Chapter 5

INVESTIGATIONS AND DISCUSSION ON THREE POINT BEND TESTING OF GFRP COMPOSITES SUBJECTED TO DIFFERENT LIQUID ENVIRONMENTS.

This chapter gives the results of experiments conducted on the GFRP composites subjected to different liquid environments using three point bend test. The results include the variation of Fracture toughness with different fibre volume and damping. The test was carried out at every 15 days of time interval up to a maximum of 60 days. The bend test was performed for all the specimens irrespective of the notch length and load criteria requirements. Appendix II gives the values of Fracture toughness ($K_{fc}$) obtained for all the notched specimens and also for the specimens satisfying the notch size and load requirements.

5.1. Variation of Fracture toughness for untreated specimens

Figure 5.1 (a) shows the variation of Fracture toughness with fibre volume for specimens with different notch lengths. It can be seen that as the fibre volume increases the Fracture toughness increases. Also the Fracture toughness values obtained for the 10mm notch length specimen are higher than the 9mm notch length specimen. There was a decrease in the Fracture toughness value for specimen with 30% fibre volume. The Figure shows almost increase in the $K_{lc}$ value with the fibre volume, except for the 30% fibre volume specimen. For 9mm notch length specimens the increase in the Fracture toughness value is from $120.67 \text{MNm}^{-3/2}$ to a maximum of $124.21 \text{MNm}^{-3/2}$ and for 10mm notch length specimens the increase was from $139.41 \text{MNm}^{-3/2}$ to $145.89 \text{MNm}^{-3/2}$.

5.2. Effect of Seawater treatment on the Fracture toughness of GFRP composite

Variation of Fracture toughness with fibre volume for specimens treated with seawater and notch length of 9mm along with untreated specimens is shown in Fig. 5.1 (b). The variation of Fracture toughness of untreated specimens is discussed in section 5.1. For specimens immersed for 15 days the Fracture toughness values decreased for all the specimens irrespective of the fibre volume compared to untreated
specimens. A minimum decrease of 0.5 MNm$^{-3/2}$ was observed which was for 25% fibre volume specimen and a maximum decrease of 4 MNm$^{-3/2}$ was observed which was for 40% fibre volume specimen and all other specimens exhibiting decrease in between these two values. The decrease in strength is due to the absorption of seawater by the composite specimen. As the diffusion process of seawater into the composite increases the strength decreases and this is reflected in the results obtained.

For specimens soaked for 30 days, the Fracture toughness values further decreased. The decrease in the Fracture toughness values ranged from a minimum of 1.5 MNm$^{-3/2}$ (for 35% fibre volume specimen) to a maximum of about 3 MNm$^{-3/2}$ (for 30% fibre volume specimen). Again this decrease in the Fracture toughness values is due to the degradation of the composite specimen due to the absorption of the seawater. Specimens soaked for 45 days exhibit further decrease in the Fracture toughness values except for 30% fibre volume specimen which showed very marginal increase in the toughness value of the order of 1 MNm$^{-3/2}$. Maximum decrease in the Fracture toughness values was observed for 20% fibre volume specimen of the order of 5.6 MNm$^{-3/2}$ and a minimum decrease of 1 MNm$^{-3/2}$ was observed for 25% fibre volume specimen. The increase in the Fracture toughness value may be to testing errors.

Further increase in the soaking time for the specimens to 60 days showed mixed results. Some specimens showed increase in Fracture toughness values and some specimens showed decrease in the Fracture toughness values. While 20% fibre volume specimen did not show any variation with respect to 45 days time period soaking, 25% fibre volume specimen showed a decrease in toughness value of the order of 2.5 MNm$^{-3/2}$. All other specimens showed increase in the Fracture toughness values. Maximum increase was found for 35% fibre volume specimen of the order of 3 MNm$^{-3/2}$ and 40% fibre volume specimen showed a minimum increase of 2 MNm$^{-3/2}$. The increase in the Fracture toughness values for some these specimens is being investigated.

Fig. 5.1 (c) shows the variation of Fracture toughness with fibre volume for specimens soaked in seawater with notch length of 10mm along with untreated specimens. The variation of Fracture toughness of untreated specimens is discussed in section 5.1. For specimens treated for 15 days the Fracture toughness almost decreased for all the specimens except for 30% fibre volume specimen which showed an increase in the Fracture toughness value. The range for decrease in the Fracture
toughness value was from 0% to a maximum of 6.43% (9 MNm^{-3/2}). The trend shown here is similar to the trend exhibited by the specimens with notch length of 9mm. The decrease in the values of Fracture toughness is due to the absorption of seawater by the specimen which reduces the mechanical properties of the composite. The increase in the Fracture toughness value for 30% fibre volume specimen may due to testing errors. 35% fibre volume specimen showed no decrease (0%) in the value of Fracture toughness. Specimens soaked for 30 days also show a similar trend as before. All the specimens except for 30% fibre volume and 35% fibre volume show decrease in the Fracture toughness value. The decrease in the Fracture toughness values range from 0.5 MNm^{-3/2} to 6 MNm^{-3/2}. Maximum decrease was observed for 40% fibre volume specimen which is the same case for 15 days treated specimens. For specimens immersed for 45 days the Fracture toughness decreased continuing the same trend as before. The decrease in the Fracture toughness value ranged from 0 MNm^{-3/2} to 4.7 MNm^{-3/2}. Maximum decrease was observed for 40% fibre volume specimen. 30% fibre volume and 35% fibre volume specimens show a small increase in the values of Fracture toughness. This common increase in these values may be due to the lower values of Fracture toughness for the untreated specimens. Specimens soaked for 60 days also exhibit trend as before. Except for 30% fibre volume and 40% fibre volume specimens, all other specimens show decrease in the Fracture toughness value. Here the decrease in the toughness values is more when compared with specimens treated for other intervals of time. The decrease ranged from a minimum of 3 MNm^{-3/2} to a maximum of 4.7 MNm^{-3/2}. The increase in Fracture toughness values was from 0 MNm^{-3/2} to 4.1 MNm^{-3/2}. The reasons for increase in the Fracture toughness values are being investigated.

5.3. Variation of damping with Fracture toughness for specimens immersed in Seawater for different immersion times in bending.

Figure 5.2(a) shows the variation of damping with Fracture toughness for specimens immersed in Seawater with notch lengths 9 and 10mm and with 20% fibre volume for different immersion times. As seen from the figure, for immersion period between 0-15 days, as the damping factor increases the Fracture toughness value decreases. The increase in damping is around 0.00075 (9%) while decrease in the Fracture toughness is 2.5MNm^{-3/2} (2%). For immersion period between 15-30 days both damping and
Fracture toughness behave in the same manner. Here both the damping as well as the Fracture toughness increased. The 9mm notch length specimen show similar trend from this immersion period onwards. For 10mm notch length specimen also, the same trend is observed except for 30 days behavior. This may be due to any experimentation error. For a time period between 15 to 30 days the damping increased by around 0.0022 (25%) and Fracture toughness increased by around 2.5 MNm$^{-3/2}$ (21%) which was for 9mm specimen. Between 30 to 45 days of time periods damping decreased by an amount of 0.00257 (23%) and Fracture toughness decreased by a maximum amount of around 5.56 MNm$^{-3/2}$ (5%) which was for 9mm specimen. For time period between 45 to 60 days damping decreased by around 0.0026 (3%) while Fracture toughness decreased by around 5.9 MNm$^{-3/2}$ (4%) which was for 10mm specimen.

Figure 5.2 (b) shows the variation of damping with Fracture toughness for specimens having notch lengths of 9mm and 10mm with 25% fibre volume for different soaking times. For initial period of immersion time between 0-15 days, as the damping increased the Fracture toughness decreased. Between 15 and 30 days of soaking time, the damping increased with fracture toughness for 10mm notch length specimen. But 9mm notch length specimen showed slightly different result exhibiting decrease in toughness value. For immersion between 30 to 45 days the damping value decreased while there was no change in the Fracture toughness values. Finally between 45 to 60 days of time period both the specimens show similar trend. As the damping value decreased the fracture toughness value also decreased. For immersion time between 0-15 days, the damping increased by 0.00127 (14%) and Fracture toughness decreased by a maximum amount of 1.2 MNm$^{-3/2}$ (1%). Maximum increase in the damping value was around 0.00097(11%) while for Fracture toughness was around 0.6 MNm$^{-3/2}$ (1%) which was for 10mm notch length specimen for time period between 15 to 30 days. Decrease in damping of 0.0012(12%) was observed while there was no decrease in the Fracture toughness value between the time period 30 to 45 days. For time period between 45 to 60 days damping value decreased by an amount 0.00017(2%) while Fracture toughness value decreased by maximum of 3 MNm$^{-3/2}$ (2%) which was for 10mm specimen.
Variation of damping with Fracture toughness for fibre volume of 30% with 9mm and 10mm notch lengths is presented in Fig.5.2 (c). These specimens presented mixed results. For initial period of immersion between 0-15 days, the damping decreased by an amount of 0.00287 along with Fracture toughness value (2.52 MNm$^{-3/2}$) for 9mm notch length specimen. The 10mm notched specimen behavior was slightly different where there was an increase in the Fracture toughness value (3.5 MNm$^{-3/2}$). Between 15 to 30 days of immersion time, the damping increased by 0.0046 (69%) while the Fracture toughness value decreased by around a maximum of 0.5 MNm$^{-3/2}$ (0.5%).

For immersion time between 30 to 45 days the damping decreased by an amount of 0.00132 (12%) and Fracture toughness decreased by 1.1 MNm$^{-3/2}$ (1%) which was for 10mm notch length specimen. Finally between 45 to 60 days of immersion time the damping decreased by an amount of 0.00124 (13%) while Fracture toughness value increased by a maximum of 4 MNm$^{-3/2}$ (1%). The reasons for this deviation in the behavior of the composites are being investigated.

In Fig. 5.2 (d) the variation of damping with Fracture toughness is presented for specimens having fibre volume of 35% and notch lengths of 9mm and 10mm. The specimens behavior for both damping and Fracture toughness is similar. Except for 9mm specimen between 45 to 60 days where there was increase in the Fracture toughness value with decrease in damping, other immersion periods behavior is similar. This deviation may be due to any experimentation error. For initial period of soaking between 0-15 days the damping and Fracture toughness decreased by 0.0001 and 1MN$m^{-3/2}$ respectively. For a immersion time between 15 to 30 days the damping value increased by around 0.00193 (24%) while Fracture toughness value increased by approximately 2 MNm$^{-3/2}$ (2%) and between 30 to 45 days soaking time the damping value decreased by 0.00105 (11%) and Fracture toughness value decreased by around 1.15 MNm$^{-3/2}$ (1%). Between 45 to 60 days of immersion period the damping value decreased by 0.0009 (10%) approximately while Fracture toughness decreased by around 5.3 MNm$^{-3/2}$ (4%) for 10mm notch length specimen. There was a slight increase of around 5% in the Fracture toughness value for 9mm notch length specimen for time period between 45 to 60 days.

Figure 5.2 (e) shows the variation of damping with Fracture toughness for specimens having fibre volume of 40% and notch lengths of 9mm and 10mm. Except for
behavior between 30 and 45 days, the other time intervals behavior is similar between damping and Fracture toughness. The initial immersion time between 0-15 days showed decrease in both damping and Fracture toughness by 0.0006 (6%) and 9.4 MNm\(^{-3/2}\) (6%) respectively. For immersion time between 15 to 30 days the damping value increased by 0.00282 (30%) while Fracture toughness value increased by a maximum of 3.5 MNm\(^{-3/2}\) (3%) and between 30 to 45 days of time interval, damping value decreased by 0.0017 (14%) and Fracture toughness value increased by around 1 MNm\(^{-3/2}\) (1%). This variation needs to be investigated. For time period between 45 to 60 days damping value increased by an amount of 0.0019 (18%) while Fracture toughness value increased by 4.7 MNm\(^{-3/2}\) (4%).

The discussion above shows that there is a relation between damping of the material and Fracture toughness. This is a very important observation made in this analysis. The following are the important observations made for specimens soaked in seawater with regards to Fracture toughness and damping:

- For all the specimens irrespective of notch length there was decrease in the Fracture toughness values for the initial period of soaking for 15 days. A maximum decrease of around 6% was observed.
- For specimens soaked for 30 days the Fracture toughness decreased when compared to untreated specimens. A maximum of around 4% of decrease was observed for the specimens.
- Specimens immersed for 45 days also showed a similar trend as before showing reduction in Fracture toughness values. Here also a maximum of around 5% of decrease was observed.
- Specimens immersed for 60 days showed an increase in the Fracture toughness value except for few specimens where there was a slight decrease. A maximum of around 3% increase was observed.
- Analysis made for material property with regards to variation of damping with Fracture toughness reveals that, there is a relation between both of them. In most of the cases both the properties exhibit same trend. Some of the cases where the trend is slightly different are being investigated.
- For specimens with fibre volume 20% and initial immersion period between 0-15 days the damping value increased by 9% while Fracture toughness
decreased by a maximum amount of around 2%. Between 15 to 30 days of time interval, the damping increased by a maximum amount of around 25% while Fracture toughness increased by 22% which was for 9mm notch length specimen. For time interval between 30 to 45 and 45 to 60 days the damping values decreased by a maximum amount of around 23% while Fracture toughness decreased by a maximum of around 5%.

➢ For the initial period of immersion between 0-15 days and 25% fibre volume the damping increased by an amount of 14% while Fracture toughness decreased by an amount of 1%. Between 15 to 30 days of interval, the damping increased by an amount of 11% while Fracture toughness increased by an amount of around 1%. For time interval between 30 to 45 days the damping decreased by an amount of 12% while Fracture toughness value increased by a maximum of 2% and between 45 to 60 days of time interval, damping decreased by 2% while Fracture toughness also decreased by a maximum of 2%.

➢ Between 0-15 days of immersion period and 30% fibre volume, the damping decreased by 30% while Fracture toughness decreased by a maximum of 2.5%. For specimens immersed between 15 to 30 days, the damping value increased by large amount of around 69% while Fracture toughness value decreased by 1%. Between 30 to 45 days of soaking time damping decreased by approximately 12% while Fracture toughness decreased by around 1% and for immersion time between 45 to 60 days the damping decreased by 13% while Fracture toughness increased by around 1%.

➢ Specimens with fibre volume 35% and immersion time between 0-15 days showed reduction in damping by 1% while the Fracture toughness reduced by 1%. Immersion time between 15 to 30 days show a increase in the damping value of 24% and Fracture toughness value of 2% and for immersion period between 30 to 45 days the damping value decreased by around 11% while Fracture toughness value decreased by an amount of 1%. For soaking time between 45 to 60 days there was decrease in the damping value of around 10% and Fracture toughness decreased by 4%.

➢ For specimens with fibre volume 40% and immersion period between 0-15 days the damping values decreased by 6% while the Fracture toughness decreased by 6%. Between time interval 15 to 30 days, the damping value
increased by 30% and Fracture toughness value by around 3% and for soaking
time between 30 to 45 days, the damping value decreased by an amount of
14% and Fracture toughness increased by a value of 1%. For immersion time
between 45 to 60 days the damping value increased by 18% and Fracture
toughness value increased by 4%.
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Fig. 5.1. Variation of Fracture toughness with fibre volume for specimens treated with Seawater in bending.
Fig. 5.2. Variation of Fracture toughness with damping for specimens immersed in Seawater with different notch lengths and fibre volume in bending.
5.4. Effect of Saline water treatment on the Fracture toughness of GFRP composite

Figure 5.3 (a) shows the variation of Fracture toughness with fibre volume for specimens having a notch length of 9mm for different immersion periods along with the untreated specimens. The variation of Fracture toughness for the untreated specimens is discussed in section 5.1. For specimens immersed for 15 days time the Fracture toughness decreased for all fibre volume percentages. The percentage decrease in Fracture toughness values range from 0.8% (1 MNm$^{-3/2}$) to 2.4% (3 MNm$^{-3/2}$). Maximum decrease in Fracture toughness value is observed for 40% fibre volume specimen. The decrease in the Fracture toughness values is due to the reduction in strength of the composite due to the absorption of the liquid. Specimens soaked for 30 days of time period also exhibit similar trend in reduction of Fracture toughness values except for 40% fibre volume specimen where there is slight increase in the value of Fracture toughness. This may be due to experimentation error. Maximum reduction of around 6.5 MNm$^{-3/2}$ (5%) was observed. A minimum reduction of 1 MNm$^{-3/2}$ (0.8%) was observed for 35% fibre volume specimen. The reason for decrease in the toughness value is discussed above. For specimens immersed for 45 days in the saline water medium, the Fracture toughness values increase for all the specimens except for 40% fibre volume specimen where there is a slight decrease in the value of toughness. The increase in the Fracture toughness values range from a minimum of 0.5 MNm$^{-3/2}$ (0.4%) to a maximum of around 2.5 MNm$^{-3/2}$ (2%). The reasons for increase in the Fracture toughness values are being investigated. For specimens soaked for 60 days of time period the Fracture toughness values decreased for almost all the specimens except for 30% fibre volume specimen where there was slight increase in the toughness value. The decrease in the Fracture toughness values range from 0% to around 3 MNm$^{-3/2}$ (2.5%). The 25% fibre volume and 35% fibre volume specimens showed no variation in the values of Fracture toughness. Maximum decrease was observed for 20% fibre volume and 40% fibre volume specimens which are around 2.5%.

In Fig.5.3 (b) the variation of Fracture toughness with fibre volume for specimens with notch length of 10mm is presented along with untreated specimens and for different time intervals of testing. The behavior of untreated specimens is discussed in
section 5.1. For specimens immersed in the saline water medium for 15 days, the Fracture toughness of all the specimens irrespective of the fibre volume decreased. A maximum of around 6 MNm^{-3/2} (4%) decreases in the value of Fracture toughness was observed for 40% fibre volume specimen. The decrease in the values of Fracture toughness is due to the reason discussed above. There was no change in the value of Fracture toughness for 30% fibre volume specimen. Specimens soaked for 30 days of time period showed the same trend of decrease in the Fracture toughness values. The decrease in the values of Fracture toughness in this case in more compared to 15 days treated specimens. 30% fibre volume and 35% fibre volume specimens showed slight increase in the toughness values. The reasons for this are being investigated. The decrease in the Fracture toughness values range from around 2 MNm^{-3/2} (1%) to 6.5 MNm^{-3/2} (4.4%). Maximum decrease in the toughness value was observed for 40% fibre volume specimen. For specimens immersed for 45 days the values of Fracture toughness decreased for most of the specimens. 20% fibre volume and 25% fibre volume specimens show a slight rise in the values of Fracture toughness. 35% fibre volume specimen showed no variation in the value of toughness. Maximum decrease in the values of Fracture toughness was observed for 40% fibre volume specimen which is around 3.5 MNm^{-3/2} (2.4%). Maximum increase was observed for 25% fibre volume specimen which is around 1.7 MNm^{-3/2} (1.2%). For an immersion period of 60 days, the specimens showed mixed results. Some specimens showed increase in toughness values and some specimens showed decrease in the values of Fracture toughness. An increase of around 3 MNm^{-3/2} (2%) was observed for 30% fibre volume specimen and a decrease of around 3.5 MNm^{-3/2} (2.4%) was observed for 40% fibre volume specimen. The reasons for this variation are being investigated.

5.5. Variation of damping with Fracture toughness for specimens immersed in Saline water for different immersion times in bending.

Figures 5.4(a)-(e) show the variation of Fracture toughness with damping factor for different fibre volumes and immersion times for specimens soaked in saline water. Figure 5.4 (a) shows the variation of Fracture toughness with damping for specimen with fibre volume of 20%. Initial period of immersion between 0-15 days showed decrease in both damping and Fracture toughness values. Damping decreased by an amount of 0.0074 (9%) while Fracture toughness value decreased by an amount of 1.5
MNm$^{-3/2}$ (1.2%). For immersion time between 15 to 30 days the damping value decreased by an amount of 0.00133 (18%) and Fracture toughness value by around 5 MNm$^{-3/2}$ (5%) and between the time interval of 30 to 45 days the damping value increased by 0.00037 (6%) while the Fracture toughness value increased by a maximum of around 7 MNm$^{-3/2}$ (6.2%). For time interval between 45 to 60 days the damping again decreased by 0.00043 (7%) while Fracture toughness decreased by a maximum of around 3.5 MNm$^{-3/2}$ (3%) which was for 9mm notch length specimen.

In Fig. 5.4(b) the variation of Fracture toughness with damping for specimens having a fibre volume of 25% is shown for different immersion periods. For a period of soaking between 0-15 days both the damping as well as Fracture toughness values decreased. The damping value decreased by 0.00008 (1%) while the Fracture toughness value decreased by 3.36 MNm$^{-3/2}$ (2.3%). For 15 to 30 days period of soaking the damping value decreased by an amount of 0.003 (39%) while Fracture toughness decreased by an amount of around 1.5 MNm$^{-3/2}$ (2%) and for immersion time between 30 to 45 days, the damping value increased by an amount of approximately 0.00074 (16%) and Fracture toughness value increased by an amount of around 6.4 MNm$^{-3/2}$ (5%) which was for 10mm notch length specimen. For soaking time between 45 to 60 days the damping value increased by an amount of 0.0014 (26%), while the Fracture toughness value decreased by a maximum amount of around 2.5 MNm$^{-3/2}$ (3%). This contrasting behavior needs further investigation to be explained.

Figure 5.4 (c) shows the variation of damping with Fracture toughness for specimens having a fibre volume of 30% and for different soaking times. Soaking time between 0 to 15 days showed reduction in both the damping as well as Fracture toughness value. The damping value reduced by 0.00076 (8%) while the Fracture toughness value reduced by 2 MNm$^{-3/2}$ (1.6%). For immersion period between 15 to 30 days the damping value decreased by a substantial amount of 0.00368 (42%) but Fracture toughness value increased by a small amount of around 2.9 MNm$^{-3/2}$ (2%) and 30 to 45 days of soaking time showed again an increase in the damping value of about 0.00133 (26%), while Fracture toughness value increased by a maximum of 2.5 MNm$^{-3/2}$ (2%) which is for 9mm specimen. Specimen with 10mm notch showed decrease in the Fracture toughness value by 3.5 MNm$^{-3/2}$ (2.5%). This may be due to
an error in experimentation. For an immersion time between 45 to 60 days the damping value increased by an amount of 0.0016 (25%), while the Fracture toughness value increased by a maximum amount of 3.5 MNm$^{3/2}$ (3%). Again it can be seen that both damping and Fracture toughness have the same trend except for few cases where it needs further investigation to explain the deviation.

In Fig. 5.4 (d) the variation of Fracture toughness with damping for specimens having a fibre volume of 35% is presented. Soaking period between 0-15 days showed reduction in damping and Fracture toughness of the specimens continuing the same trend exhibited by other previous specimens. The damping reduced by 0.0032 (38%) and Fracture toughness reduced by a maximum of 2.9 MNm$^{3/2}$ (2%) which was for 10mm notched specimen. For the period of soaking between 15-30 days the damping increased by an amount of 0.00219 (43%), while Fracture toughness increased by an amount of around 3.5 MNm$^{3/2}$ (3%). Specimen with notch length of 9mm showed no change in the Fracture toughness value. For immersion time between 30 to 45 days the damping value decreased by small amount of around 0.00052 (7%) and Fracture toughness by an amount of approximately 0.57 MNm$^{3/2}$ (1%). Specimen with notch length of 9mm showed increase in the Fracture toughness value by 1.5 MNm$^{3/2}$ (1%). Between 45 to 60 days of immersion time, the damping value increased slightly by 0.0003 (5%) and Fracture toughness value increased by a maximum of around 2.33 MNm$^{3/2}$ (2%). Again the 9mm notch length specimen showed decrease in the Fracture toughness value by 0.5 MNm$^{3/2}$ (0.5%).

Figure 5.4(e) shows the variation of Fracture toughness with damping for specimens with fibre volume of 40%. For the beginning period of immersion between 0-15 days, the same trend observed for other four specimens previously was also observed. Damping decreased by an amount of 0.0016 (10%) while Fracture toughness decreased by 5.8 MNm$^{3/2}$ (4%). For immersion period between 15 to 30 days, the damping value decreased slightly by 0.00036 (4%), while Fracture toughness value decreased by around 0.6 MNm$^{3/2}$ (1%). 9mm notch length specimen showed increase in the Fracture toughness value by 3.5 MNm$^{3/2}$ (3%) and for soaking time between 30 to 45 days the damping value increased by an amount of 0.0006 (7%), while the Fracture toughness value increased by around 3 MNm$^{3/2}$ (2%). Again 9mm notch length specimen showed decrease in the Fracture toughness value by 2 MNm$^{3/2}$.
soaking time between 45 to 60 days the damping value increased by an amount of around 0.00052 (6%) and in contrast to this the Fracture toughness value decreased by very small amount around 1 MNm$^{-3/2}$ (1%). The 10mm notch length specimen showed no change in the Fracture toughness values. This behavior is to be investigated for the deviation of the values.

The following are the important observations made for specimens soaked in saline, water with regards to Fracture toughness and damping:

- For specimens soaked for 15 days of time period the Fracture toughness values decreased for all the specimens irrespective of the fibre volume and by a maximum amount of around 4%.
- Specimens soaked for 30 days showed similar decrease in the Fracture toughness value for all the specimens except for some specimens where very small amount of increase was observed of the order of around 2%. The maximum decrease in value of Fracture toughness in this case is around 6%.
- For an immersion period of 45 days the Fracture toughness values increased for almost all the specimens. The maximum increase in the value of Fracture toughness is around 3%. In case of 10mm notch length specimen, a decrease in Fracture toughness values is observed for some specimens.
- Specimens immersed for 60 days of time period showed again a decrease in the Fracture toughness values except for some specimens where a small increase is observed. The maximum decrease in the Fracture toughness values is around 3%.
- Soaking period between 0 to 15 days showed reduction in both the damping and Fracture toughness values for all the specimens irrespective of the fibre volume. A maximum reduction of around 38% for damping and 4% for Fracture toughness was observed.
- For immersion period between 15 to 30 days, the damping and Fracture toughness values decreased for almost all the specimens. A maximum decrease of 42% was observed for damping and a maximum decrease of around 4% was observed for Fracture toughness.
- For soaking time between 30 to 45 days, the damping and Fracture toughness values increased for almost all the specimens. The maximum increase for the
damping is of the order of 27% and for Fracture toughness the increase was around 7%.

- For immersion period between 45 to 60 days, some specimens showed increase in damping and Fracture toughness and some specimens showed decrease in damping and Fracture toughness. There requires further investigation to understand the correct behavior between damping and Fracture toughness.
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(a) Saline water immersed, 9mm notch length

(b) Saline water immersed, 10mm notch length.

Fig.5.3. Variation of Fracture toughness with fibre volume for specimens treated with Saline water in bending.
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(a) 20% Fibre volume (b) 25% Fibre volume (c) 30% Fibre volume (d) 35% Fibre volume (e) 40% Fibre volume

Fig. 5.4. (a)-(e) Variation of Fracture toughness with damping for specimens immersed in saline water with different notch lengths and fibre volume in bending.
5.6. Effect of Normal water treatment on the Fracture toughness of GFRP composite in bending.

Variation of Fracture toughness with fibre volume for specimens having a notch length of 9mm is shown in Fig. 5.5(a) for different immersion times. For initial period of soaking of 15 days all the specimens irrespective of the fibre volume exhibit decrease in the value of Fracture toughness. The decrease in the toughness values range from 0% to around 5MNm$^{-3/2}$ (4%). Maximum decrease in the Fracture toughness value was observed for 40% fibre volume specimen. This decrease in the Fracture toughness values are due to the reasons discussed in section 5.2. There was no change in the Fracture toughness value of 35% fibre volume specimen. For specimens soaked for 30 days, the Fracture toughness values decreased continuing the same trend exhibited by saline and seawater treated specimens. The decrease in Fracture toughness values is more when compared to 15 days treated specimens. A maximum decrease of about 6 MNm$^{-3/2}$ (5%) was observed for 40% fibre volume specimen. Again the decrease in the Fracture toughness values is due to the reasons discussed in section 5.2. Specimens immersed for 45 days time period show increase in the Fracture toughness values except 20% fibre volume where there was sight reduction in the toughness values of around 6.5 MNm$^{-3/2}$ (5%). Remaining specimens exhibit either increase or no change in the Fracture toughness values. A maximum increase of around 0.5 MNm$^{-3/2}$ (0.5%) was observed for 25% fibre volume specimen. For specimens immersed for 60 days of time period, the Fracture toughness values show mixed results. Except for 30% fibre volume and 40% fibre volume which have got slight decrease in the Fracture toughness values, other specimens show good increase. A maximum of around 2.5 MNm$^{-3/2}$ (2%) increase was observed for 25% fibre volume specimen. A maximum of around 3 MNm$^{-3/2}$ (3%) decrease in Fracture toughness value was observed for 30% fibre volume specimen.

In Fig. 5.5 (b) the variation of Fracture toughness with fibre volume for different soaking periods is presented for a notch length of 10mm. For initial period of immersion of 15 days the Fracture toughness values decrease for almost all the specimens continuing the same trend as before. 30% fibre volume specimen showed a small increase in the Fracture toughness value of the order of around 2 MNm$^{-3/2}$ (2%). The other specimens show decrease in the Fracture toughness values. A maximum
decrease of about 7 MNm$^{-3/2}$ (5%) Fracture toughness value was observed for 40% fibre volume specimen. 25% fibre volume specimen showed no variation in the toughness value. For specimens immersed for 30 days of time period, the Fracture toughness values decreased for all the specimens except for 30% fibre volume specimen which show a small increase of the order of around 3 MNm$^{-3/2}$ (2%). The reasons for decrease in the values of Fracture toughness are discussed in section 5.2. Specimens immersed for 45 days time show almost increase in the Fracture toughness values. Except for 25% fibre volume and 40% fibre volume specimens where there was a slight decrease of the order of 1 MNm$^{-3/2}$ (0.8% maximum) other specimens showed good increase in the values of Fracture toughness. A maximum increase of the order of about 3 MNm$^{-3/2}$ (2%) was observed for 30% fibre volume specimen. The reasons for increase in the Fracture toughness values are being investigated. Specimens soaked for 60 days of time show a decrease in the Fracture toughness values regardless of the fibre volume. All specimens show good reduction in the toughness values. The reduction in Fracture toughness values ranged from 1 MNm$^{-3/2}$ (0.8%) to 11 MNm$^{-3/2}$ (8%). Maximum reduction was observed for 25% fibre volume specimen. The reduction in the Fracture toughness values are for the reasons discussed section 5.2.

5.7. Variation of damping with Fracture toughness for specimens immersed in Saline water for different immersion times in bending.

Figures 5.6 (a)-(e) show the variation of Fracture toughness with damping for different fibre volumes and immersion times. In Fig. 5.6 (a) the variation of damping with Fracture toughness for specimens with fibre volume 20% is shown. Soaking period between 0 to 15 days showed reduction in both the damping and Fracture toughness of the specimen. Damping reduced by an amount of 0.00137 (16%) and Fracture toughness reduced by a maximum of 3 MNm$^{-3/2}$ (2.5%). For the immersion period between 15-30days, the damping and Fracture toughness of the composite increased by around 0.00051 (8%) and1 MNm$^{-3/2}$ (1%) respectively. For soaking time between 30 to 45 days the damping value decreased by an amount of 0.0011 (15%) while Fracture toughness decreased by 3.5 MNm$^{-3/2}$ (3%). The 10mm notch length specimen showed a small increase in the Fracture toughness value of the order of 1 MNm$^{-3/2}$ (1%). The behavior of specimens between 45 to 60 days of immersion time
shows that damping value increased by an amount of 0.00115 (20%) while the Fracture toughness increased by a maximum of around 7 MNm$^{-3/2}$ (7%). The 10mm notch length specimen showed slight reduction in Fracture toughness value of the order of 5%.

The variation of Fracture toughness with damping for specimens having a fibre volume of 25% is shown in Fig. 5.6 (b). The trend shown by 20% fibre volume specimens is observed here also. For initial period of soaking between 0-15 days show reduction in both the damping and Fracture toughness values. The damping reduced by an amount of 0.0015 (20%) and Fracture toughness reduced by 2.5 MNm$^{-3/2}$. For the soaking time between 15 to 30 days, the damping value increased by an amount of around 0.00197 (31%), while Fracture toughness decreased by a very small amount of the order of 0.58 MNm$^{-3/2}$ (0.4%). The 9mm notch length showed no variation the value of toughness. For the immersion time between 30 to 45 days, the damping value decreased by an amount of 0.00173 (17%), while Fracture toughness increased by a maximum of 3 MNm$^{-3/2}$ (2.5%). The 10mm notch length specimen showed no variation in the value of Fracture toughness. For soaking period between 45 to 60 days, the damping value increased by an amount of 0.00173 (25%) while Fracture toughness value increased by around 2 MNm$^{-3/2}$ (2%). The 10mm notch exhibited decrease in the Fracture toughness value. The mismatch shown by some specimens need further investigations for explanation of the deviations.

In Fig. 5.6 (c) the variation of damping with Fracture toughness for specimens having fibre volume of 30% is presented. Soaking time between 0 and 15 days showed reduction in both the damping and Fracture toughness values continuing the same trend exhibited by the other specimens explained above. The damping reduced by an amount of 0.00285 (30%) while Fracture toughness reduced by a maximum of 4 MNm$^{-3/2}$ (3%). Between the immersion time of 15 to 30 days the damping values increased by an amount of around 0.00022 (3%) while the Fracture toughness increased by a maximum of 4 MNm$^{-3/2}$ (4%). For the immersion time between 30 to 45 days, the damping increased by an amount of 0.0003 (4%) and the Fracture toughness remained unchanged. For the immersion period between 45 to 60 days, the damping value decreased by around 0.00048 (8%) and the Fracture toughness value
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decreased by a maximum amount of 6 MNm$^{-3/2}$ (4%). The damping and Fracture toughness properties show similar trend here also.

Figure 5.6 (d) shows the variation of Fracture toughness with damping for the specimens having fibre volume of 35% and different immersion times. For the initial immersion period between 0 to 15 days, the same trend continued here also as the previous specimens. Damping reduced by an amount of 0.0026 (31%) while Fracture toughness reduced by around 1.18 MNm$^{-3/2}$ (1%). For the immersion time between 15-30 days, the damping value increased by an amount of 0.00196 (34%) while Fracture toughness increased by a small amount of around 1.18 MNm$^{-3/2}$ (1%). The 9mm notch length specimen showed decreased in Fracture toughness by 1%. For the soaking time between 30 to 45 days, the damping value decreased by an amount of 0.00193 (25%) while Fracture toughness increased by a maximum amount of around 2 MNm$^{-3/2}$ (2%). Immersion time between 45 to 60 days showed an increase in the damping value by an amount of 0.00226 (39%) while Fracture toughness value increased by an amount of around 4.7 MNm$^{-3/2}$ (4%). In this case also both the damping and Fracture toughness values vary in a similar trend except a few readings where it needs further investigation to study the deviation.

In Fig. 5.6 (e) the variation of Fracture toughness with damping value for specimens having fibre volume of 40% is presented. Immersion period between 0-15 days showed reduction in both the damping and Fracture toughness values. The damping of the specimen reduced by an amount of 0.0018 (18%) while the Fracture toughness reduced by a maximum of 7 MNm$^{-3/2}$ (5%). For the soaking time between 15 to 30 days the damping value increased by an amount of 0.00045 (5%) while Fracture toughness value increased by an amount of around 4.7 MNm$^{-3/2}$ (4%). The 9mm notch length specimen showed a small decrease in the Fracture toughness value by an amount of around 1 MNm$^{-3/2}$ (1%). For the immersion time between 30 to 45 days, the damping value decreased by an amount of around 0.00096 (11%) while, the Fracture toughness values increased by a maximum amount of 6 MNm$^{-3/2}$ (5%). This is a contrasting behavior. For soaking period between 45 to 60 days, the damping value increased by an amount of 0.00092 (12%) and the Fracture toughness value decreased by a very small amount of 0.5 MNm$^{-3/2}$ (0.4%). The 10mm notch length specimen showed no variation in the Fracture toughness value.
The following are the important observations made for specimens soaked in normal water with regards to Fracture toughness and damping:

- For 15 days of soaking period the Fracture toughness values decreased for all the specimens irrespective of the fibre volume. The maximum amount of decrease was observed to be around 5%.
- Specimens soaked for 30 days showed decrease in the Fracture toughness values of around a maximum of 5%.
- For 45 days of soaking period the Fracture toughness values increased for almost all the specimens. An increase of around a maximum of 2% was observed.
- Specimens immersed for 60 days showed decrease in the Fracture toughness values for all the specimens irrespective of the fibre volume. A maximum of around 8% decrease was observed.
- The immersion period between 0 to 15 days showed reduction in both the damping and Fracture toughness values irrespective of the fibre volume. The maximum reduction in the damping value is of the order of 31% while the Fracture toughness values reduced by a maximum of 4%.
- For an immersion period between 15 to 30 days, the damping value of the composite increased by a maximum amount of 40%, while the Fracture toughness value increased by an amount of approximately 4%.
- For soaking time between 30 to 45 days, the damping value decreased for almost all the specimens and was of the order of around a maximum of 17% and the Fracture toughness value decreased by an amount of around 3%.
- Immersion period between 45 to 60 days showed increase in the damping value of about 39% while, the Fracture toughness value decreased by an amount of around 6%. 
(a) Normal water immersed, 9mm notch length  
(b) Normal water immersed, 10mm notch length.  

Fig.5.5. Variation of Fracture toughness with fibre volume for specimens treated with Normal water in bending.
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Fig. 5.6. Variation of Fracture toughness with damping for specimens immersed in Normal water with different notch lengths and fibre volume in bending.

(a) 20% Fibre volume (b) 25% Fibre volume (c) 30% Fibre volume (d) 35% Fibre volume (e) 40% Fibre volume