

# Free Vibration and Damping Characteristics of GFRP and BFRP Laminated Composites at Various Boundary Conditions

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## Abstract

**Objectives:** During the motion of aircraft, wing and control surfaces undergo through severe vibration. This vibration can be controlled by selecting proper material, thickness, fiber orientation etc. This work focuses to compare vibration characteristics such as natural frequency and damping coefficient of BFRP composites with GFRP composites at various fiber orientations and end conditions. **Methods/Analysis:** BFRP and GFRP composites with unidirectional cloth and Owen fabric are fabricated by compression moulding machine and their mechanical properties were determined by using UTM as per ASTM standards. Vibration analysis of these materials was carried out by using modal analysis set up for various end conditions. Natural frequencies and damping coefficients were determined by for all materials and end conditions. These results were compared with numerical results which are carried by using ABACUS software. **Findings:** Fundamental natural frequency of glass/epoxy composites is better than the basalt/epoxy composites. The natural frequency changes with end condition and fiber orientations. Due to high stiffness, the natural frequency of Basalt Owen fabric composites is higher than that of unidirectional basalt/epoxy composites. Damping coefficient of unidirectional Basalt laminate at cantilever condition is good (0.0837) but the same value for Owen fabric with CNT is 0.00818. Increment in damping coefficient is due to compression moulding process. Due to high pressure the fiber volume fraction increases and correspondingly the stiffness also increases. **Novelty of the Study:** No literature gives the comparative study of vibration analysis of Owen fabric Basalt composites with Unidirectional Basalt fiber composites. **Conclusion/Application:** Due to high damping coefficient of Basalt/epoxy composites and better vibration characteristics. This material can be used in the construction of control surfaces and high lift devices of small aircraft.

**Keywords:** BFRP, Damping Coefficient, Free Vibration, GFRP, Natural Frequency

## 1. Introduction

Fiber Reinforced Plastics (FRP) composites are available in various forms like unidirectional fiber, bidirectional Woven fabrics, twill weave, quadraxial fiber etc. Woven fabrics are used for general applications at different thickness and structures. These composites are having very good static and dynamic mechanical properties and they are light weight in nature. Good strengths, stiffness and high damping are the desirable properties of structural

applications. These properties are found to be good in these composites and can be used in Aerospace applications like Airplane wings, fuselage, control surfaces, high lift devices, landing gear struts or any other struts and beams. They are also used in general applications like marine industry, automobile industry, civil industry etc. Aircraft structures are subjected to aerodynamic flutter during their service, due to air load. The resonant amplitude of vibration is considerably influenced by damping associated with each mode of the structure. It is

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mandatory to find the natural frequency and the modal damping.

Many research works have been carried out in the dynamic characteristics of composite materials<sup>1-6</sup>. Static properties, dynamic properties, storage modulus and damping are the important characteristics which gives vital role in the design of composite materials. Storage modulus is related to the stiffness of composites and damping is associated with the energy dissipation of composites<sup>7,8</sup> proved that through toughening of polymer matrix the damping effect can be improved. Vibration, mechanical and thermal properties of structural composites can be improved by adding some nanoparticles with natural fibers<sup>9</sup>. Chandra et al.<sup>10</sup> suggested that visco-elastic nature of matrix is one of the reasons for contribution of damping in composites. A combined experimental and numerical study of the free vibration of composite GFRP plates has been carried out<sup>11,12</sup> and performed free vibration analysis of the laminated composite beam with various boundary conditions<sup>13</sup> and also investigated the damping behavior composites with various array. Consider that the woven fabric reinforced composite materials are not entirely homogeneous, large resin-rich areas are formed in the margin areas from the interlaced warps and fills. In the high performance fiber-polymer matrix system, the difference of damping is much larger than that of the stiffness. Large resin-rich areas act as the built-in damper elements. Their distribution, depending on the architectures of the weave and type of material, determines the damping of the composite structure<sup>14,15</sup> investigated the vibration effect on laminated composites during drilling<sup>16</sup>; investigated the natural frequency of laminated composites at various angle ply using higher order shear deformation theory<sup>17</sup>. Proved the natural frequency of GFRP composites increases when treated with NaOH<sup>18</sup>, investigated the damping characteristics of Basalt/epoxy/CNT hybrid composites at sea water absorption condition and proved the vibration damping increased to 50%. In order to get better vibration less works have been carried out in fiber array and yarn patterns, especially for BFRP composites.

In the present investigation, unidirectional (UD) fabric, woven fabrics of basalt fiber and glass fiber mats have been used as reinforcement in epoxy LY556 matrix. The main aim of this work is to compare vibration characteristics such as natural frequency and modal damping of BFRP composites with GFRP composites. The tensile properties are determined using UTM. The natural

frequencies and modal damping are determined experimentally and numerically.

## 2. Specimen Preparation and Experimental Procedures

### 2.1 Materials

Basalt Owen fabric (plain weave with surface density 220kg/cm<sup>2</sup> and) and unidirectional fabric (density 550 kg/cm<sup>2</sup>) were imported from Incotology, Germany and Glass Owen fabric(plain weave with surface density(450 kg/cm<sup>2</sup>) and Glass unidirectional fabric were purchased from sakthi fibers, Chennai. Epoxy LY556 and the hardener Aradur Hy 951 were purchased from Javanthy Enterprises, Chennai. Epoxy resins are general purpose resin which is used for high strength applications like Aircraft components, automobiles, marine etc. to increase the reaction rate and to form effective cross linking aromatic amines are added with epoxy. Epoxy gets cure when mixed with hardener.

### 2.2 Fabrication of BFRP Laminates

GFRP and BFRP laminates were fabricated by using compression molding machine (Figure 1.) at 30 bar pressure and 60°C which is available at Indian Institute of Technology (IIT), Madras. All Fiber mats are cut into 300mm x 300mm size. 16 layers of fabrics were laid for basalt Owen fabric, 4 layers are taken for UD fabric and 7 layers were taken for Glass Owen fabric. Epoxy resin and the fibers are taken at the ratio of 1:1.5 by weight.



**Figure 1.** Compression moulding machine.

Hardener and resin are taken at 1:10 by weight in order to activate the curing. This mixture was stirred well by using a stirrer and was applied over the fabric. This is kept in the bed of the compression moulding machine and compressed hydraulically for about 2 hours duration. Then the laminate is taken out of the machine and cured at room temperature for about 24 hours. Fiber, matrix volume fractions were determined by using burnt test as per ASTM D-2584 standard. For all laminates the fiber, matrix ratio is found to be 60:40.

### 2.3 Specimen Preparation

Specimens are cut from the laminate using abrasive water jet cutting machine at Alind, Ambattur, Chennai as per ASTM standards. Water jet cutting machines are used to avoid fiber damage and to get the accurate result. Specimens are cut for both tensile test and vibration analysis. ASTM D3930 is used for tensile test. 200mm x 40mm size specimens are used for vibration analysis for various end conditions like fixed-fixed, fixed-free and hinged-hinged.

### 2.4 Mechanical Properties

To determine the material properties like tensile strength, elastic modulus in the longitudinal and lateral directions ( $E_1$  and  $E_2$ ), tensile tests were conducted by INSTRON UTM at IIT Madras. As per ASTM D3930 the specimen size is 280X25X3 mm. Tensile test was conducted for all four materials at 2mm/mm cross head speed.

### 2.5 Experimental set up for Vibration Analysis

The dynamic responses of the composite materials are obtained as a combination of its modes, knowledge of the mode shapes, modal frequencies and damping ratios. The experimental set up used for free vibration analysis of BFRP and GFRP laminates using impact exciter are shown in Figure 2. The accelerometer is attached over the

beam using wax and is connected to the one of the channel of the 64 channel Data Acquisition System (DAQ). The accelerometer converts the physical motion given by the exciter to the laminate into an electrical signal. A signal conditioning amplifier is used to transfer the accelerometer characteristics compatible with the input electronics of the DAQ. The data received is channeled on to the DEWESOFT 7.0.5 software in the PC via a power adaptor. Two adapters are used, one to receive signal from accelerometer and the other to measure the magnitude of response by the exciter from the laminates. Each vibration or input given with the help of a hammer is picked up by the accelerometer and converted into frequency values in DEWESOFT and displayed in the computer screen.

### 2.6 Damping Factor

The presence of damping is helpful in many cases. Damping limits the amplitude of vibration. In any structural application, damping can be introduced to avoid resonance. One of the methods is selecting structural materials having high internal damping. Laminated composite materials are having very high material damping. The damping ratio can be determined from the frequency response curve shown in Figure 3. In this method the frequency response graph is portioned into several frequency ranges. Each partitioned frequency range is then considered as the frequency response function of a single degree of freedom. This implies that the frequency response function in each frequency range is dominated by that specific single mode. The peak denotes the resonance point. Thus the resonance frequencies can be identified as the peaks in the graph of  $Q$ . The damping ratio corresponding to peak  $i$ , with resonant frequency  $\omega_i$ , the model damping ratio can be determined using

$$\xi_i = (\omega_{i2} - \omega_{i1}) / 2\omega_r$$

$\omega_{i2}$ ,  $\omega_{i1}$  are known as half power points lie either side of the resonant frequency  $\omega_i$  and satisfy the relation



**Figure 2a,b,c.** Experimental set up for vibration analysis.

$$Q(\omega_{ii}) = Q(\omega_{ii}) = Q(j\omega_i) // \sqrt{2}$$

$\omega_i$  is the damped natural frequency.

The same procedure is repeated for all the degrees of freedom from selecting the successive peaks.

Where  $\omega_r$ - Frequency at resonance

$Q$ -Amplitude (frequency response function)

Theoretical value of damping ratio is  $\xi = c/c_c$

$c$ - Damping coefficient,  $c_c$  –critical coefficient=  $\sqrt{2m\omega_n}$

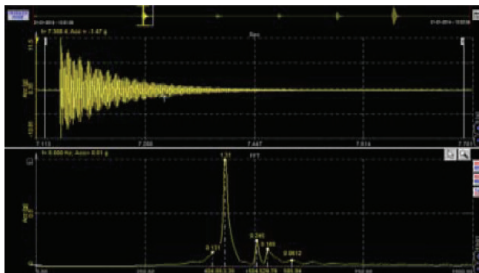
$\omega_n$ - Natural frequency=  $\sqrt{k/m}$

$k$ - Stiffness of the laminate,  $m$ -mass of the laminate

### 3. Results and Discussion

#### 3.1 Tensile Properties

The tensile strength and Elastic modulus of BFRP, GFRP Uni Directional and Owen fabric laminated composites are shown in Table 1. The tensile tests were carried out as per ASTM D3930 standards. Results show the tensile strength and the tensile modulus are high for BFRP composites. The young's modulus of the BFRP composites are 12.5% higher than that of GFRP composites and the tensile strength of GFRP composites are 12% higher than that of BFRP composites.



**Figure 3.** The triggered excitation and the frequency response curve for GFRP (UD) laminate with fixed-fixed end condition.

**Table 1.** Material Properties of the GFRP and BFRP Laminates

| Material           | Young's Modulus(Gpa) |      | Tensile Strength(Mpa) |
|--------------------|----------------------|------|-----------------------|
|                    | E1                   | E2   |                       |
| BFRP (UD)          | 46.4                 | 7    | 649                   |
| BFRP (Owen Fabric) | 3.6                  | 3.6  | 292                   |
| GFRP (UD)          | 40.49                | 6.9  | 738                   |
| GFRP (Owen Fabric) | .59                  | 0.59 | 564                   |

#### 3.2 Modal Analysis

The vibrational analysis of BFRP (both UD and Owen fabric) and GFRP (both UD and Owen fabric) laminated composites have been carried out and modal analysis was studied. In the present analysis, three different end conditions are considered (fixed-fixed, fixed-free and simply supported). The first three natural frequencies and three mode shapes were determined for all four materials and three end conditions. The results are shown in the Table 2. The effect of material and the end conditions are analyzed. The excitation was given by using a small hammer and the magnitude of the impact of the hammer is measured piezoelectric force transducer through the adopter connected to the hammer. The force caused by the hammer, which is nearly proportional to the mass of the hammer and the impact velocity. The shape of the frequency response is dependent on the mass of the hammer and the stiffness of the material structure. The displacement signal of the laminates was received by a light weight accelerometer which is fixed at the free end of the cantilever and at the midpoint in the simply supported beam and the fixed beam. The signal from the transducer is sent to the analyzer via DAQ for signal processing. Fast Fourier Transform (FFT) analyzer is used which receives analog voltage signals from a signal conditioning amplifier for computation. The signal analyzed by the analyzer is used to find the natural frequency, damping ratio and mode shapes. DEWESOFT 7.0.5 software is used to get the frequency response. This software is generally designed for vibration control and monitoring. The natural frequency and the amplitude were measured directly from the software. The model triggered excitation and the frequency response curve is shown in Figure 3. From Table 2 it is understood that the fundamental natural frequencies varies with material, end conditions of the beam and fiber orientation. The vibrational response BFRP composite is slightly lesser than that of GFRP laminate. But when we compare the density, BFRP laminate used in the present analysis is lesser than that of GFRP laminate. The natural frequency is the function of stiffness of the material and the mass. Figure 7 shows the variation of fundamental natural frequency of BFRP and GFRP composites with various end conditions. BFRP Owen fabric with fixed-fixed end condition has higher natural frequency. The dynamic behavior of Basalt fiber reinforced plastic composite is comparatively good and this material can be used in aircraft structural applications in the place of Glass fiber reinforced plastic composites.

The experimental results were compared with the numerical results. Numerical analysis was carried out by using ABACUS software. The model first three mode shapes of BFRP Unidirectional composites at cantilever conditions are shown in Figure 4, 5 and 6. The experimental and the numerical values are having very good agreement which is shown in Table 3. There is 10% variation in the experimental and numerical result. These variations may be due to the experimental set up and the

material properties measured experimentally and also due to the laminate manufacturing process.

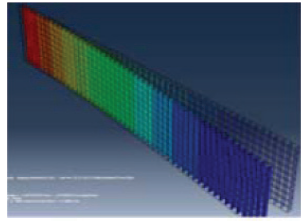
Damping is one of the ways to limit the amplitude of vibration in dynamic structural applications. Generally laminated composites are having high internal damping. The variation of material damping for GFRP and BFRP are shown in Figure 8. Results are obtained from the experiments using half power method and are projected in Table 4. BFRP composites are having very good

**Table 2.** Amplitude and natural frequencies of BFRP and GFRP composites at various end conditions

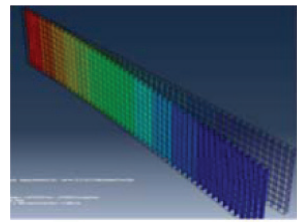
| Material         | Boundary conditions | 1 <sup>st</sup> Mode            |           | 2 <sup>nd</sup> Mode            |           | 3 <sup>rd</sup> Mode            |           |
|------------------|---------------------|---------------------------------|-----------|---------------------------------|-----------|---------------------------------|-----------|
|                  |                     | Natural frequency<br>$\omega_n$ | Amplitude | Natural frequency<br>$\omega_n$ | Amplitude | Natural frequency<br>$\omega_n$ | Amplitude |
| BFRP (UD)        | Cantilever          | 31.7                            | 12.8      | 63.48                           | 0.723     | 205                             | 1.92      |
|                  | Fixed-fixed         | 212                             | 0.236     | 286                             | 0.241     | 350.3                           | 0.192     |
|                  | Simply support      | 78.1                            | 0.113     | 214                             | 0.0431    | 329.6                           | 0.054     |
| BFRP Owen fabric | Cantilever          | 37.8                            | 9.2       | 117.2                           | 0.36      | 246                             | .93       |
|                  | Fixed-fixed         | 251                             | 3.23      | 681                             | 0.647     | 1353                            | 0.614     |
|                  | Simply support      | 40.2                            | 0.04      | 84.23                           | 0.18      | 107.4                           | 0.239     |
| GFRP (UD)        | Cantilever          | 197.7                           | 2.7       | 550                             | 3.51      | 1094                            | .58       |
|                  | Fixed-fixed         | 203                             | 4.4       | 559                             | 4.69      | 1115                            | 0.618     |
|                  | Simply support      | 56.15                           | 0.41      | 86.7                            | 0.32      | 189.2                           | 0.278     |
| GFRP Owen fabric | Cantilever          | 47.6                            | 0.814     | 309                             | 5         | 838                             | 3.49      |
|                  | Fixed-fixed         | 219                             | 2.1       | 429                             | 0.8       | 783.7                           | 0.39      |
|                  | Simply support      | 26.86                           | 0.85      | 50                              | 0.81      | 97.66                           | 0.56      |

**Table 3.** Natural frequencies of cantilever

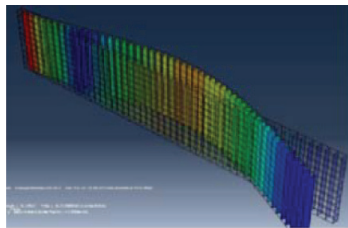
| Material         | Mode no | Experimental<br>$\omega_n$ | Numerical<br>$\omega_n$ | % Of error with Numerical value |
|------------------|---------|----------------------------|-------------------------|---------------------------------|
| BFRP (UD)        | 1       | 31.7                       | 23.4                    | -26.18                          |
|                  | 2       | 63.48                      | 60.8                    | -4.22                           |
|                  | 3       | 205.08                     | 211.7                   | +2.8                            |
| BFRP Owen fabric | 1       | 37.84                      | 39.19                   | +3.56                           |
|                  | 2       | 117.19                     | 109.77                  | -6.33                           |
|                  | 3       | 246.58                     | 199.59                  | -19.06                          |
| GFRP(UD)         | 1       | 197.75                     | 212.56                  | +7.489                          |
|                  | 2       | 550.54                     | 448.11                  | -18.48                          |
|                  | 3       | 1094.97                    | 1123.49                 | +2.6                            |
| GFRP Owen fabric | 1       | 197.75                     | 212.56                  | +7.489                          |
|                  | 2       | 550.54                     | 448.11                  | -18.48                          |
|                  | 3       | 1094.97                    | 1123.49                 | +2.6                            |



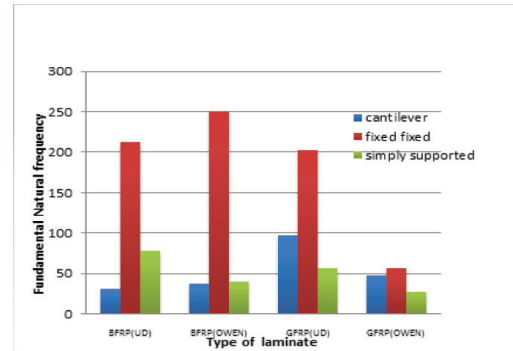
**Figure 4.** 1<sup>st</sup> Mode shape of cantilever beam-BASALT UD.



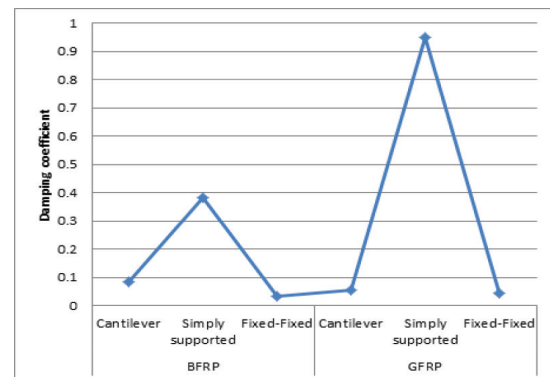
**Figure 5.** 2<sup>nd</sup> Mode shape of cantilever beam-BASALT UD.



**Figure 6.** 3<sup>rd</sup> Mode shape of cantilever beam-BASALT UD.



**Figure 7.** Variation of Fundamental natural frequency of different material with various end conditions.



**Figure 8.** Variation of damping coefficient of BFRP and GFRP at various end conditions.

**Table 4.** Damping coefficient of BFRP and GFRP composites at various end conditions

| Material | Boundary conditions | Damping ratio | Critical damping coefficient | Damping coefficient |
|----------|---------------------|---------------|------------------------------|---------------------|
| BFRP     | Cantilever          | 0.0483        | 1.737                        | 0.0837              |
|          | Simply supported    | 0.2143        | 1.79                         | 0.383               |
|          | Fixed-Fixed         | 0.0073        | 4.48                         | 0.0327              |
| GFRP     | Cantilever          | 0.0256        | 2.081                        | 0.0532              |
|          | Simply supported    | 0.273         | 3.484                        | 0.951               |
|          | Fixed-Fixed         | 0.0083        | 5.249                        | 0.0435              |

damping coefficient which is comparable with GFRP composites.

## 4. Conclusions

- Compression moulding techniques are used to fabricate the BFRP and GFRP composites to investigate the free vibration characteristics.
- Tensile properties of BFRP composites are better than GFRP composites.

- The dynamic behavior of BFRP composites is comparable with GFRP composites. Hence BFRP composites can be suggested for aerospace applications in the place of GFRP composites.
- Fundamental natural frequency of Owen fabric composites is better than unidirectional composites due to its high stiffness.
- Natural frequencies are changing with respect to boundary conditions. Laminate with fixed-fixed end conditions are having very high natural frequency.

- The structural damping coefficients of BFRP composites are as good as GFRP composites.
- There is better agreement between the experimental and numerical results.

## 5. References

1. Botelho EC, Costa ML, Pardini LC, Rezende MC. Processing and hygrothermal effects on viscoelastic behavior of glass fiber/epoxy composites. *J Mater Sci*. 2005; 40:3615–23.
2. Kumar LR, Datta PK, Prabhakara DL. Dynamic instability characteristics of laminated composite doubly curved panels subjected to partially distributed follower edge loading. *Int J Solid Struct*. 2005; 42:2243–64.
3. Rio TG, Barbero E, Zaera R, Navarro C. Dynamic tensile behavior at low temperature of CFRP using a split Hopkinson pressure bar. *Compos Sci Technol*. 2005; 65:61–71.
4. Thomas S, Geethamma VG, Kalaprasad G, Groeninckx G. Dynamic mechanical behavior of short coir fiber reinforced natural rubber composites. *Composites Part A*. 2005; 36:1499–506.
5. Yang W-P, Chen L-W, Wang C-C. Vibration and dynamic stability of a traveling sandwich beam. *J Sound Vibr*. 2005; 285:597–614.
6. Hao XY, Gai GS, Lu FY, Zhao XJ, Zhang YH, Liu JP, et al. Dynamic mechanical properties of whisker/PA66 Composites at high strain rates. *Polymers*. 2005; 46:3528–34.
7. Biggerstaff JM, Kosmatka JB. Effect of particulate tougheners on the damping of composite laminates. *Smart Struct Mater*. 2000; 3989:531–8.
8. Kishi H, Nagao A, Kobayashi Y, Matsuda S, Asami T, Murakami A. Carboxyl-terminated butadiene acrylonitrile rubber/epoxy polymer alloys as damping adhesives and energy absorbable resins. *J Appl Polym Sci*. 2007; 105:1817–24.
9. Sanjoy KN, Manoranjan B, Smita M. Mechanical, thermal and dynamic-mechanical behavior of Banana fiber reinforced polypropylene nanocomposites. *Polymer Composites*. 2011; 32(8):1190–201.
10. Chandra R, Singh SP, Gupta K. Damping studies in fiber reinforced composites - a review. *Compos Struct*. 1999; 46(1):41–51.
11. Chakraborty S, Mukhopadhyay M, Mohanty A.R. Free vibrational responses of frp composite plates: experimental and numerical studies. *Journal of Reinforced Plastics and Composites*. 2000; 535–51.
12. Salim S, Iyengar NGR, Yadav D. Natural frequency characteristics of composite plates with random properties. Department of Aerospace, IIT Kanpur. *Journal on Structural Engineering and Mechanics*. 1998; 6(6).
13. Tsai JL, Chi YK. Effect of fiber array on damping behaviors of fiber composites. *Composites Part B*. 2008; 39:1196–204.
14. Xu L, Wang R, Zhang S, aLiu Y. Vibration characteristics of glass fabric/epoxy composites with different woven structures. *Journal of Composite Materials*. Sage Publications. 2010; 45(10):1069–75.
15. Rajamurugan TV, Shanmugam K, Palanikumar K. Mathematical model for predicting thrust force in drilling of GFRP composites by multifaceted drill. *Indian Journal of Science and Technology*. 2013 Oct; 6(10):5316–24.
16. Suresh Kumar J, Dharma Raju T, Vijaya Kumar Reddy K. Vibration analysis of composite laminated plates using higher-order shear deformation theory with zig-zag function. *Indian Journal of Science and Technology*. 2011 Aug; 4(8):960–6.
17. Ganesa P, Thirumavalavan S. Free vibration behavior of Glass Fiber Reinforced Polymer Composite. *Middle East Journal of Scientific Research*. 2014; 20(6):734–7.
18. Kim MT, Rhee KY, Jung I, Park SJ, Hui D. Influence of seawater absorption on the vibration damping characteristics and fracture behaviors of basalt/CNT/epoxy multiscale composites. *Composites: Part-B*. 2014; 63:61–6.