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Research Article

Investigations on Properties of Glass Fibre Reinforced Polymer Composite

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Abstract:

The aim of present study is to investigate the water absorption, mechanical and thermal properties of glass fibre reinforced polymer composites (GFRPCs). Multi layers of woven glass fibres are reinforced into epoxy matrix to prepare the composites by hand lay-up technique. Water absorption properties are investigated in terms of percentage of water uptake, and sorption, diffusion and permeability coefficients. On the other hand, mechanical properties are investigated in terms of tensile, flexural and impact test as per ASTM standards. Moreover, thermal properties are investigated using thermogravimetric analysis (TGA) and dynamic mechanical analysis (DMA). The results have been shown that water absorption, mechanical and thermal properties are increased with increase in numbers of layers of woven glass fibres in epoxy matrix.

Keywords: Fibres; Mechanical properties; Water absorption properties; Thermal properties

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1. Introduction

Recently, fibre reinforced polymer composites (FRPC) have been considered as the most promising structural materials in the sustainable engineering technology on account of high strength-weight ratio, higher stiffness, cost effectiveness and good reproductively. In FRPCs, high strength fibres are reinforced into low modulus continuous polymeric matrix to make the composites. In the case of FRPCs, reinforcement may be either synthetic fibres (glass, carbon, aramid or basalt) or natural fibres (banana, jute, sisal, hemp, bamboo, coir, kenaf and so on), while matrix materials may be thermosets, thermoplasts or bio polymers [1]. Fibres are the backbone of the FRPCs and verify the strength of the composites. The properties of FRPCs mainly depends upon strength and stiffness of fibres, polymer matrices, fibres loading, fibres sizes, fibres orientations, adhesion between fibres and polymeric matrices [2].

Glass fibres are being used in many industries such as automotive, aerospace, construction and military due to their unique properties such as lightweight, high strength and modulus, good availability, recyclability, high strength and toughness, and ease of processing [2-7]. Glass fibres are the most frequently used reinforcement for polymeric matrix to prepare its composites. The E-glass and S-glass are the most common and commercially used glass fibres. E-glass is the least expensive than other glass fibres and having a wide range of applications in plastic industry. On the other hand, S-glass shows the higher tensile strength and modulus than E-glass. However, E-glass fibre is very popular as compare to S-glass due to its low cost. Alkali-resistant glass fibres have a small amount of zirconium which helps to prevent corrosion by alkali attacks. Nowadays, GSRPCs have been used in electronics parts such as circuit board, televisions, radios, computers and phones [8-10]. Moreover, these composites are also being used in many other areas such as house wares, constructions, aerospace, boats, marine and medical applications [11-12].

Epoxy resin is one of the most used thermosets polymers due to its excellent properties such as good interface, low curing time, high stiffness, better mechanical properties, lower moisture absorption and ease processing at room temperature [13] . They are transparent, light amber color and have very little shrinkage. In addition, as adhesive theses materials have shown extremely high bond strengths without the need of pressure for curing [14]. Moreover, it also has excellent resistance to chemicals and heat, which make them ideal for electronics and electrical systems as well as other industrial applications. Epoxy resin was used by many researchers by reinforcing different fibres such as glass fibres [2, 15-16], and natural fibres such as jute [17], sisal [18], banana [19-20], hemp[21], kenaf [22], bamboo[23] to prepare the composites in order to analysis of their properties.

In present work, glass composites are subjected to water absorption, mechanical and thermal properties. The enhanced mechanical and thermal properties of present glass composites compared to natural fibres reinforced polymer composites (NFRPCs) proves their worth for more advanced applications.

2. Materials and methods

2.1. Materials

Woven glass fibres are used as reinforcement and epoxy resin as a matrix in this work. Glass fibres and epoxy matrix were purchased from the local resource. Epoxy resin (Araldite Klear 4+) and corresponding curing agent (Hardener Klear 4+) are mixed in ratio of 10:8 to make the matrix as recommended by the suppliers.

2.2. Fabrication of composites

The composites were fabricated by reinforcing woven glass fibres into epoxy matrix by hand- lay- up technique. A stainless steel mould having dimensions of 300 × 200 × 3 mm^3 was used to maintain the required thickness of the composites. During fabrication process, a releasing agent was used to assist easy removal of the composites from the mould after curing. The cast of each composite was cured under a load of 50 kg for 24 hours before it was removed from the mould. The specimens were cut from the laminates using a diamond cutter for characterization as per ASTM standard.

The composites manufactured with varying wt. % of fibres are designated as G3 (epoxy composite reinforced by 3 layers of glass fibre), G6 (epoxy composite reinforced by 6 layers of glass fibre**)**, G9 (epoxy composite reinforced by 9 layers of glass fibre) and G12 (epoxy composite reinforced by 12 layers of glass fibre).

3. Characterization

The fabricated composites were tested for water absorption, mechanical and thermal properties as per ASTM standards. Descriptions about these experiments are provided in following paragraphs.

3.1. Water absorption behavior

Normally, GFRPCs have lower water absorption than NFRPCs due to hydrophobic nature of glass fibres. Water absorption of polymer composites mainly depends upon micro-voids present in the composites and interfacial area between fibres and matrix. The water absorption by composites may be causes of reduction in mechanical properties along with change in dimensions of composite samples. Water absorption of FRPCs was found very similar to Fickian's diffusion process at low temperature [24].

Water absorption behavior of GFRPCs was carried out as per ASTM D 570. The percentage of water absorption is calculated using following equation:

$$\text{Water absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100 \quad (1)$$

where W_1 = weight before soaking into water (g) and W_2 = weight after soaking into water (g).

Many researchers have developed models to study the water absorption behaviour of FRPCs [25-27]. Total water absorption by composites can be expressed as follows:

$$\frac{M_t}{M_S} = 1 - \sum_{n=0}^{S} \frac{8}{(2n+1)^2 \pi^2} \exp\left[\left(-D(2n+1)^2 \pi^{2t} / (4b^2)\right)\right] \quad (2)$$

where M_t = total amount of diffusion at time t, M_s = diffusion at saturation time and b = half thickness of sample.

The kinetic parameters such as sorption, diffusion and permeability coefficient derived from equation (2) , as given in following equations [28]:

$$\text{Sorption coefficient } S = M_s \,/\, M_t \quad (3)$$

where M_s and M_t are percentage of water uptake at saturation time and at a specific time t.

$$\text{Diffusion coefficient}(D) = \pi \left(\frac{t^2 m^2}{16 M_s^2} \right) \quad (4)$$

where m is the slope of water absorption versus time graph, and t is the initial sample thickness in (mm).

Permeability coefficient $P = D \times S$ (5)

3.2. Mechanical properties

3.2.1 Tensile test

Tensile test of the composite samples was performed on Universal Testing Machine (model, Tinius Olsen H 10 K-L) as per ASTM D638. Tests were conducted at a crosshead speed of 1 mm/min using samples in dimensions of 165 mm × 20 mm × 3 mm. Five specimens of each composite are tested and their average values along with standard deviations are reported.

3.2.2. Flexural test

Flexural test of the composite sample was performed using a three point bending mode on Universal Testing Machine (model, Tinius Olsen H 10 K-L) as per ASTM D790. The rectangular samples were prepared for the flexural test with dimensions of 80 mm × 12.7 mm × 3 mm. The flexural test was carried out at 30 °C using crosshead speed of 1 mm/min. Flexural strength and flexural modulus are calculated using following equation.

$$\text{Flexural strength} = \frac{3FL}{2bd^2} \quad \text{and} \quad \text{Flexural modulus} = \frac{mL^3}{4bd^3} \quad (6)$$

where F is failure load (N), L is span length (mm), b and d are width and thickness of specimen in (mm) respectively and m is slope of load-displacement curve. Five specimens of each composite are tested and their average values along with standard deviations are reported.

3.2.3. Impact test

Izod Impact test with notch of composites sample was performed on Impact Testing Machine (model, Tinius Olsen Impact-104) as per ASTM D 256. The samples were prepared for the impact test with dimensions 65 mm × 12.7 mm × 3 mm and 2.5 mm notch thickness. Five specimens of each composite are tested and their average values along with standard deviations are reported.

3.3. Statistical analysis

Statistical analysis is commonly used tool to see that performed test is significant or not. T-test and Analysis of variance (ANOVA) were used to carried out the statistical analysis of tensile, flexural and impact test. Probability value p =0.05 was consider as an analytical of significance compared to the control composite (G3).

3.4. Thermogravimetric analysis (TGA)

Thermal stability of the glass composites sample was analyzed by Thermogravimetric Instrument

(model, Perkin Elmer TGA 4000). TGA measurements were carried out on 15-20 mg of samples placed in a platinum pan and heated from 30 ºC - 800 ºC at a heating rate of 10 ºC / min in a nitrogen atmosphere.

3.5. Dynamic mechanical analysis

The dynamic mechanical properties of GFRPCs were studied using the dynamic mechanical analyzer (model, Seiko instruments DMA 6100). The dynamic mechanical properties were determined using 3 point bending test as a function of temperature. The composites were cut into samples having dimensions of 50 mm × 13 mm × 3 mm as per ASTM D 5023. Experiments were carried out in the temperature range of 30 °C–200 °C at 5 Hz frequency. The dynamic mechanical properties such as storage modulus, loss modulus, damping and glass transition temperature of prepared composites were investigated.

4. Results and discussion

4.1. Water absorption properties

The percentage of water absorption of GFRPCs is plotted against the square root of time in order to study its characteristic parameters, as shown in Figure 1. It can be observed that percentages of saturated water uptake are found to increase with increase in fibres loading (Table 1). Initial rates of water absorption of all glass composites are high due to presence of micro-voids in epoxy matrix which allows diffusing the water molecules till saturation state. Initial water absorption rate and percentage of saturated water uptake are found the maximum for glass composite G12. This can be due to higher fibres loading leads to development of much micro-voids which results in higher diffusion of water molecules. The composite G12 shows the higher water absorption which is 85%, 14% and 5% more than those of composites G3, G6 and G9 respectively at saturation state.

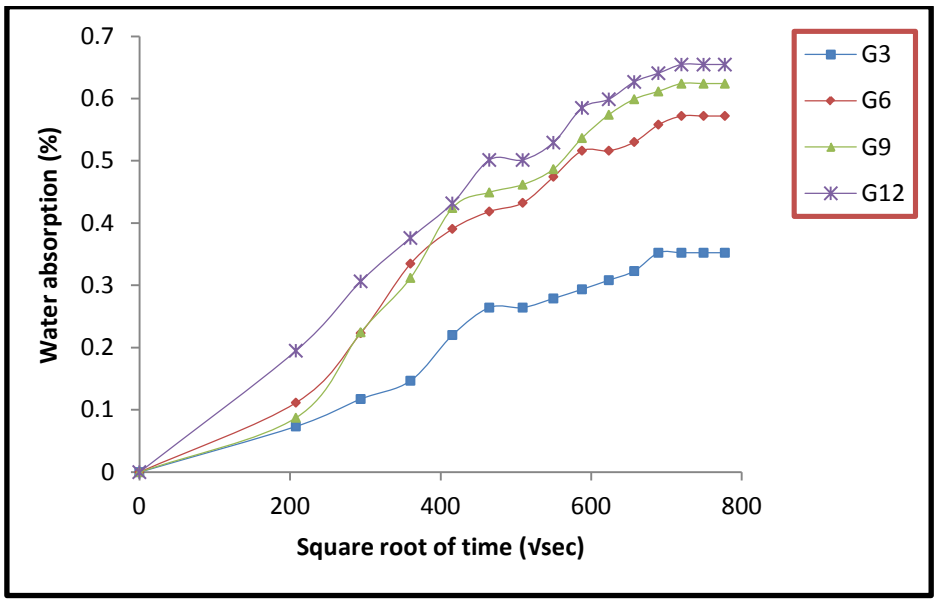

Figure 1 Variation of water absorption (%) with square root of time for glass composites

Table 1 Sorption, diffusion and permeability coefficient of glass composites

Composites	Percentages of water uptake at infinite time	Sorption coefficient S	Diffusion coefficient D ($mm^2/s \times 10^{-6}$)	Permeability coefficient P($mm^2/s \times 10^{-6}$)
G3	0.35	4.79	1.78	8.53
G6	0.57	5.13	1.55	7.95
G9	0.62	7.13	0.80	5.70
G12	0.65	3.35	3.66	12.26

The characteristic parameters such as sorption, diffusion and permeability coefficient of glass composites are calculated and provided in Table 1. Diffusion coefficient is one of the most important parameter of water absorption behavior, shows capacity to absorb the water. It can be seen that the composite G12 shows the highest value of diffusion coefficient followed by G3, G6 and G9. Permeability coefficient that shows the net effect of water absorption is found maximum in glass composite G12 as expected. The lower value of sorption coefficient of glass composite G12 is due to higher slope of percentage water absorption versus square root of time curve. The calculated values of water absorption characteristics parameters are found close to previously published literatures [17-18, 28-31].

4.2. Mechanical properties

4.2.1 Tensile properties

The tensile properties in terms of tensile strength, tensile modulus and percentage of maximum tensile strain of GFRPCs are given in Table 2. It is observed that tensile strength, tensile modulus and tensile strain of glass composites are found to increase with increase in numbers of layers of woven glass fibres in epoxy matrix. This can be due to maximum loading of high strength glass fibres which provides an effective stress transfer results in increase in tensile properties. The glass composite G12 has 165%, 106% and 28% higher tensile strength than those of composites G3, G6 and G9 respectively. In addition, glass composite G12 has 71%, 62% and 69% higher tensile modulus than those of composites G3, G6 and G9 respectively. The increase in values of tensile strain follows the order: G9 > G6 > G12 > G3. According to statistical analysis the values of tensile strength and modulus are found to be significant as compared to glass composite G3. The results of ANOVA also show the differences among composites as shown in Table 2.

Table 2 Tensile properties of glass composites

Composites	Tensile strength (MPa)	Tensile modulus (GPa)	Maximum tensile strain (%)
G3	45.00 ± 3.44	1.16 ± 0.08	4.78 ± 0.31
G6	57.92 ± 4.96	1.22 ± 0.09	10.85 ± 0.85
G9	93.68 ± 6.08	1.17 ± 0.10	11.39 ± 0.78
G12	119.46 ± 8.93	1.98 ± 0.11	6.67 ± 0.43

4.2.2 Flexural test

The flexural properties in terms of flexural strength, flexural modulus and percentage of maximum

flexural strain of GFRPCs are given in Table 3. Similar to results of tensile tests, flexural properties are also found to increase with increase in numbers of layers of woven glass fibres in epoxy matrix. This fact credited to incorporation of high strength and stiffer glass fibres which provides better adhesion between fibres and matrix thereby increase in flexural properties. Flexural strength shows the stiffness of composites and mainly depends upon strength, stiffness and loading of fibres. The glass composite G12 has the maximum value of flexural strength which is 70%, 41% and 3% higher than those of composites G3, G6 and G9 respectively. In addition to this, glass composite G12 has 46%, 45% and 11% higher flexural modulus than those of composites G3, G6 and G9 respectively. The increase in values of flexural strain follows the order: G3 > G9 > G6 > G12. According to statistical analysis the values of flexural strength and modulus are found to be significant as compared to the glass composite G3. The results of ANOVA also show the significant differences among composites as shown in Table 3.

Table 3 Flexural properties of glass composites

Composites	Flexural strength (MPa)	Flexural modulus (GPa)	Maximum flexural strain (%)
G3	97.67 ± 7.44	3.89 ± 0.25	7.19 ± 0.58
G6	117.38 ± 8.43	3.93 ± 0.23	5.12 ± 0.17
G9	161.72 ± 11.64	5.12 ± 0.22	5.55 ± 0.26
G12	165.78 ± 11.68	5.69 ± 0.31	4.84 ± 0.19

4.2.3 Impact test

The impact strength of prepared GFRPCs is provided in Table 4. Similar to tensile and flexural test results, impact strength is also found to be increase with increase in layers of woven glass fibres in epoxy matrix. The maximum value of impact strength is found for glass composite G12, which is 223%, 177% and 23% more than those of composites G3, G6 and G9 respectively. The glass composite G12 shows the highest impact strength than other all glass composites due to increased stiffness by maximum fibres loading thereby improvement in impact energy absorption capability. According to statistical analysis the value of impact strength is found to be significant as compared to glass composite G3. The results of ANOVA also show the significant differences among composites as shown in Table 4.

Table 4 Impact strength of glass composites

composites	Impact strength (J/m)
G3	31.22 ± 2.01
G6	36.49 ± 2.21
G9	81.99 ± 4.09
G12	100.90 ± 5.05

Table 5 Peak height and glass transition temperature (°C) from loss modulus and tan delta curve

Composites	Peak height of loss modulus curve (MPa)	Peak height of Tan delta curve	T_g from Loss modulus curve	T_g from Tan delta curve
G3	42.60	0.47	69.36	74.08
G6	46.00	0.54	56.15	74.06
G9	67.70	0.59	65.18	73.25
G12	129.00	0.63	69.29	77.53

4.3. Thermogravimetric analysis

Figure 2 shows variation of weight loss with increase in temperatures of GFRPCs. It can be observed that thermal stability of glass composites increases due to increase in layers of woven glass fibres in epoxy matrix. The initial weight loss (~ 5%) of glass composites G3, G6, G9, and G12 are obtained at temperatures 194, 198, 202 and 199 ºC respectively. The initial low temperature weight loss is due to removal of solvent from the composites [32]. The initial degradation temperatures of glass composites are found close to each other because percentage of fibres at lower temperature doesn't much effected the thermal stability. The major weight loss up to 75 % of glass composites lies between 350- 400 ºC. The major weight loss is due to degradation and volatization of epoxy along with fibres present in the composites. After increasing the temperature above to 400 ºC, it is observed that there is a large variations in degradation temperatures. This fact can be explained as strength and percentage of fibres much affected the thermal stability at higher temperature. At about 700 ºC , the glass composites G3, G6, G9, and G12 have 93%, 86%, 79% and 65% weight loss. The minimum weight loss at higher temperature is found for glass composite G12 which shows its better thermal stability than other all glass composites.

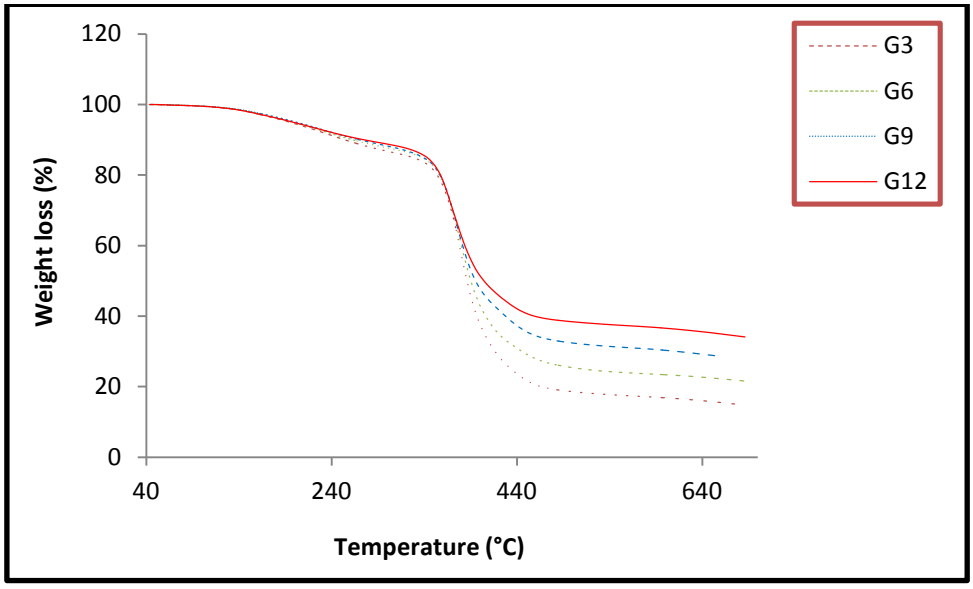

Figure 2 Variation of weight loss (%) with temperature for glass composites

4.4 Dynamic mechanical analysis

4.4.1. Storage modulus (E')

Fig. 3 shows the variation of storage modulus of glass composites as a function of temperature at 5 Hz frequency. Storage modulus of glass composites are found to be increase with increase in layers of woven glass fibres in epoxy matrix. In the glassy region, increase in storage modulus of glass composites follows the order: G12 > G9 > G6 > G3. It is also very interesting to observe that in glassy region (at low temperature) there is a large variations in values of storage modulus due to variation in percentages of fibres loadings. In all cases, the storage moduli are found to decrease with increase in temperature. This is due to loss in stiffness of fibres at high temperature [33-37]. In transition region, it can be seen that all glass composites have gradual fall in values of E' with increase in temperature. In

rubbery region, it is observed that the glass composite G12 has the highest value of E' whereas G6 has its lowest value. The lowest value of E' shows increase in molecular mobility due to increase in temperature [35]. The higher value of E' for glass composite G12 shows its higher thermal stability than other all composites.

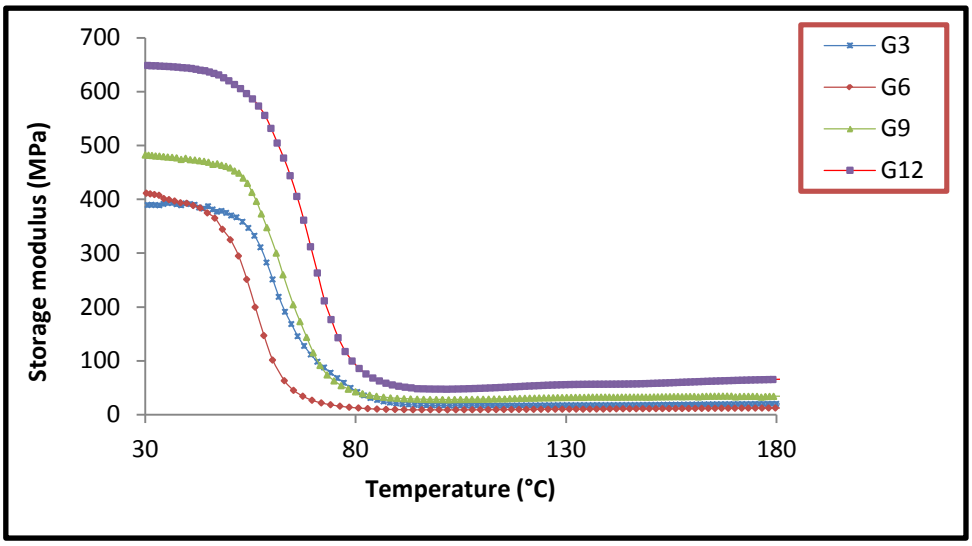

Figure 3 Variation of storage modulus with temperature for glass composites

4.4.2. Loss modulus (E'')

Loss modulus is an imaginary part of complex modulus, presents the viscous response of the polymeric materials. It depends upon interfacial adhesion between fibres and matrix, and motion of polymer chains in the composites at higher temperature. Glass transition temperature ($\boldsymbol{T}_g$) is defined as point where materials changes from glassy to rubbery state. It can be obtained from either peak of loss modulus or $Tan\delta$ curve [34-37]. The variation of loss modulus of glass composites as a function of temperature at 5 Hz frequency is shown in Fig. 4. It can be seen that the values of E'' increased up to $\boldsymbol{T}_g$ and then decreased with increase in temperature. The glass composite G3 has the lowest value of loss modulus as compared to other all glass composites. On the other hand, its highest value is shown by glass composite G12 due to strong interfacial adhesion. The maximum value of $\boldsymbol{T}_g$ is found for composite G3 which is very close to that of G12 (Table 5). The values of $\boldsymbol{T}_g$ for the glass composites which is obtained from peaks of loss modulus curve is given in Table 5.

4.4.3. Damping ($Tan\delta$)

Tan delta or damping is the ratio of loss modulus and storage modulus which is related to impact resistance and load bearing capacity of composite materials [35]. The variation of $Tan\delta$ of glass composites as a function of temperature at 5 Hz frequency is shown in the Fig. 5. The glass composite G12 has the highest peak of $Tan\delta$ curve which shows better damping as compared to those of other all glass composites. The peak of $Tan\delta$ curve for glass composites follows the order: G12 > G9 > G6 > G3. Shifting of $\boldsymbol{T}_g$ towards higher temperature is found for glass composite G12. This is due to decreased mobility of polymer chain by addition of glass fibres into epoxy matrix. The glass composite G12 has the highest value of $\boldsymbol{T}_g$ (77.53°C) which shows its better thermal stability than other all glass composites. The values of $\boldsymbol{T}_g$ obtained from $Tan\delta$ curve for glass composites is given in Table 5.

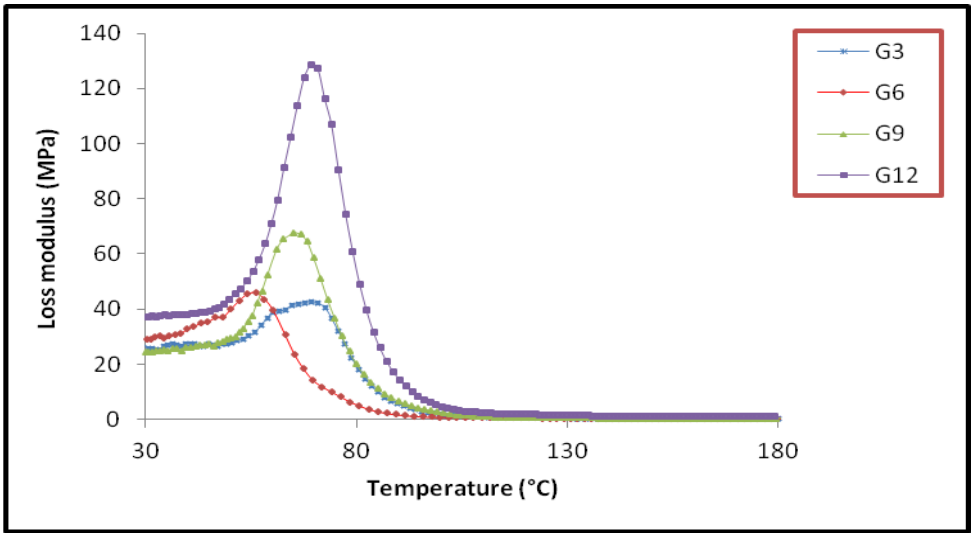

Figure 4 Variation of loss modulus with temperature for glass composites

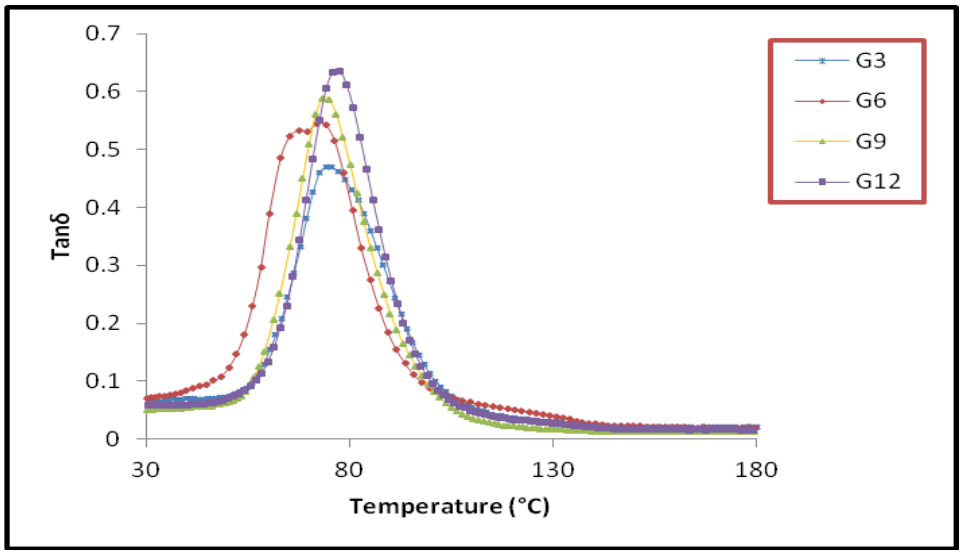

Figure 5 Variation of Tan δ with temperature for glass composites

5. Conclusions

The prepared glass composites are tested for water absorption, mechanical and thermal properties and following conclusions are drawn:

- Water absorption property of prepared glass composites is found to increase with increase in layers of woven glass fibres in epoxy matrix.
- The mechanical properties such as tensile, flexural and impact are found to be maximum for glass composite with maximum number of layers of glass fibres (G12).
- The glass composite G12 has the highest values of storage modulus, loss modulus and glass transition temperature than those of other glass composites.
- The TGA and DMA both results show that glass composite G12 has the highest thermal stability.

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