate easy removal from the mould. Initially, epoxy resin and hardener were mixed together with ratio 2:1 to form a matrix. Then the chopped kenaf fibres and matrix was mixed together using a mixer for 10-20 minute to disperse fibres in the matrix. The mixture was poured into the mould and closed before manual compression took place. The sample was left to cure for about 24 hours at room temperature. Finally the panel was taken out of the mould and post-cured in the air for another 24 hours.

3.2 Experimental set up

The test performed was the experimental analysis of passive impact strain waves in the KFC panel. The objective was to obtain wave velocity characteristics based on the modified triangulation procedure, prescribed in Figure 2. An impact hammer, as used for modal testing, was applied to produce impacts on the KFC plate. The experiments were conducted on a laboratory, where the plate was positioned on foam without any mechanical constraints.

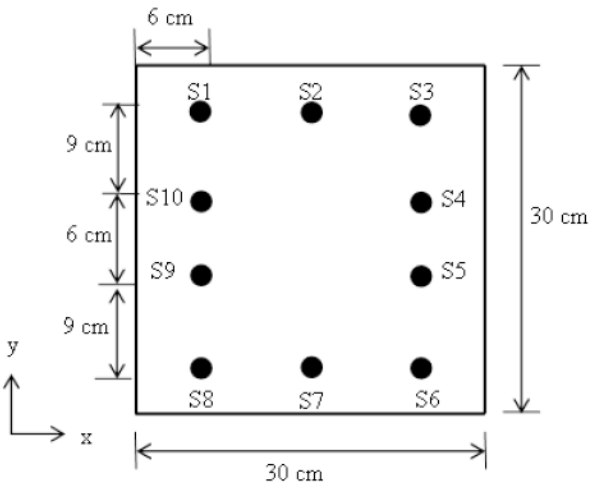


Figure 2. Schematic diagram for sensor placement on the KFC panel

4. Finite element model and analysis

The finite element model was built in ABAQUS/Explicit. The model is develop for a simple three-dimensional model of an impactor impacting a KFC panel. In this model the impactor is dropped onto the panel, as illustrated in Figure 3. The objective of this investigation is to model/replicate simulation from the experimental work. The material is modeled using certain assumptions such as the material property for all the constituents are attributed as isotropic material for both volumes. The assumptions used for this work have been gathered by the literature [14-16].

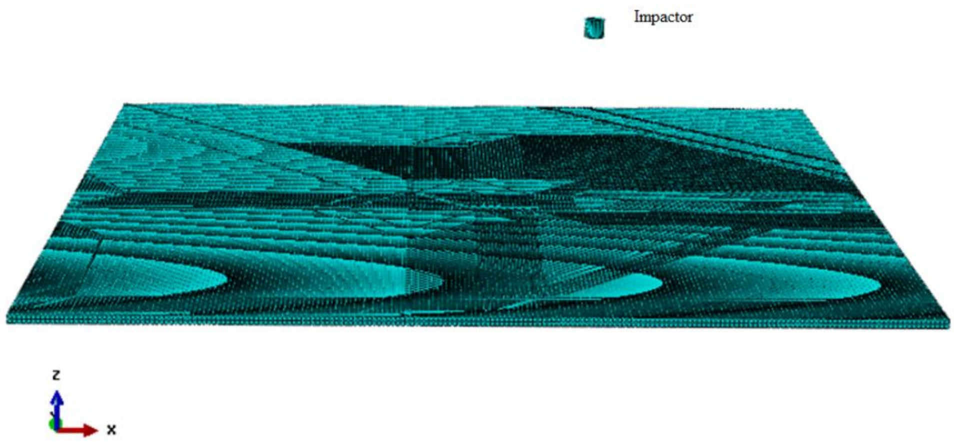


Figure 3. FE impact modelling of the KFC panel

4.1 Material and Element Selection

The impactor is a cyclindrical of 17.4 mm diameter and the target is a rectangular KFC panel of 300 mm × 300 mm × 3 mm. The material properties for KFC panel are given in Table 1. The composite panel was fabricated with kenaf fibres reinforcing an epoxy resin matrix. Due to undeformable of impactor during experimental testing, the impactor projectiles mechanical properties for finite element simulation is not determined and are considered as rigid body. All the properties of the materials for simulation were obtained from the experimental data.

Table 1. Material properties of the KFC panel

Physical Properties	KFC panel
Young Modulus (GPa)	E=2.46
Yield stress (MPa)	28.32
Poisson’s ratio	0.25
Density (kg/m^3)	1400

The KFC panel was used as a deformable solid using elements C3D8R with ‘reduce integration’, while the projectile was modelled as an analytical rigid body using four node bilinear quadrilateral elements (R3D4). This is due to the undeformable of projectile structure during experimental testing. The KFC panel was uniformly meshed with rectangular elements.

4.2 Boundary and Loading Conditions

The square KFC panel, was simply supported at each corner, as illustrated in Figure 4. The displacements of these four corner nodes were restricted only in the z-direction, in order to create a similar condition to a free boundary condition. The projectile nose tip was assigned with a reference point (RP) moving only in the z-direction and assumed to have no rotation during impact. The initial position of the projectile was such that the projectile would only travel to impact the KFC panel. Overall the boundary conditions are also kept the same throughout all the experiments. The impact of a projectile with a mass of 2.9g on a target was then simulated. The initial impact velocity was chosen from the velocity value of which is close to the experiments work.

The thickness of the elements was equal to the thickness of the panel 3 mm. An adaptive mesh which is consists the most refined mesh was applied to the models in the impact areas. Using adaptive mesh will help to avoid error termination of the program due to excessive distortion occurred within the elements.

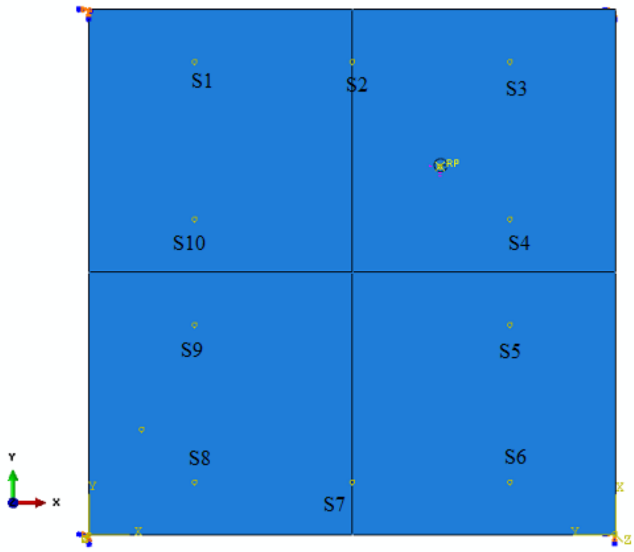


Figure 4. Boundary condition

5. Results and Discussion

A low-energy impacts were performed at the position of the panel (X=200 mm, Y=210.5). The amplitude and its arrival time, *ta*, were analysed for each impact events. All the related data such as strain data, energy, velocity, displacement were recorded each time for further analysis. Figure 5 depicts an example of the strain wave recorded for sensor 1.

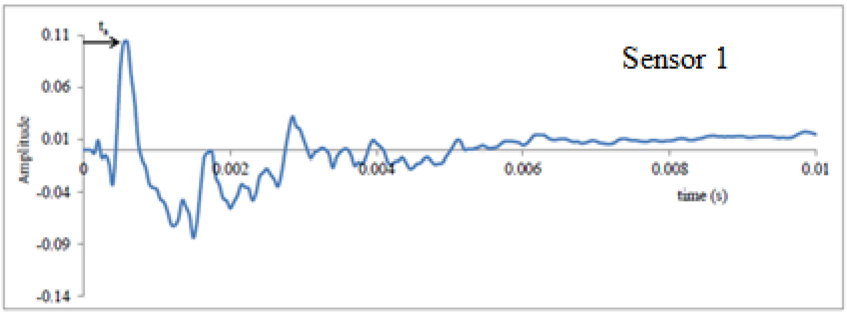


Figure 5. An example of a strain wave measurement obtained from FE model

Figure 6 shows the arrival time as a function of the distance between impact position and sensor location. The arrival time increase linearly with the impact position. The time of arrival is almost found similar for all the sensors but the maximum amplitudes are different. The near the sensor with the impact location the fastest arrival time and the higher amplitude. This is due to the fact that the energy of a strain wave decays as it propagates away from the source of impact. So it will take a longer time for the far impact position.

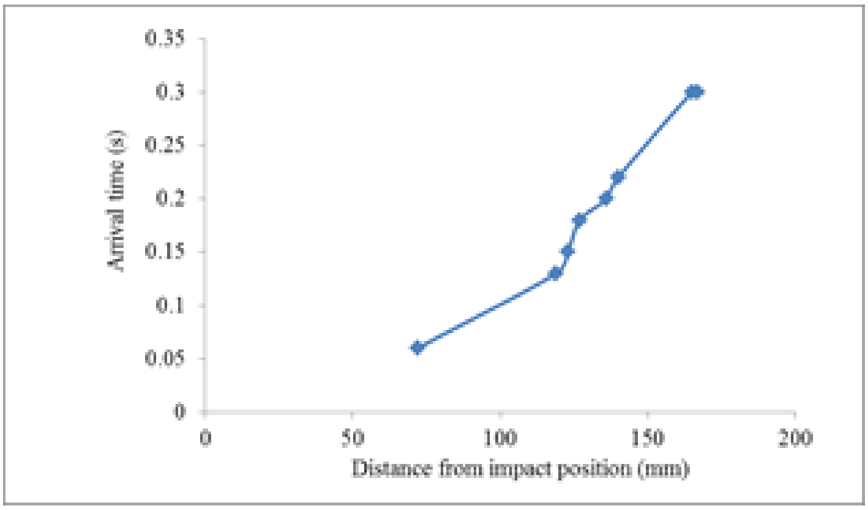


Figure 6. Arrival time versus wave propagation distance

For known distances between impact point and sensor positions, the wave velocity can be calculated, provided the arrival time was estimated. The time of arrival was estimated at the time which first maximum amplitude was obtained. The strain wave velocities were also analysed for various angles of wave propagation in FE. The results, presented in Figure 7, demonstrate that the wave velocity changes linearly from approximately 0.3 m/s for 0^{o} to 45^{o} and decreased nonlinearly to the value 0.04 for 180^{o}.

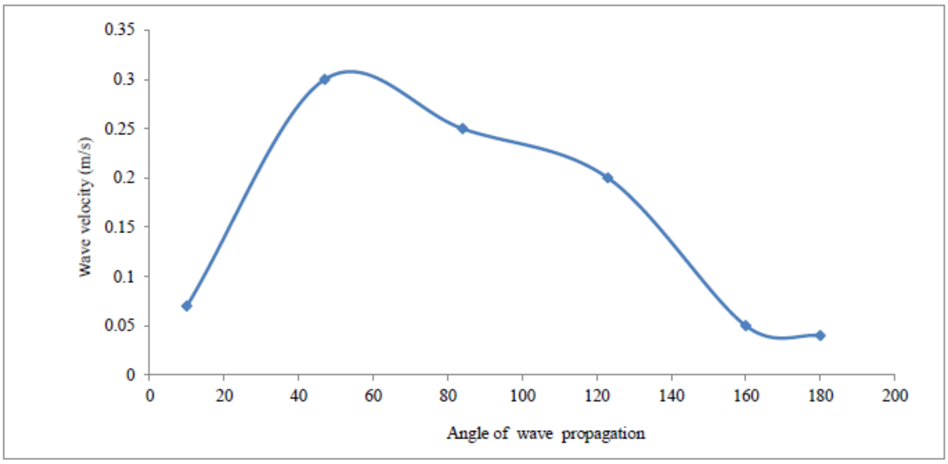


Figure 7. Wave velocity versus angle of wave propagation

Then, the amplitude normalisation was performed to match FE displacement amplitudes with experimental voltage levels of the analysed strain waves. A zero-mean type of normalisation was used in this measurement. By using this type of normalisation, the mean of the transformed set of data points is reduced to zero. The calculation of data normalisation is as follow

$$\hat{x}_i = \frac{x_i - \mu_i}{\sigma_i} \tag{2}$$

Where $\hat{x}_i$ is the normalised data, x_i is the i-th component of the original data, μ_i and σ_i are the mean and standard deviation of the original data respectively.

Figure 8 show the wave velocity characteristics comparison between experimental and FE for KFC. Although the experimental strain waves and FE modeling results do not match exactly, the shape of both waves is similar. The FE strain waves propagate faster than the experimentally measured strain waves. This is acceptable for this research work due to the boundary conditions applied to the KFC panel in the FE model could be different from those actually occurring in the experimental case. The difference between the experimental and simulation wave velocity characteristics was calculated as Mean Square Error (MSE) function. The MSE was defined as

$$MSE(u) = \frac{100}{N\sigma_{\upsilon}^2} \sum_{i=1}^{N} (\upsilon_i - \hat{\upsilon}_i)^2 \tag{3}$$

Where υ_i is estimated velocity value from experimental, $\hat{\upsilon}_i$ is the simulated velocity value, σ_{υ}^2 is the standard deviation of the estimated velocity data from experimental and N is the number of experimental velocity estimated. The MSE value for the result is 10.17 %.

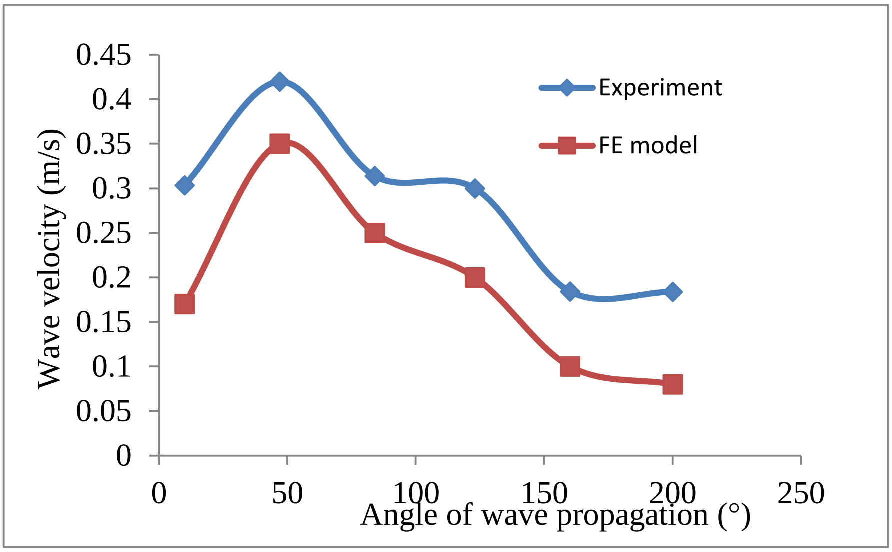
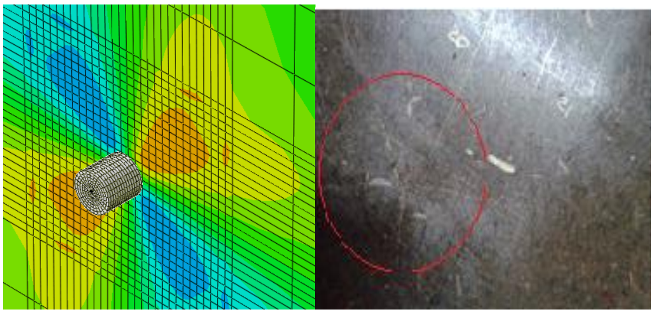


Figure 8. Strain wave velocity characteristics – comparison between the FE and experimental results

While Figure 9 (a) depicts the example of damage image from experimental work and Figure 9 (b) shows FE simulation for impact force 600N. The pattern of the damage almost same. Since the size of damage cannot be evaluated in the FE, so the comparison is just through the pattern of the damage only.



(a) Experimental (b) FE simulation

Figure 9. Example of damage image obtained from experimental and FE simulation

CONCLUSIONS

The wave velocity characteristics for a KFC has been developed using experimental impact strain data and ABAQUS simulated data. The pattern of the wave propagation of experimental and simulation agreed well with the different less than 11%. Although a classical sensor triangulation method offer a good solution but different natural fibre may produce different wave propagation depending on the configuration of the fibres. Therefore, further investigation is needed such as using different type of fibre and different type of fibre orientation in order to establish these methods. To date, only an experimental study of damage severity for chopped fibre has currently been conducted.

Acknowledgements

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References

[1] Karnani R, Krishnan. M and Ramani N 1997 Biofiber-Reinforced Polypropylene Composites. *Polymer Engineering and Science,* **37(2)** 475
[2] Faruk. O, Andrzej K.B,Fink H.P and Sain M 2012 Biocomposites reinforced with natural fibers: 2000–2010. *Progress in Polymer Science.* **37** 1552
[3] Saba N, Jawaid M, Hakeem K R , Paridah M T , Khalina A and Alothman O Y 2015 Potential of bioenergy production from industrial kenaf (Hibiscus cannabinus L.) based on Malaysian perspective, *Renewable and Sustainable Energy Reviews*. **42** 446
[4] Chang F H, Choi Y, Stanford L and Jeng S T 1990 Study on Impact Damage in Laminated Composites, *Mechanics of Materials.* **10** 83
[5] Sung D, Kim C and C. Hong 2002 Monitoring of Impact Damages in Composite Laminates using Wavelet Transform*, Science.* **33** 35
[6] Kim I G 2005 Impact Damage Detection in Composite Laminates Using PVDF and PZT Sensor Signals, *Journal of Intelligent Material Systems and Structures*. **16** 1007
[7] Aktas M, Atas C, Icten B and Karakuzu R 2009 An Experimental Investigation of the Impact Response of Composite Laminates, *Composite Structures*. **87** 307
[8] Aymerich F and Staszewski W J 2010 Impact Damage Detection in Composite Laminates using Nonlinear Acoustics, *Composites Part A: Applied Science and Manufacturing*, **41** 1084
[9] Wildy S J, Kotousov A G and Codrington J D 2008 A new passive defect detection technique based on the principle of strain compatibility, *Smart Mater. Struct*.**17** 1

[10] Nemat N S, Huang Y, Fabrizia G and Trick P R 2008 2008 Passive Damage Detection in Composite Laminates with Integrated Sensing Networks *Health Monitoring of Structural and Biological Systems* Proc. of SPIE **6935** 0277

[11] Staszewski, W J, Mahzan S and Traynor R. 2009 Health monitoring of aerospace composite structures – Active and passive approach. *Composites Science and Technology*, **69** 1678

[12] Mahzan S, Staszewski W J and Worden K 2010 Experimental studies on impact damage location in composite aerospace structures using genetic algorithms and neural networks *Smart Structures and Systems*, ***6*(2)** 147

[13] Tippmann J D, X Zhu and Lanza F di Scalea. 2015 Application of damage detection methods using passive reconstruction of impulse response functions. *Philosophical Transactions*,

[14] Kebir H and Ayad R. 2014 A specific finite element procedure for the analysis of elastic behaviour of short fibre reinforced composites. The projected fibre approach. *Composite Structures*, **118** 580

[15] Bayat M. and Aghdam M 2012 A micromechanics based analysis of hollow fiber composites using dqem. *Composites Part B: Engineering*, **43(8)** 2921

[16] Behzad T and Sain M. 2007 Finite element modeling of polymer curing in natural fiber reinforced composites. *Composites Science and Technology*, **67(8)** 1666