



SRTTU

JCARME

Journal of Computational and Applied Research in Mechanical Engineering

<http://jcarme.srttu.edu>

ISSN: 2228-7922

Vol. X, No. X, XXXX



## High-velocity impact properties of multi-walled carbon nanotubes/E-glass fiber/epoxy anisogrid composite panels

Hamed Khosravi<sup>a,b</sup> and Reza Eslami-Farsani<sup>a,\*</sup>

<sup>a</sup> Faculty of Materials Science and Engineering, K. N. Toosi University of Technology, Tehran, Iran.

<sup>b</sup> Department of Materials Engineering, Faculty of Engineering, University of Sistan and Baluchestan, Zahedan, Iran.

### Abstract

This work reports on high-velocity impact response of multiscale anisogrid composite (AGC) panels. The aim of the present study was to evaluate the influence of surface-modified multi-walled carbon nanotubes (S-MWCNTs) at different S-MWCNTs contents (0-0.5 wt.% at an interval of 0.1 wt.%) on the high-velocity impact responses of E-glass/epoxy AGC. Surface modification of MWCNTs was confirmed by fourier-transform infrared (FTIR) and thermogravimetric (TGA) analyses. AGC panels were fabricated via a manual filament winding technique. E-glass fiber roving and E-glass woven fabric were employed as reinforcing agents in ribs and skin, respectively. The impact test was done on the composite panels by a cylindrical projectile with a conical nose. The obtained results showed that the highest enhancement in the impact characteristics was attributed to the panel containing 0.4 wt.% S-MWCNTs. Based on the analysis of fracture surfaces, enhanced interfacial fiber/matrix bonding was observed for the S-MWCNTs loaded specimen. Furthermore, the incorporation of MWCNTs led to reduced damaged area and enhanced tolerance of damage.

**Keywords:** Grid panels, Multi-walled carbon nanotubes, Silanization, Ballistic limit, Energy absorption.

### 1. Introduction

Using grid-stiffened composites (GSCs) as advanced and high performance structures is increasing in aerospace, aircraft, and automotive industries. GSC structures are considered as preferred substitutes for common components [1,2]. They are thin shell structures having helical or axial ribs in their network, where the ribs bear the most of the applied load [3,4]. Several research works have been done on the design and preparation of these structures [1-8].

The composite materials are very susceptible to damages caused by various types of loadings and their behavior in the presence of damages should be properly understood. Energy absorption capability which can be defined as the resistance of impact-exposed composite to penetration and perforation is a critical factor for high technology applications [9]. There exist various mechanisms for energy absorption of

\*Corresponding author

Email address: [eslami@kntu.ac.ir](mailto:eslami@kntu.ac.ir)

fibrous composites such as matrix cracking, shear plugging, and delamination [10].

Due to extensive applications of fiber-reinforced polymers (FRPs), several works have been reported on the mechanical properties of these structures [11-13]. The matrix modification of FRPs through the incorporation of nanoparticles can further increase their mechanical properties [14-16]. Among the various types of nanofillers, the very favorable mechanical properties of CNTs and their high aspect ratio make them ideal reinforcing material for polymer composites [17]. Literature review on the various properties of CNTs indicates the high elastic modulus, and strength of this type of materials [18]. According to the literature, several works have been performed on the mechanical behaviors of CNT-loaded nanocomposites [19-23].

For example, Pandya et al. [20] found that through the incorporation of 0.5 wt.% CNTs, the energy absorption capability of the epoxy/glass fiber specimen enhanced by 25%. Rahman et al. [21] showed that the ballistic-limit of the epoxy/glass fiber specimen increased through the incorporation of 0.3 wt.% MWCNTs. Laurenzi et al. [22] investigated the impact resistance in CNTs filled epoxy. They found that the CNT-reinforced panels demonstrated an enhanced ballistic response in comparison with the neat ones. Rahman et al. [23] found that the flexural strength and modulus of the epoxy/glass fiber specimen increased by 38% and 22%, respectively, with the introduction of 0.3 wt.% CNTs.

A scan through the literature illustrates little research works have been done on using nanoparticles as reinforcement in GSC structures [24-26]. Herein, the impact response of MWCNTs filled GSC panels was assessed. The energy absorption capability and ballistic-limit velocity of the specimens were reported and compared.

## 2. Experimental

### 2.1. Materials

The matrix resin used in composites for the current study was ML-506 epoxy resin based on epoxy bisphenol F with hardener HA-11, supplied by Mokarrar Engineering Materials Co, Iran. The resin- hardener ratio was 100:15 by weight, as recommended by the manufacturer. This resin system was chosen because of its low viscosity (1450 centipoise) and long gel time (60 min) at 25 °C. Also, the mixed system density is 1.1 g/cm<sup>3</sup>. The tensile and flexural strengths of employed resin are 761 and 960 kgF/cm<sup>2</sup>, respectively.

Unidirectional E-glass fiber (density: 2.58 g/cm<sup>3</sup>, average diameter: 12 μm) and 2-dimensional plain weave E-glass fabric (surface density: 400 g/m<sup>2</sup>), both supplied by LINTEX International Co., Ltd, China, were used as fibrous reinforcements. The silica nanoparticles as filler part were purchased from US Research Nanomaterials, Inc, USA. Fig. 1 illustrates FE-SEM image of as-received silica nanoparticles. These particles have an average particle size of 65 nm and specific surface area of 380 m<sup>2</sup>/g. 3-glycidoxypropyltrimethoxysilane (3-GPTS) as a silane coupling agent was provided by Merck Chemical Co, Germany. The molecular formula of the 3-GPTS is C<sub>9</sub>H<sub>20</sub>O<sub>5</sub>Si. This compound has been selected because of its epoxide groups which can easily react with epoxy matrix in the presence of amine hardener.

**Table 1.** Details of MWCNTs

Diameter (nm)	Length (μm)	COOH content (gr/cm <sup>3</sup> )	Specific area (m <sup>2</sup> /g)
10-20	20-30	2	233

### 2.2. Surface modification of MWCNTs

In the first step, 0.5 g MWCNTs was added to the 100 mL solution (95 mL ethanol-5 mL water). After that, 3-GPTMS coupling agent (silane/CNT weight ratio: 1/1) was incorporated to the solution. In the next step, the mixture was sonicated for 10 min and refluxed for 8 h at temperature of 80°C. pH of the solution was regulated at around 4.5 by HCl (37%) acid [27]. To separate the silanized MWCNTs (S-MWCNTs), the resultant mixture was centrifuged for 8 h. In the final step, obtained

powders were washed twice with ethanol and then dried in an oven.

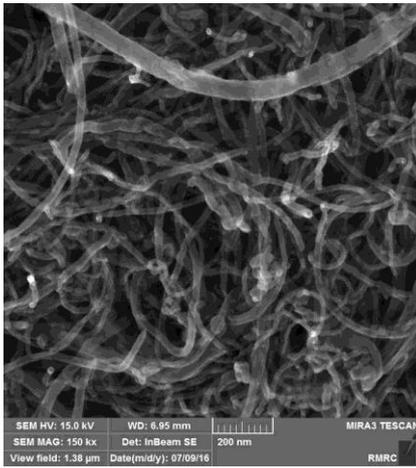


Fig. 1. SEM image of as-received MWCNTs.

### 2.3. Preparation of GSC panels

Various weight percentages of S-MWCNTs (0-0.5 wt.% at an interval of 0.1) were added to the epoxy resin. After initial mechanical stirring by an overhead mechanical stirrer, ultrasonic waves were applied to the mixture for 90 min [24]. After mixture degassing, curing agent was added drop-to-drop. The panels were fabricated via a manual filament winding route. At initial stage, pre-impregnated unidirectional E-glass fibers were placed into the silicone mold grooves (Fig. 2) to establish the ribs. Then, the skin was laid up using four layers of E-glass fabrics over the network of ribs. Fabricated specimens are shown in Fig. 3. The panels were cured at room temperature. The characteristics of specimens are displayed in Table 2.

Table 2. Characteristics of the fabricated specimens

Rib cross section (mm <sup>2</sup> )	Length (mm)	Width (mm)	Skin thickness (mm)
6×6	300	125	1.8

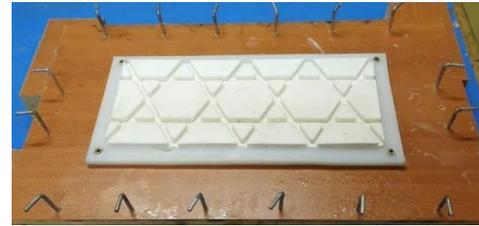


Fig. 2. The fabricated silicone mold.

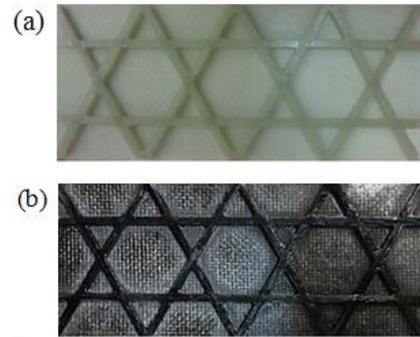


Fig. 3. Fabricated specimens a) neat, and b) multiscale.

### 2.4. Impact test

For conducting the impact test, an aluminum cylindrical projectile with conical nose, as indicated in Fig. 4, was used. The weight of the projectile was 27 g. The position of the specimens when exposed to the impact loading can be seen in Fig. 5. The GSC specimens with a dimension of 15×15 cm<sup>2</sup> were used.

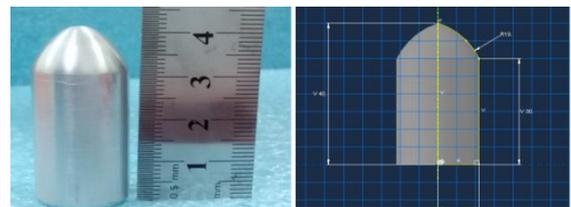


Fig. 4. Conical cylindrical projectile.

The impact response of the specimens was reported in terms of impact-limit velocity ( $V_{50}$ ) and the amount of energy absorption ( $E_{abs}$ ), calculated from the following equations [28]:

$$V_{50} = \sqrt{V_i^2 - V_r^2} \tag{1}$$

$$E_{abs} = \frac{1}{2} m_p (V_i - V_r)^2 \quad (2)$$

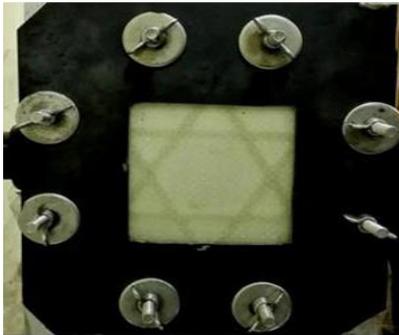


Fig. 5. GSC specimen in the fixture of the impact test.

### 2.5. Characterization

To characterize the silanized MWCNTs, fourier-transform infrared (FTIR) spectrometer (JASCO, 460-plus) in the 400-4000  $\text{cm}^{-1}$  range (resolution: 4  $\text{cm}^{-1}$ ) was employed. TGA analysis (model: STA504) was conducted in a nitrogen atmosphere (temperature range: 25-800°C, and heating rate: 10  $^{\circ}\text{C min}^{-1}$ ). The fracture surface of specimens after impact test was examined using a field emission electron microscopy (FESEM-MIRA3 TESCAN).

## 3. Results and discussion

### 3.1. Results of FT-IR and TGA

The surface properties of COOH-MWCNTs and S-MWCNTs were studied using FTIR analysis. FTIR spectra of these powders are displayed in Fig. 6. Regarding to the FTIR spectrum of COOH-MWCNTs, the observed bands at 1716.5  $\text{cm}^{-1}$  and 1156.6  $\text{cm}^{-1}$  show the C-O and C=O stretching vibrations, respectively [29]. The bands at 2519.7  $\text{cm}^{-1}$  and 3179.5  $\text{cm}^{-1}$  show the presence of OH groups, and the peaks at 801.5  $\text{cm}^{-1}$  and 1412.9  $\text{cm}^{-1}$  indicate the bending deformation of OH [30]. The appearance of two bands at 1592.7  $\text{cm}^{-1}$  and 2872.9  $\text{cm}^{-1}$  is related to the presence of C-H and C=C. On the contrary, an extra peak is visible in the FTIR spectrum of modified CNTs

at 852  $\text{cm}^{-1}$ , indicating the formation of Si-O-C [31]. These results clearly show that silane compound is grafted on the surface of CNTs. Fig. 7 shows the TGA weight loss data over a range of temperatures for COOH-MWCNTs and S-MWCNTs. As indicated in this figure, the weight loss for S-MWCNTs at 500°C is higher than that of COOH-MWCNTs, which is due to the 3-GPTMS thermal decomposition.

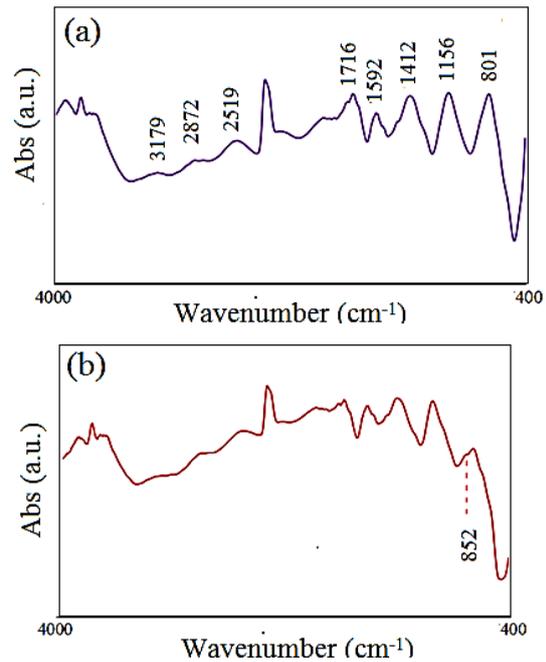


Fig. 6. FT-IR spectra of a) COOH-modified MWCNTs, and b) silane-modified MWCNTs.

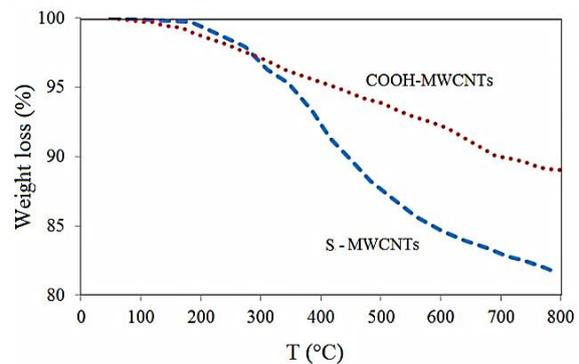


Fig. 7. TGA results of COOH-modified and silane-modified MWCNTs.

### 3.2. Impact response

The results of impact properties for different S-MWCNTs loadings are shown in Fig. 8. As indicated, the introduction of S-MWCNTs to the matrix of composites can affect the impact response of panels. A summary of the results of impact test for various specimens is shown in Table 3.

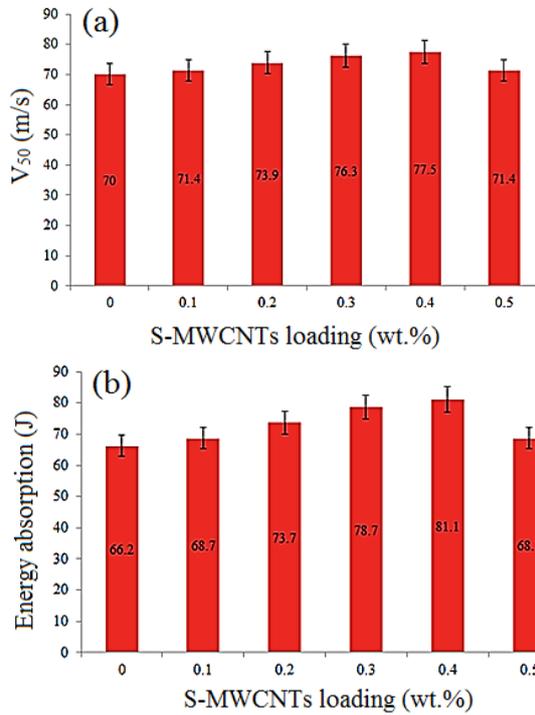


Fig. 8. The values of a)  $V_{50}$ , and b) energy absorption of GSC panels reinforced with various contents of S-MWCNTs.

**Table 3.** The values of impact results

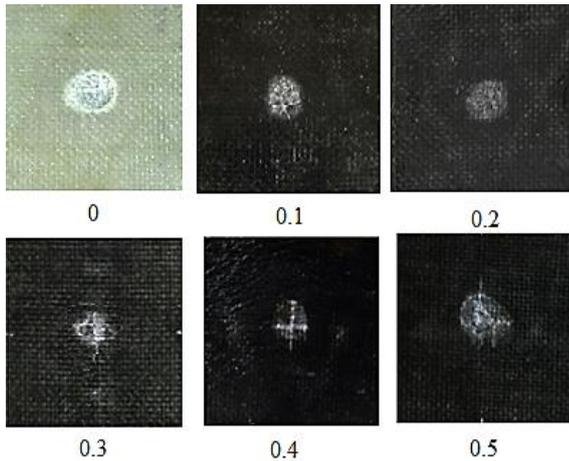
S-MWCNTs (wt. %)	Initial velocity (m/s)	Residue velocity (m/s)	$V_{50}$ (m/s)	Absorbed energy (J)
0	120	95	70	66.2
0.1	120	94	71.4	68.7
0.2	120	92	73.9	73.7
0.3	120	90	76.3	78.7
0.4	120	89	77.5	81.1
0.5	120	94	71.4	68.7

As it is observed from Fig. 8 and Table 3, through the incorporation of 0.4 wt.% S-MWCNTs, the values of ballistic limit velocity

and energy absorption capability of the E-glass/epoxy GSC specimen were increased by 11% and 23%, respectively, compared to the neat specimen. It seems that the observed increase in the impact responses of the multiscale specimens having S-MWCNTs is as a result of the following reasons: First, by reinforcing the matrix through the S-MWCNTs addition, the frictional slippage of interface is hindered because of the presence of S-MWCNTs. This indicated that for specimens containing S-MWCNTs, an efficient transferring of the applied load between the matrix and fibers can be occurred [32-34]. Thus, the impact properties of specimens including S-MWCNTs are higher than control specimen. The second reason is related to this fact that modulus of S-MWCNTs is higher than epoxy matrix [35, 36]. Third, MWCNTs can act as rigid barriers against the crack initiation and propagation, via crack bridging [37]. So, a higher amount of energy for crack growth is required. Forth, the rib-skin adhesion can enhance due to the S-MWCNTs addition. This suggested that GSC specimens reinforced with S-MWCNTs have higher energy absorption than the neat specimen. The observed drop in the impact characteristics of the 0.5 wt.% S-MWCNT loaded specimen is related to the decrement of adhesion in the fiber-matrix interface due to the CNT agglomerate formation at higher S-MWCNT loading as a result of increased viscosity of the resin. The presence of CNT agglomerates can create regions of stress concentration [38]. As it can be seen in Fig. 9, with the addition of S-MWCNTs, the damage size is decreased due to the higher bending stiffness of CNT loaded specimen.

In GSC composites, some of the main energy absorption mechanisms in the high-velocity impact test are delamination, matrix cracking, fiber breakage, and perforation. By the addition of CNTs, delamination resistance is enhanced as a result of improved matrix-fiber interface bonding. In fact, in MWCNTs loaded specimens less delamination is observable. Accordingly, the size of damaged area is declined. However, for the specimen reinforced with 0.5 wt.% CNTs compared to the 0.4 wt.% CNTs loaded one, the damaged area is

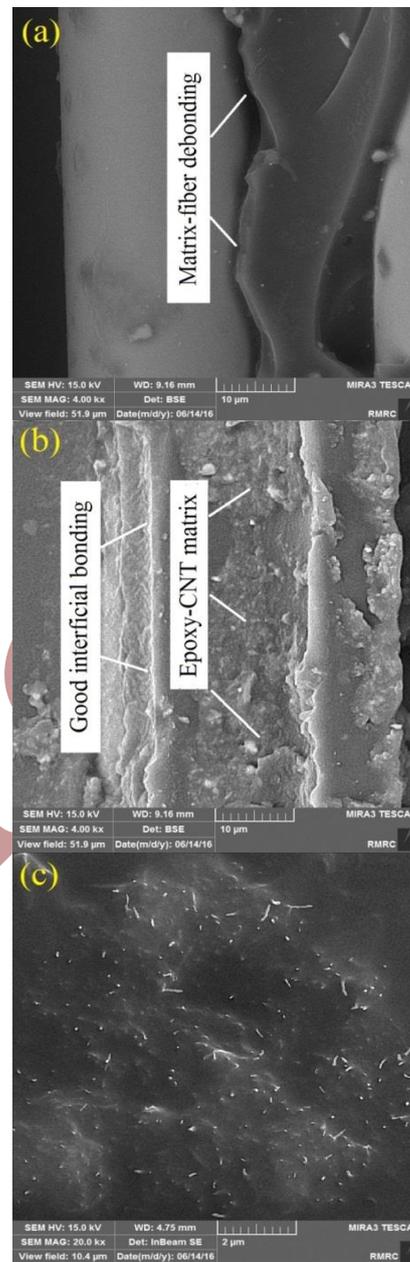
increased due to the improper dispersion of MWCNTs within the polymeric matrix. In fact agglomeration of S-MWCNTs caused the reduction of delamination resistance of composite and as a result, the damaged area was increased.



**Fig. 9.** Damaged area of GSC specimens containing various weight contents of S-MWCNTs.

### 3.3. Microstructural examination

The surface morphology of the unfilled and filled GSCs after impact test was investigated by FESEM. The fracture surface of the neat composite illustrates that the epoxy matrix is separated from the fibers due to the poor adhesion, as indicated by the clean surface of the fibers (Fig. 10a). Fig. 10b illustrates the presence of adhered matrix to the surface of glass fibers, showing a considerable bonding between the fibers and matrix for the nanocomposite specimen. From Fig. 10c, a uniform dispersion of CNTs within the matrix is observable. Moreover, CNTs are seen on the fracture surface in the form of pulled out or broken, manifesting the existence of crack bridging [39].



**Fig. 10.** The surface morphology of GSC specimens after impact test, a) non-filled specimen, b) containing 0.4 wt.% S-MWCNTs, and c) High magnification image from the matrix of 0.4 wt.% reinforced specimen.

### 4. Conclusions

In the present work, the behavior of AGS composites filled with various loadings of S-MWCNTs was investigated under high-velocity impact test. The main results obtained from this study are as follows:

1. Surface modification of MWCNTs was confirmed by FTIR and TGA analyses.
2. Ballistic limit and energy absorption of the AGS specimen containing 0.4 wt.% S-MWCNTs enhanced by 11% and 23% over the neat specimen.
3. The introduction of S-MWCNTs enhanced the interfacial bonding between the E-glass fiber and polymeric matrix.
4. The introduction of S-MWCNTs decreased the damage size of specimens exposed to the high-velocity impact.

## References

- [1] V. V. Vasiliev, and A. F. Razin, "Anisogrid composite lattice structures for spacecraft and aircraft applications", *Composite Structures*, Vol. 76, No. 1-2, pp. 182-189, (2006).
- [2] V. V. Vasiliev, V. A. Barynin, A.F. Rasin, S.A. Petrovskii, and V.I. Khalimanovich, "Anisogrid composite lattice structures-development and space applications", *Composite structures*, Vol. 94, No. 3, pp. 38-50, (2009).
- [3] J. Eskandari-Jam, M. Noorabadi, H. Taghavian, M. Mohammadi, and N. Namdaran, "Design of anisogrid composite lattice conical shell structures", *Journal of Science and today's world*, Vol. 7, No. 9, pp. 140-146, (2013).
- [4] C. Gan, R. F. Gibson, and G. Newaz, "Analytical/experimental investigation of energy absorption in grid-stiffened composite structures under transverse loading", *Experimental Mechanics*, Vol. 44, No. 2, pp. 185- 194, (2004).
- [5] M. Buragohainand, and R. Velmurugan, "Optimal design of filament wound grid-stiffened composite cylindrical structures", *Defence Science Journal*, Vol. 61, No. 1, pp. 88-94, (2011).
- [6] E. Wodesenbe, S. Kidane, and S.S. Pang, "Optimization for buckling loads of grid stiffened composite panels", *Composite Structures*, Vol. 60, No. 2, pp. 159-169, (2003).
- [7] R. F. Gibson, "Energy Absorption in Composite Grid Structures", *Advanced Composite Materials*, Vol. 14, No. 2, pp. 113-119, (2005).
- [8] R. Zamani, G. H Rahimi, M. H. Pol, and M. Hedayatian, "Reinforcing effect of nanoclay on buckling behavior of nanocomposite grid shells: Experimental investigation", *Modares Mechanical Engineering*, Vol. 15, No. 3, pp. 411-418, (2015).
- [9] K. S. Pandya, and N. K. Naik, "Analytical and experimental studies on ballistic impact behavior of carbon nanotube dispersed resin", *International Journal of Impact Engineering*, Vol. 76, pp. 49-59, (2015).
- [10] A. R. Sabet, M. H. Beheshty, and H. Rahimi, "High velocity impact behavior of GRP panels containing coarse-sized sand filler", *Polymer Composites*, Vol. 29, No. 8, pp. 932-938, (2008).
- [11] U. Alkan, Y. Ozcanli, and V. Alekberov, "Effect of temperature and time on mechanical and electrical properties of HDPE/glass fiber composites", *Fibers and Polymers*, Vol. 14, No. 1, pp. 115-120, (2013).
- [12] A. Brenes-Acosta, and B. A. Stradi-Granados, "Comparative study of the mechanical properties of polyester resin with and without reinforcement with fiber-glass and furcraea cabuya fibers", *Fibers and Polymers*, Vol. 15, No. 10, pp. 2186-2192, (2014).
- [13] J. Li, and Y. C. Xia, "The reinforcement effect of carbon fiber on the friction and wear properties of carbon fiber reinforced PA6 composites", *Fibers and Polymers*, Vol. 10, No. 4, pp. 519-525, (2009).
- [14] R. Eslami-Farsani, H. Khosravi, and S. Fayazzadeh, "Using 3-Glycidoxy propyltrimethoxy silane functionalized SiO<sub>2</sub> nanoparticles to improve flexural properties of glass fibers/epoxy grid-stiffened composite panels", *International Scholarly and Scientific Research & Innovation*, Vol. 9, No. 12, pp. 1350-1353, (2015).
- [15] A. Abdi, R. Eslami-Farsani, and H. Khosravi, "Evaluating the mechanical behavior of basalt fibers/epoxy composites containing surface-modified CaCO<sub>3</sub> nanoparticles", *Fibers and Polymers*, Vol. 19, No. 3, pp. 635-640, (2018).
- [16] M. M. Shokrieh, A. Saeedi, and M. Chitsazzadeh, "Evaluating the effects of multi-walled carbon nanotubes on the mechanical properties of chopped strand mat/polyester composites", *Materials and Design*, Vol. 56, pp. 274-279, (2014).
- [17] M. T. Byrne, and Y. K. Gunko, "Recent advances in research on carbon nanotube-polymer composites", *Advanced Materials*, Vol. 22, No. 15, pp. 1672-1688, (2010).
- [18] Z. Spitalsky, D. Tasis, K. Papagelis, and C. Galiotis, "Carbon nanotube-polymer composites: chemistry, processing, mechanical and electrical properties", *Progress in Polymer Science*, Vol. 35, No. 3, pp. 357-401, (2010).
- [19] H. Ulus, Ö. S. Şahin, and A. Avcı, "Enhancement of flexural and shear properties of carbon fiber/epoxy hybrid nanocomposites by boron nitride nanoparticles and carbon nanotube modification", *Fibers and Polymers*, Vol. 16, No. 12, pp. 2627-2635, (2015).
- [20] K. S. Pandya, K. Akella, M. Joshi, and N. K. Naik, "Ballistic impact behavior of carbon nanotube

and nanosilica dispersed resin and composites”, *Journal of Applied Physics*, Vol. 112, pp. 1-6, (2012).

[21] M. Rahman, M. Hosur, Sh. Zainuddin, U. Vaidya, A. Tauhid, A. Kumar, J. Trovillion, and Sh. Jeelani, “Effects of amino-functionalized MWCNTs on ballistic impact performance of E-glass/epoxy composites using a spherical projectile”, *International Journal of Impact Engineering*, Vol. 57, pp. 108-118, (2013).

[22] S. Laurenzi R. Pastore G. Giannini, and M. Marchetti, “Experimental study of impact resistance in multi-walled carbon nanotube reinforced epoxy composite structures”, *Composite Structures*, Vol. 99, pp. 62-68, (2013).

[23] M. M. Rahman, Sh. Zainuddin, and M. V. Hosur, “Improvements in mechanical and thermo-mechanical properties of e-glass/epoxy composites using amino functionalized MWCNTs”, *Composite Structures*, Vol. 94, pp. 2397-2406, (2012).

[24] H. Khosravi, and R. Eslami-Farsani, “Reinforcing effect of surface-modified multiwalled carbon nanotubes on flexural response of E-glass/epoxy isogrid-stiffened composite panels”, *Polymer composites*, Vol. 32, No. S2, pp. E677-E686, (2018).

[25] M. Hedayatian, G.H. Liaghat, Gh. Rahimi, M.H. Pol H. Hadavinia and R. Zamani, “Investigation of the high velocity impact behavior of grid cylindrical composite structures”, *Polymer composites*, Vol. 38, No. 11, pp. 2603-2608, (2017).

[26] H. Khosravi, and R. Eslami-Farsani, “On the flexural properties of multiscale nanosilica/E-glass/epoxy anisogrid-stiffened composite panels”, *Journal of Computational and Applied Research in Mechanical Engineering*, Vol. 7, No. 1, pp. 99-108, (2017).

[27] H. Khosravi, and R. Eslami-Farsani, “Enhanced mechanical properties of unidirectional basalt fiber/epoxy composites using silane-modified Na<sup>+</sup>-montmorillonite nanoclay”, *Polymer Testing*, Vol. 55, pp. 135-142, (2016).

[28] R. Eslami-Farsani, and A. Shahrabi-Farahani, “Improvement of high-velocity impact properties of anisogrid stiffened composites by multi-walled carbon nanotubes”, *Fibers and Polymers*, Vol. 18, No. 5, pp. 965-970, (2017).

[29] Y. M. Jen, and C. Y. Huang, “Fatigue characterization of acid treated carbon nanotube/epoxy composites”, *Journal of Composite Materials*, Vol. 47, No. 13, pp. 1665-1675, (2013).

[30] V. Brancato, A. M. Visco, and A. Pistone, “Effect of functional groups of multi-walled carbon nanotubes on the mechanical, thermal and electrical performance of epoxy resin based nanocomposites”,

*Journal of Composite Materials*, Vol. 47, No. 24, pp. 3091-3103, (2013).

[31] Y. B. Tee, R. A. Talib, and K. Abdan, “Thermally grafting aminosilane onto kenaf-derived cellulose and its influence on the thermal properties of poly (lactic acid) composites”, *BioResources*, Vol. 8, No. 3, pp. 4468-4483, (2013).

[32] M. T. Kim, K. Y. Rhee, S. J. Park, and D. Hui, “Effects of silane-modified carbon nanotubes on flexural and fracture behaviors of carbon nanotube-modified epoxy/basalt composites”, *Composites*, Vol. 43, No. 5, pp. 2298-2302, (2012).

[33] M. M. Rahman, S. Zainuddin, M. V. Hosur, C. J. Robertson, A. Kumar, J. Trovillion, and S. Jeelani, “Effect of NH<sub>2</sub>-MWCNTs on crosslink density of epoxy matrix and ILSS properties of e-glass/epoxy composites”, *Composite Structures*, Vol. 95, pp. 213-221, (2013).

[34] J. E. Garcia, B. L. Wardle, and A. J. Hart, “Joining prepreg composite interfaces with aligned carbon nanotubes”, *Composites part A*, Vol. 39, No. 6, pp. 1065-1070, (2008).

[35] D. Micheli, A. Vricella, R. Pastore, A. Delfini, A. Giusti, M. Albano, M. Marchetti, F. Moglie, and M. V. Primiani, “Ballistic and electromagnetic shielding behavior of multifunctional Kevlar fiber reinforced epoxy composites modified by carbon nanotubes”, *Carbon*, Vol. 104, pp. 141-156, (2016).

[36] J. Zhang, S. Jua, D. Jiang, and H. X. Peng, “Reducing dispersity of mechanical properties of carbon fiber/ epoxy composites by introducing multi-walled carbon nanotube”, *Composites Part B*, Vol. 54, No. 1, pp. 371-376, (2013).

[37] S. Zhang, W. Liu, J. Wang, B. Li, L. Hao, and R. Wang, “Improvement of interfacial properties of carbon fiber-reinforced poly(phthalazinone ether ketone) composites by introducing carbon nanotube to the interphase”, *Polymer Composites*, Vol. 36, No. 1, pp. 26-33, (2015).

[38] P. Udatha, C. V. S. Kumar, S. N. Nair, and N. K. Naik, “High velocity impact performance of three-dimensional woven composites”, *The Journal of Strain Analysis for Engineering Design*, Vol. 47, No. 7, pp. 419-431, (2012).

[39] H. Khosravi, and R. Eslami-Farsani, “On the mechanical characterizations of unidirectional basalt fiber/epoxy laminated composites with 3-glycidoxypropyltrimethoxysilane functionalized multi-walled carbon nanotubes-enhanced matrix”, *Journal of Reinforced Plastics and Composites*, Vol. 35, No. 5, pp. 421-434, (2016).