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AN INVESTIGATION ON CHARACTERISTICS AND FREE VIBRATION ANALYSIS OF LAMINATED CHOPPED GLASS FIBER REINFORCED POLYESTER RESIN COMPOSITE

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ABSTRACT

In this paper material characterization and free vibration analysis of polyester resin based two, four and six layers chopped strand mat (CSM 450g/m^2 specific weight) glass fiber reinforced with (CGRP) composite materials has been determined. In material characterization the tensile, flexural, impact, inter-laminar shear strength, fracture toughness has been evaluated. The results have revealed that, the four layer CGRP composite material has high impact, inter laminar shear strength and fracture toughness compared to two and six layers composite material. Free vibration analysis was carried out to determine the natural frequency of the CGRP composite materials theoretically and numerically (FEA). The result obtained from free vibration analysis indicated that natural frequency of six layers CGRP composite material is more than two and four layers CGRP composite material.

Keywords: chopped strand mat, polyester resin, scanning electron microscopy, ANSYS.

INTRODUCTION

Composite materials are finding increased usage in many applications mainly due to their high strength to weight ratio and focussed R&D work is undertaken in developing high performance materials for building and construction, railways, automobiles, aerospace, bio-medical etc. Zhihang *et al.* [1] found that adding oxidised multi walled carbon nano tubes (OMWNT) to the resin will increase the inter laminar shear strength (ILSS) of the hybrid OMWNT/glass/epoxy composites. Tayeb *et al.* [2,3] fabricated CSM with polyester resin by hand-layup method and used SEM to determine damage of different features in the matrix and CSM glass fiber associated with higher values of load, speed, and sliding distance such as micro and macro cracks in the matrix, interface separation, fiber debonding and fracture, and different sizes of fractured fibers.

Franz *et al.* [4] conducted experimental investigation to determine the response of glass fiber chopped strand mat laminates under air pressure blasts. From the experimental investigation it is found that strength of the laminate increases with laminate thickness. Shokrieh *et al.* [5] determined that by the addition of 0.3 weight percentage of multi walled carbon nanotubes on CSM/polyester resin will increase both the tensile and compressive strength and modulus of the composite material. Arifin *et al.* [6] fabricated six different CSM/ woven roving/ polyester/ epoxy composite and conducted charpy impact test to determine the strength and failure of the material. Sern *et al.* [7] performed traction–compression biaxial testing in chopped glass-reinforced polyester, they found the shear strength and the shear failure strain of the composite. Ramesh *et al.* [8] developed sisal-jute-glass fiber reinforced polyester composites and determined the mechanical properties such as tensile strength, flexural strength and impact strength. In their study they found that sisal–jute fiber with glass fiber reinforced polymer can improve the properties and used as an alternate material for glass fiber reinforced polymer composites.

Arina *et al.* [9] fabricated CSM 600 GSM reinforced with polyester resin and determined the basic failure modes occurred in four layers CGRP composite specimen subjected to tensile test. Chandradass *et al.* [10] carried out an experimental and theoretical study of free vibration analysis and damping characteristics of hybrid nano composite laminates by reinforcing short fiber chopped strand mat and organically modified montmorillonite clay (0, 1, 3 and 5 wt.%) in the vinyl ester matrix by hand lay-up technique.

Many researchers investigated the mechanical characteristics of glass fiber reinforced polyester composite specimen. However, experimental investigation on different layers of CSM has not received much attention. Therefore, the aim of this study is to fabricate two, four and six layers laminated CSM and determining the mechanical characteristics and free vibration analysis of the material.

EXPERIMENTAL DETAILS

a) Composite preparation

A mould of 250 mm x 250 mm was selected for sample preparation. By means of hand-layup process CSM glass fiber of 450 g/m^2 is reinforced with polyester resin and samples of two, four and six layers CGRP composites as shown in Figure-1 are prepared. Initially a 2 wt % cobalt and catalyst as accelerator were pre-mixed with the polyester resin. A release agent is applied over the mould then prepared polyester resin is spread over the release agent. Before the polyester resin gets dried CSM is kept over polyester resin and again polyester resin is spread over this CSM. Then second layer CSM is kept over the polyester resin and above this layer again polyester resin is

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applied. By using roller polyester resin is equally distributed to the surface of CSM. Voids between the layers are properly squeezed out. After this the CGRP composite material is allowed to cure in room temperature. Similarly four and six layers CGRP composite samples are prepared.

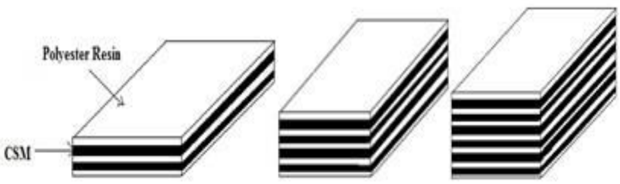

Figure-1. Two, four and six layers laminated CGRP composite.

The mechanical properties of CSM and polyester resin are shown in Table-1 and composition of CGRP composite materials are shown in Table-2.

Table-1. Mechanical properties of reinforcement and matrix [6].

Material	Young's modulus (GPa)	Poisson's ratio	Density (g/cm³)
CSM	75	0.2	2.54
Polyester resin	3.5	0.25	1.161

Table-2. Composition of CGRP composite.

Layers	Sample thickness (mm)	CSM fiber volume %	Polyester resin volume %
2	2	45	55
4	3.5	51.43	48.57
6	5	54	46

The volume percentage of reinforcement and matrix was calculated by using rule of mixture.

$$V_C = V_f + V_m \tag{1}$$

Where, V_C is the volume of CGRP composite material.

V_f is the volume of CSM.

V_m is the volume of resin.

EXPERIMENTAL RESULTS

a) Tensile test

Based on ASTM D3039 standard [12] samples are cut at 250 mm length and 25 mm width. The gage length is taken as 150 mm and speed of testing is set as 2 mm/min in universal testing machine (UTM). The experimental tensile test results of CGRP composite samples were shown in Figure-3 and Table-3. The Figure-3 shows the nature of material failure and the curve shows that the failure occurs by means of linear plastic strain. Six layers CGRP composite material has achieved a maximum tensile stress of 144 MPa, four and two layers CGRP composite material has tensile stress of 118 and 81.6 Mpa respectively.

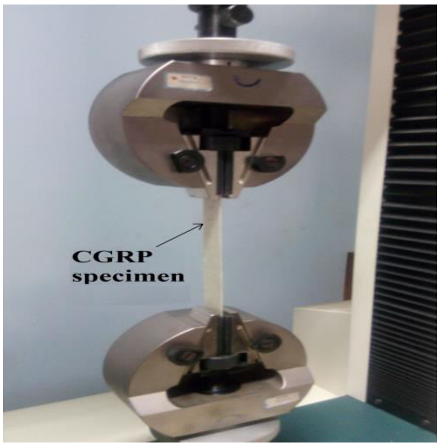

Figure-2. Experimental tensile testing in UTM.

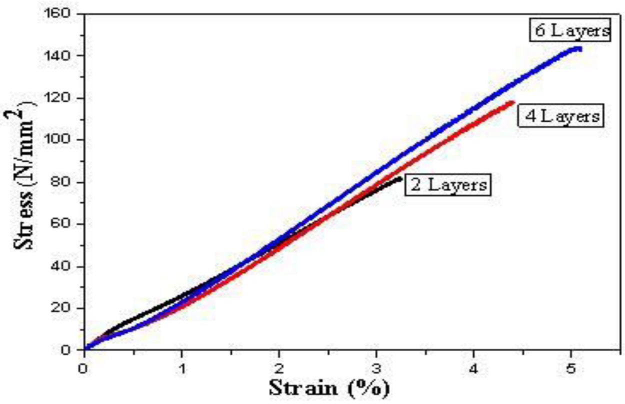

Figure-3. Tensile stress vs strain curve of CGRP composite samples.

Table-3. Experimental tensile results.

Composite samples	Tensile load (N)	Tensile stress (MPa)	Tensile Modulus (MPa)	Elongation (%)
2 Layers	4070	81.6	3280	3.25
4 Layers	10900	118	3390	4.41
6 Layers	18500	144	3800	5.08

b) Bending (Flexural) test

The CGRP composite samples are prepared based on ASTM D790 standard [13] for conducting the flexural test. The span length of 16 x thickness of samples is

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prepared. Speed of testing (crosshead motion) in UTM is set as,

$$R = \frac{ZL^2}{6d} \quad (2)$$

Where, R = rate of crosshead motion (mm/min).
L = support span (mm).
d = depth of beam (mm).
Z = rate of straining of the outer fiber (mm/mm/min), Z = 0.01.

The flexural experimental result helps to determine the maximum bending load and maximum bending stress that material can withstand, when external bending load is applied. The experimental flexural results are shown in Figure-4 and Table-4. The two layers CGRP composite material has more strain percentage with respect to stress than four and six layers CGRP composite material. This identifies that two layers CGRP composite material has less stiffness compared to four and six layers CGRP composite material.

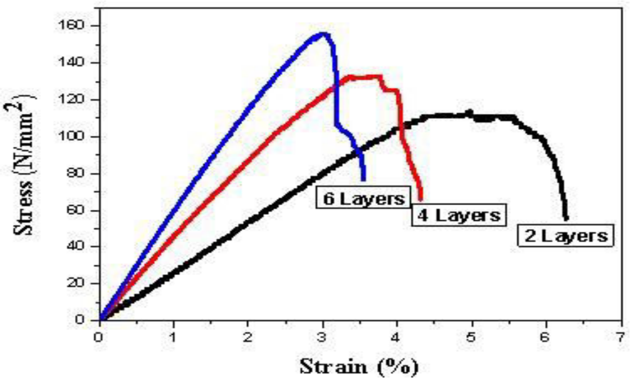

Figure-4. Flexural stress vs strain curve of CGRP composite samples.

Table-4. Bending load and maximum bending stress of composite samples.

Composite samples	Maximum flexural load (N)	Flexural Stress (MPa)	Flexural Modulus (MPa)
2 Layers	110	114	2700
4 Layers	280	133	4490
6 Layers	398	156	5910

c) Charpy impact test

Charpy impact test has been carried out to find the impact strength and absorbed energy of CGRP composite samples. Four layers CGRP composite samples have higher impact strength than two and six layers CGRP composite samples. Absorbed energy of six layers CGRP composite samples is more than two and four layers CGRP composite samples. Figures-5 and 6 show the impact and absorbed strength of two, four and six layers CGRP composite samples. Figures-7 to 9 show the cross sectional SEM images of two, four and six layers CGRP composite sample subjected to charpy impact test. These SEM images help to identify the interface between matrix and reinforcement of CGRP composite samples. Figure-7 shows the fractured matrix and separated reinforcement of two layers CGRP composite sample due to charpy impact test.

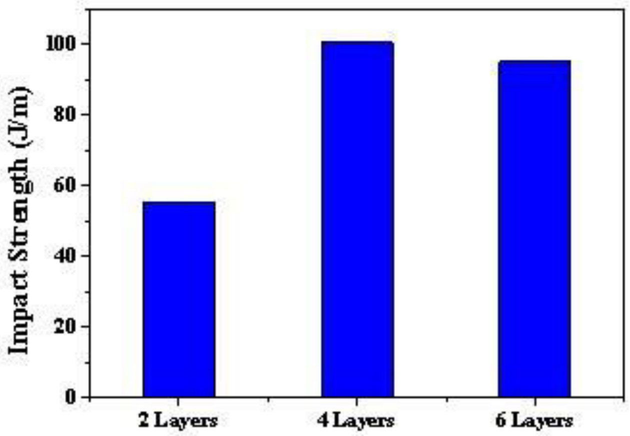

Figure-5. Impact strength of CGRP composite samples.

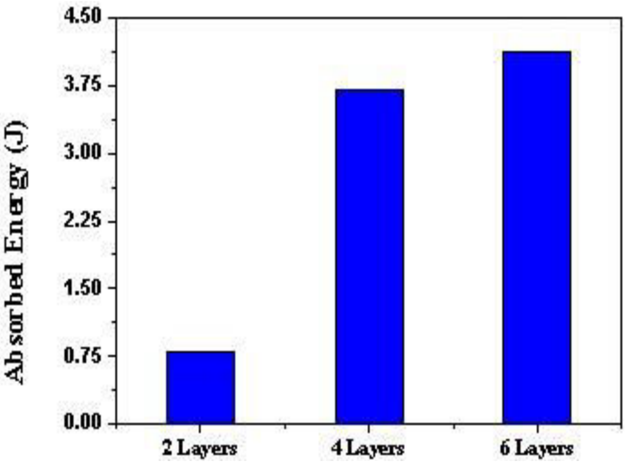

Figure-6. Absorbed energy of CGRP composite samples.

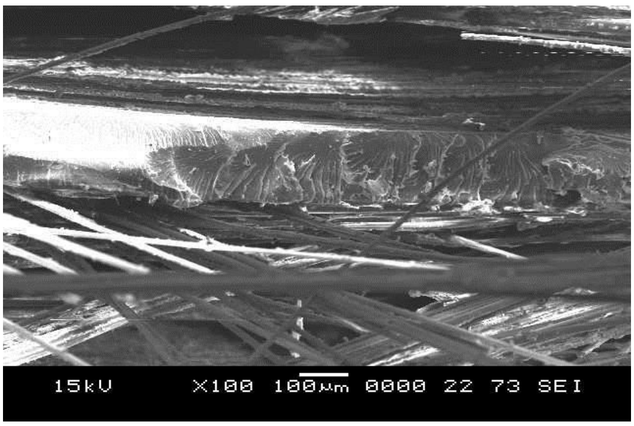

Figure-7. Cross sectional SEM image of two layers CGRP composite sample.

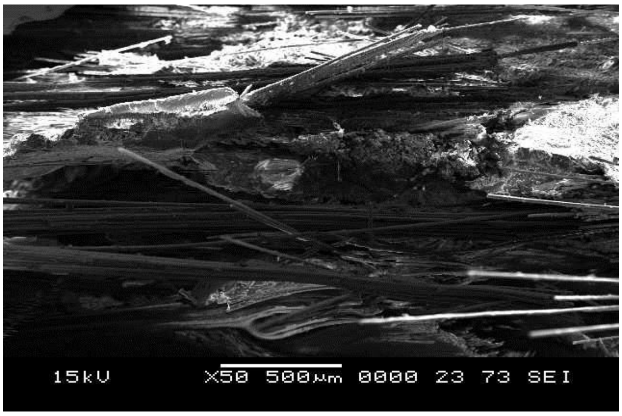

Figure-8. Cross sectional SEM image of four layers CGRP composite sample.

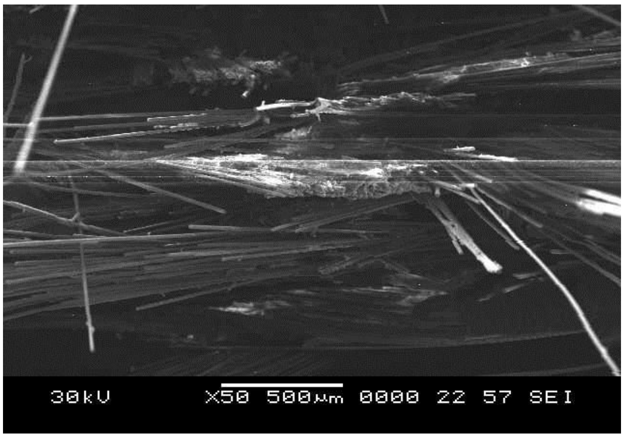

Figure-9. Cross sectional SEM image of six layers CGRP composite sample.

d) Density of composite samples

The actual density of the CGRP composite material was determined by using Archimedes principle. From the testing it was found that density of six layers laminated CGRP composite sample is lower than two and four layers CGRP composite sample. The theoretical density of CGRP composite sample is calculated by using Rule of Mixtures as shown in equation (3).

$$\rho_C = \rho_f V_f + \rho_m V_m \quad (3)$$

Table-5. Density of composite samples.

Composite samples	Density	
	Actual (g/cm³)	Theoretical (g/cm³)
2 Layers	1.456	1.781
4 Layers	1.463	1.870
6 Layers	1.445	1.905

e) Fracture toughness

Figure-10. Fracture toughness testing in UTM.

Fracture toughness is a property which describes the ability of a material containing a crack to resist fracture. Based on ASTM D5045 standard [14], crack is created at the samples and three point bend specimen testing is carried on the UTM. The obtained results are shown in Figure-11. This result shows that the ultimate force required for fracturing the sample increase with increase in layers, whereas ultimate stress and modulus of elasticity of four layers sample is higher than two and six layers CGRP composite samples. The fracture load P_Q, obtained from the single edge notch bend (SENB) test are used to determine K_Q values (MPa.m$^{1/2}$) as a measure of fracture toughness by using equation (4).

$$K_Q = \left(\frac{P_Q}{BW^{1/2}}\right) f(x) \quad (4)$$

Where (0<x<1),

$$f(x) = 6x^{1/2}\,\frac{\left[1.99 - x(1-x)(2.15 - 3.93x + 2.7x^2\right]}{(1+2x)(1-x)^{3/2}}$$

Where, B = specimen thickness (cm).
W = specimen width (cm).
a = crack length (cm).
x = a/W.

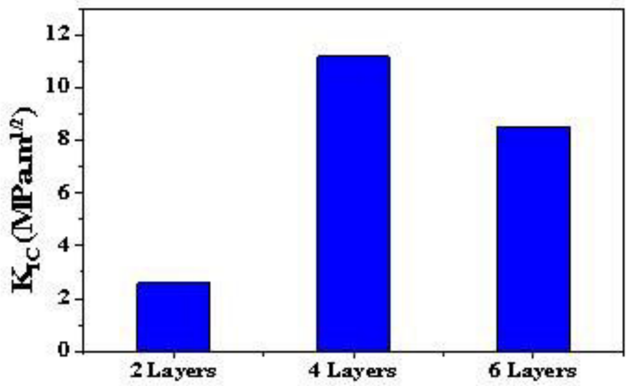

Figure-11. Fracture toughness of composite samples.

f) Inter laminar shear strength

Inter laminar shear strength (ILSS) helps to determine the de-lamination in the laminated samples.

Maximum ILSS occurred at the mid thickness of the beam. Based on ASTM D2344 standard [15], CGRP composite samples are tested in the UTM. Inter laminar shear strength calculated by using short beam strength equation (5). From the experimental result, four layers CGRP composite material has more ILSS than six and two layers CGRP composite samples.

$$F = 0.75X \frac{P}{bXh} \quad (5)$$

Where, F = short-beam strength (MPa).
P = maximum load observed during the test (N).
b = measured specimen width (mm).
h = measured specimen thickness (mm).

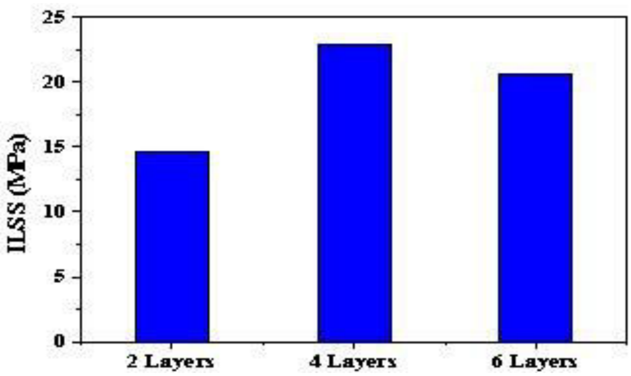

Figure-12. Inter laminar shear strength of CGRP composite samples.

FREE VIBRATION ANALYSIS

Free vibration analysis is carried out to determine the natural frequency of CGRP composite. The computational and theoretical natural frequency corresponding to first four mode shapes of two, four and six layers CGRP composite material was determined and readings are shown in Table-6. A cantilever beam of length 200 mm and width 25 mm of CGRP composite material is modelled in ANSYS software and corresponding mode shape and natural frequency is determined and shown in Figure-13. Theoretical natural frequency for 1st four mode shape is calculated using Euler-Bernoulli cantilever beam equation (6).

$$\omega_1 = 1.875^2 \sqrt{\left(\frac{EI}{\rho A l^4}\right)} \text{ rad/sec}$$

$$\omega_2 = 4.694^2 \sqrt{\left(\frac{EI}{\rho A l^4}\right)} \text{ rad/sec}$$

$$\omega_3 = 7.854^2 \sqrt{\left(\frac{EI}{\rho A l^4}\right)} \text{ rad/sec}$$

$$\omega_4 = 10.995^2 \sqrt{\left(\frac{EI}{\rho A l^4}\right)} \text{ rad/sec} \quad (6)$$

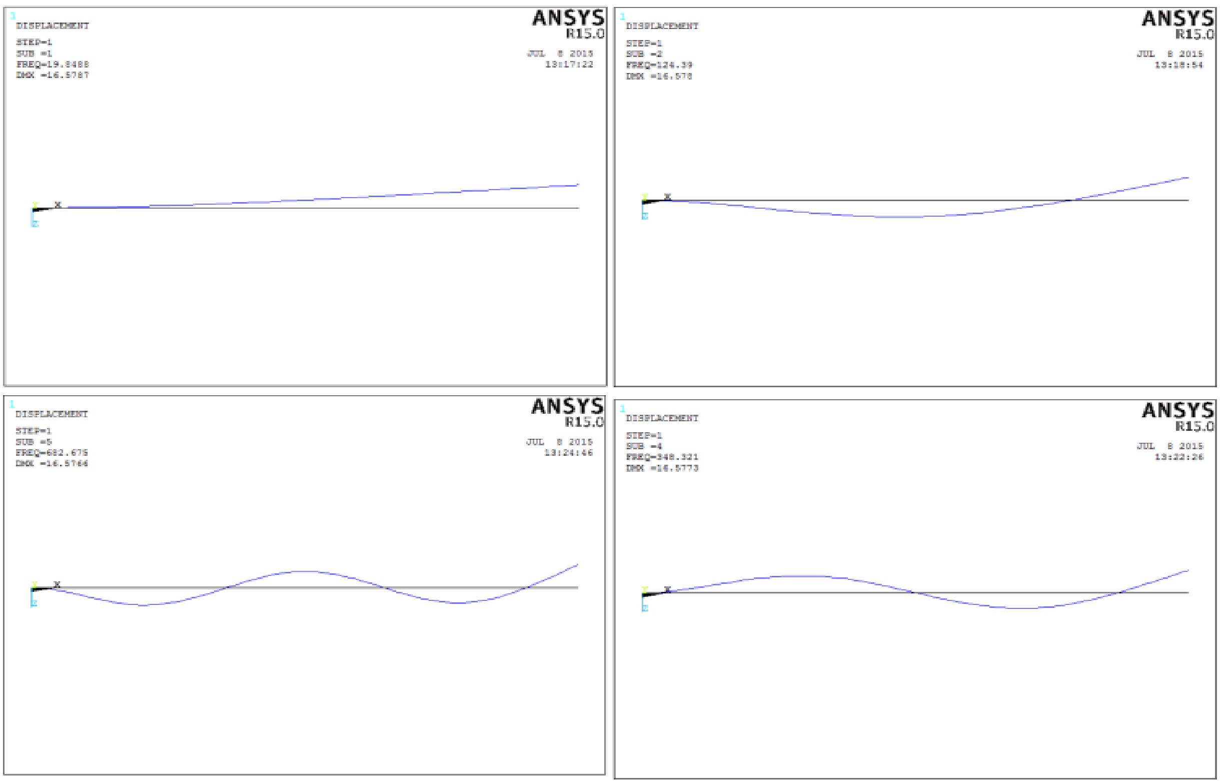

Figure-13. Mode shape of two layers CGRP composite cantilever beam shown in clockwise direction.

Table-6. Natural frequencies of CGRP composite material.

Mode Shape	Natural Frequency (Hz)					
	2 Layers		4 Layers		6 Layers	
	ANSYS	Theoretical	ANSYS	Theoretical	ANSYS	Theoretical
1	19.84	25.10	49.79	45.51	71.11	65.00
2	124.39	157.31	311.67	285.23	444.51	412.99
3	348.32	440.41	871.15	798.54	1239.65	1156.21
4	682.68	863.12	1702.81	1564.00	2415.30	2265.93

DISCUSSION

The experimental tensile result indicates that increase in number of layers in CGRP composite samples will increase the tensile strength in the material. The flexural experimental results shows that increase in number of layers will increase the maximum bending load and decrease the strain percentage of CGRP composite samples. The density test shows that four layers CGRP composite material has more density than two and six layers CGRP composite material. In two layers CGRP composite material the volume percentage of resin is more than the volume percentage of reinforcement and in six layers CGRP composite material the volume percentage of reinforcement is more than the volume percentage of resin. Hence from the experimental analysis it is clearly determined that equal volume percentage of resin and reinforcement gives more strength to the CGRP composite material. Hence four layers CGRP composite materials have high impact strength, fracture toughness and inter laminar shear strength than two and six layers CGRP composite material. Hence its clearly identified that impact strength, fracture toughness and inter laminar shear strength of the CGRP composite material does not depend on increasing the number of layers i.e. increase in thickness of the material but it depends on volume percentage of matrix and resin.

Free vibration analysis is used to determine the natural frequency of CGRP composite. The natural frequency for 1st four mode shape of CGRP composite was determined using ANSYS software and theoretically. The natural frequency of CGRP composite was increased with respect to increase in number of layers of CSM in CGRP composite samples. Hence from the numerical and theoretical result it was found that stiffness of CGRP composite material will increases with increase in the number of layers of CSM.

CONCLUSIONS

Four layers CGRP composite material has high impact strength, fracture toughness, and interlaminar shear strength compared to two and six layers CGRP composite material. For better characteristics and mechanical properties of CGRP composite, equal volume percentage of CSM and resin is recommended. From the vibration analysis it is found that natural frequency of CGRP composite material is increased with increase in number of layers of CSM.

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