INVESTIGATIONS AND DISCUSSION ON CHARPY IMPACT ENERGY TESTING OF GFRP COMPOSITES SUBJECTED TO DIFFERENT LIQUID ENVIRONMENTS.

This chapter gives the results of experiments conducted on GFRP composites subjected to different liquid environments using Charpy impact energy testing machine. Five types of composites were fabricated by varying the fibre volume in step of 5% and up to a maximum of 40% fibre volume. Five notch lengths were used on the specimens for determining impact energy starting from 1mm and up to 5mm with an increment of 1mm. The specimens were soaked in three different liquid environments viz. normal water, sea water and saline water. Testing was done every 15 days of time interval and up to a maximum soaking period of 60 days. Appendix V gives the values of Charpy impact energy for all the specimens.

8.1. Effect of normal water treatment on the Charpy impact energy of GFRP composites.

Figures 8.1(a)-(e) show the variation of Charpy impact energy for different notch lengths and for different treatment times. Figure 8.1 (a) shows the variation of the Charpy impact energy with fibre volume for 1mm notch length along with untreated specimens. For untreated specimens, the Charpy impact energy increased for increasing fibre volume. The increase in the impact strength is more or less gradual with increase in fibre volume. The minimum value obtained is 2.6J and the maximum is 4.76J.

Specimens treated for 15 days time showed an increase in energy absorbed for all the specimens than untreated specimens irrespective of the fibre volume. The increase is almost gradual and the values vary from 2.8J to a maximum of 4.8J. The highest increase in the energy value is for 30% fibre volume specimen, the value being 0.26J. The increase in the impact energy for specimens treated for 15 days may be due to the absorption of water molecules by the composite which occupies the space between two molecules or in voids or in fibre-matrix interphase. Since the soaking time is less, the degradation of the composite may have not started. Thus the water molecules
combined with the composite structure behaves as entirety and offers greater resistance for impact. The increase in impact value for 20% fibre volume specimen is 0.2J. Remaining specimens also exhibited similar trend. 25% and 35% fibre volume specimens had an increase of 0.15J and 0.2J respectively while 40% fibre volume had an increase of 0.04J. Further, as the duration of soaking increased for 30 days, the impact behavior of the composite changed. The specimens treated for 30 days exhibited decrease in impact energy than untreated specimens. The specimen 40% fibre volume showed maximum decrease in impact energy of the order of 0.76J. The 20% and 35% fibre volume specimens showed a decrease of 0.1J each. The 25% and 30% fibre volume specimens impact energy decreased by an amount of 0.45J and 0.14J respectively. As the soaking time increases, the water uptake by the composite increases till it reaches saturation. The water absorption by the composite has been shown to lead to a general reduction in the mechanical properties of composites and in part, to degradation of the fibre-matrix interfacial bond. The mechanical properties to a certain extent are altered by the void content of the composite. If void content is more, the water absorption capacity increases steeply. The degradation of the composite starts very early in this case. This total effect can be seen in the composites as reduction in the strength of the composite. Another factor which also leads to decrease in the mechanical strength is the microcracks present in the composite. These may be formed during the composite production or caused by service condition. These microcracks increase the water uptake by the composite and leads to reduction in the strength of the composite. These are the reasons attributed to the decrease in the impact strength of the composite. Specimens treated for 45 days showed a similar trend as before. The impact strength of the composite specimens further reduced when compared to 30 days treated specimens. The decrease in the impact energy ranged from 0.2J to 0.76J. The maximum decrease was observed for 40% fibre volume specimen having the highest fibre volume. The decrease in the impact strength is due to the degradation of the composite due to exposure to liquid environment. As the soaking time increases, the composite experiences different degradation mechanisms like hydrolysis, leaching, swelling etc. which leads to decrease in the strength of the composite. On further soaking the specimens for 60 days, the strength of the composites further decreased significantly. The decrease in the impact strength varied from 1.1J to 1.25J. The maximum decrease in this case was
observed for 25% fibre volume specimen. The decrease in the impact strength of the composite is due to the reasons discussed above.

Figure 8.1 (b) shows the variation of impact energy with fibre volume for a notch length of 2mm. For untreated specimens, the Charpy impact energy increased with increasing fibre volume continuing the same trend as shown by previous specimens. The highest impact energy was exhibited by 40% fibre volume specimen containing the highest fibre volume. Specimens treated for 15 days exhibited the same trend as specimens with notch length 1mm. The impact energy increased and ranged from 0J to 0.6J, the maximum value being shown by 20% and 25% fibre volume specimens. The increase in the impact energy is due to the reasons discussed in the above section. On further increasing the soaking time to 30 days, the impact energy of all the specimens decreased below the untreated specimens. The decrease in impact energy ranged from 0.2J to 0.4J. The maximum decrease was exhibited by 40% fibre volume specimen. The decrease in impact energy may be because of the reasons discussed in above section. Further decrease in impact energy was observed for specimens treated up to 45 and 60 days. The maximum decrease in impact energy value is observed for 40% fibre volume specimen with 0.6J and 2.6J for 45 and 60 days respectively. Specimens 20% and 25% fibre volume also shows a maximum reduction in the impact strength for the case of 45 days treatment time. The reduction in the impact energy is attributed to the reasons discussed in the above section. Specimens treated for 60 days exhibited greater reduction in the strength than specimens with 1mm notch length for the same time period.

In Fig.8.1 (c) the variation of impact energy for specimens with notch length of 3mm is presented. Untreated specimens show an increase in impact energy for increasing fibre volume. The values ranged from 2.2J to 3.8J. For initial period of 15 days soaking, the impact energy increased from a minimum of 0.2J to maximum of 0.64J. The maximum energy increase was observed for 35% fibre volume specimen. Specimens soaked for 30 days showed a similar trend as exhibited by 1mm and 2mm specimens. The impact energy decreased for all the specimens and varied from a minimum of 0.16J to a maximum of 0.3J. Maximum decrease in the impact energy was observed for 40% fibre volume specimen and minimum decrease was observed for 35% fibre volume specimen. The reasons for decrease in the impact energy can be
attributed to the factors explained in the above section. On further extension of soaking period to 45 days, the impact energy decreased and varied from a minimum of 0.36J to a maximum of 0.8J. The 35% fibre volume specimen exhibited minimum decrease in impact energy value and maximum decrease was observed for 40% fibre volume specimen. As the degradation of composite proceeds, the strength of the composite begins to decrease. The water molecules, as the time progresses, reach the fibre matrix interphase and then diffuse in to the fibre and decrease the strength. This effect can be clearly seen from the results obtained. For 60 days of soaking time, the impact energy further decreased and ranged from a minimum of 1.4J to a maximum of 2J. The maximum decrease in the impact energy is observed for 40% fibre volume specimen and minimum decrease for 30% fibre volume specimen. The decrease in the impact energy values may be because of the reasons discussed in the above section.

Figure 8.1 (d) shows the variation of impact energy with fibre volume for specimens having notch length of 4mm. Untreated specimens showed the same behavior as discussed in the above sections and the impact energy values varied from minimum of 2J to a maximum of 3.2J. For 15 days treated specimens, the impact energy increased showing the same trend as shown by other notched specimens. The increase in impact energy varied from a minimum of 0.2J to a maximum of 0.5J. The maximum increase in impact energy was observed for 30% fibre volume specimen. On further increase in soaking time to 30 days, the impact energy decreased for all the specimens and the decrease in impact energy values ranged from a minimum of 0.2J to a maximum of 0.3J. The 30% fibre volume specimen exhibited maximum decrease in the impact energy. For 45 days treatment time the impact energy decreased from a minimum of 0.4J to a maximum of 0.5J. The 30% fibre volume specimen showed maximum decrease in impact energy. Further soaking the specimens for 60 days resulted in further decrease in the impact energy. Here the maximum decrease of impact energy was observed for 35% and 40% fibre volume specimens. The decrease in the impact energy ranged from 1.5J to 2J. Specimens treated for 60 days showed a large decrease in the impact energy values than the other specimens treated for 45 and 30 days.

For specimens having a notch length of 5mm, the variation of Charpy impact energy with fibre volume is shown in the Fig.8.1 (e). The untreated specimen impact energy values varied from 1.5J to 2.8J. The impact energy increased for increasing fibre
volume, showing the same trend as discussed in the above sections. Specimens soaked for 15 days showed increase in the impact energy, similar to the trend shown by previous specimens with different notch lengths. The increase in the impact energy is from a minimum value of 0.2J to a maximum value of 0.7J. Here the maximum increase in impact energy was observed for 20% fibre volume specimen and minimum increase for 25% and 30% fibre volume specimens. This increase in impact energy is due to the reasons enumerated in the above sections. Further increasing the soaking time to 30 days decreased the impact energy of the specimens and varied between 0.1J to 0.4J maximum. Specimen 40% fibre volume exhibited maximum decrease in impact energy. Soaking time for 45 days further decreased the impact energy values, showing similar trend as discussed for specimens earlier. The decrease in impact energy ranged from 0.3J to 0.6J maximum. The maximum decrease was shown by 25% and 40% fibre volume specimens. Further increase in treatment period reduced the impact energy values and ranged from 1.1J to 1.8J maximum. Maximum decrease was observed for 40% fibre volume specimen.

The following important observations were made for specimens treated with normal water specimens.

- All specimens irrespective of notch length exhibited an increase in the impact energy for 15 days initial period of soaking. Maximum increase in the impact energy was up to 47%.
- All specimens showed decrease in impact energy values for 30 days soaking period. The maximum decrease in impact energy was up to 18%.
- For specimens treated for 45 days and 60 days, the impact energy further reduced by a large amount. For 45 days treated specimens, the maximum decrease was found to be around 27% and for 60 days treated specimens, the maximum decrease was found to be around 73%.
Fig. 8.1 Variation of Charpy impact energy with fibre volume for specimens treated with normal water.
Fig. 8.1 (contd...) Variation of Charpy impact energy with fibre volume for specimens treated with normal water.
8.2. Effect of Sea water treatment on the Charpy impact energy of GFRP composites.

Figures 8.2 (a)-(e) show the variation of Charpy impact energy with fibre volume for different notch lengths. In Fig.8.2 (a), the variation of Charpy impact energy for specimens having a notch length of 1mm is presented. For untreated specimens, the impact energy values remain same as discussed in section 8.1. For specimens treated for 15 days, the impact energy increased for all the specimens. The increase in the impact energy values ranged from 0.24J to 0.46J. The maximum increase in the impact energy values is for 30% fibre volume specimen. The increase in the impact energy values is due to the reasons discussed in section 8.1. As the soaking time was increased to 30 days, the specimens showed a decrease in the impact energy values. The decrease in impact energy value ranged from a minimum of 0.1J to a maximum of 0.76J. The 40% fibre volume specimen having the maximum fibre volume exhibited maximum decrease in impact energy of about 16%. The decrease in the impact energy values can be attributed to the reasons discussed in section 8.1. For specimens soaked for 45 days, the impact energy value further decreased and ranged from 2.5J to 3.2J. The maximum decrease in impact energy was observed for 40% fibre volume specimen having the highest fibre volume of about 29%. Further, as the soaking time increased to 60 days, the specimens further degraded and the impact energy values reduced and varied between 2.8J to 4.0J. Here again, the maximum decrease in impact energy value was observed for 40% fibre volume specimen of about 47%. This shows the effect of fibre volume on impact energy values.

Figure 8.2 (b) shows the variation of Charpy impact energy with fibre volume for specimens with notch length of 2mm. For specimens treated for 15 days, the impact energy increased and varied from a minimum of 0J to a maximum of 0.2J. All specimens show almost equal increase in the impact energy values except for 30% fibre volume specimen which show no increase in the impact energy value. The increase in impact energy values was small. On further increase in soaking time to 30 days, the impact energy decreased and the decrease in impact energy ranged from 0.25J to 0.6J. Maximum percentage decrease in impact energy was observed for 20% and 40% fibre volume specimens with around 16% and 14% respectively. The decrease in the impact energy is due to the reasons discussed in section 8.1. Further increase in the soaking time to 45 days showed further reduction in the impact energy.
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values. The maximum decrease in the impact energy value was observed to be for 40% fibre volume specimen, of the order of 1.2J coming around 28%. This decrease in the impact energy value can be attributed to the reasons discussed in section 8.1. For specimens soaked for 60 days, the impact energy further reduced to a large extent. Again the maximum decrease in impact energy value was observed for 40% fibre volume specimen containing the highest fibre volume percentage. Maximum decrease in impact energy was of the order of 1.7J.

Figure 8.2 (c) presents the variation of Charpy impact energy with fibre volume for specimens having notch length of 3mm. Specimens soaked for 15 days showed an increase in the impact energy exhibiting the same trend shown by previous specimens. The increase in impact energy was from a minimum of 0J to a maximum of 0.2J. This increase in the impact energy is due to the reasons discussed in section 8.1. The maximum percentage increase was of the order of 9%. Further treating the specimens for 30 days duration, the impact energy values were found to decrease and a maximum value of 0.6J was shown by 40% fibre volume specimen which was around 15%. For specimens treated for 45 days, the impact energy values further decreased. The decrease in impact energy values was from a minimum of 0.2J to a maximum of 0.8J. The maximum decrease in the impact strength was observed for 40% fibre volume specimen which is around 21%. Specimens exposed to 60 days time duration showed further reduction in the impact energy values. This is due to the environmentally assisted degradation mechanism occurring in the composite. Maximum decrease in the impact energy values was observed for 40% fibre volume specimen, of the order of 2J.

In Fig. 8.2 (d), the variation of Charpy impact energy value with fibre volume is presented for specimens having a notch length of 4mm. The impact energy increased for increasing fibre volume. For specimens treated for 15 days, the impact energy increased from a minimum of 0J to a maximum of 0.4J. Maximum increase in impact energy was observed for 40% fibre volume specimen which was around 12.5%. On further increasing the treatment to 30 days, the impact energy decreased, the maximum decrease being 0.2J. The 20%, 25%, 35% and 40% fibre volume specimens showed maximum decrease in the impact energy values. Impact energy values further reduced for specimens treated for 45 days. The decrease in the impact energy was
from a minimum of 0.3J to a maximum of 0.4J. The 20%, 25%, 35% and 40% fibre volume specimens showed maximum decrease in the impact energy. Specimens treated for 60 days showed further reduction in the impact energy. Maximum decrease of impact energy was about 1.8J and minimum decrease was of the order of 1.5J. Maximum percentage decrease was around 75%.

Figure 8.2 (e) shows the variation of Charpy impact energy with fibre volume for specimens having a notch length of 5mm. Specimens treated for 15 days showed an increase in impact energy values showing the same trend shown by previous specimens. The impact energy values ranged from a minimum of 0.2J to a maximum of 0.5J. The increase in impact energy values is due to the reasons discussed in the section 8.1. Specimens treated for 30 days showed a reduction in impact energy values from a minimum value of 0.1J to a maximum of 0.3J. Maximum decrease in impact energy was shown by 40% fibre volume specimen which was around 10%. Specimens treated for 45 days showed further reduction in the impact strength values. The decrease in the impact energy values ranged from 0.3J to 0.6J. In this case the maximum decrease was observed for 25% fibre volume specimen which is around 27%. On further treating the specimens for 60 days, the impact strength values reduced significantly. The reduction in impact energy values ranged from 0.4J to 1.4J. The maximum decrease was observed for 40% fibre volume specimen. The decrease in the impact strength values is due to the reasons discussed in section 8.1.

The following important observations were made for specimens treated with sea water:

- All specimens irrespective of notch length showed an increase in the impact energy for initial treatment period of 15 days. Maximum percentage increase in the impact energy value was around 33%.
- All specimens exhibited decrease in impact energy values for 30 days treatment. The decrease in impact energy was small. Maximum percentage decrease in this case was around 17%.
- For specimens treated for 45 days and 60 days, the impact energy further reduced by a large amount. For 45 days treated specimens, the maximum percentage decrease was around 29%. For 60 days treated specimens the
decrease in the impact strength was significantly low and the maximum percentage decrease was around 77%.
Fig. 8.2. Variation of Charpy impact energy with fibre volume for specimens treated with Seawater.
(d) 4mm notch length  (e) 5mm notch length

Fig.8.2. (contd...) Variation of Charpy impact energy with fibre volume for specimens treated with Seawater.
8.3. Effect of Saline water treatment on the Charpy impact energy of GFRP composites.

Figures 8.3 (a)-(e) show the variation of Charpy impact energy with fibre volume for different notched specimens subjected to saline water environment. In Fig.8.3 (a), the variation of impact energy with fibre volume is presented for a notch length of 1mm. For untreated specimens the impact energy increased for increasing fibre volume. For specimens treated for 15 days the impact energy either decreased or slightly increased. There was very small increase in the case of 30% fibre volume specimen only. Remaining specimens showed small reduction in the impact energy values. This behavior is different from the behavior shown by the same specimens when subjected to other environments. The decrease in impact energy may be because of uncured resin or testing errors. Any specimens having uncured resin will not exhibit good impact resistance because of reduction in the strength of the specimen. Maximum decrease in the strength is observed for 40% fibre volume specimen which is 0.56J. Increasing the soaking time to 30 days further reduced the impact strength. The reduction of impact energy ranged from 0J to 0.96J. Highest reduction in the impact energy values is found for 40% fibre volume specimen. This reduction in the impact strength is due to the water absorption by the composite. Water absorption makes the composite to degrade and decreases its strength. Water absorption mainly affects the fibre-matrix interphase area which is mainly responsible for the strength of the composite. Moisture can directly reduce the chemical bonding strength at the interface and affect the matrix properties and this result in the decrease of strength of the composite. The weakening of bonding between fibre and matrix and softening of matrix material are also reasons of the decreased composite strength. Specimens soaked for 45 days showed further reduction in the impact strength. The reduction in the impact energy ranged from a minimum of 0.4J to a maximum of 1.16J. The maximum decrease in the strength was observed for 40% fibre volume specimen which is around 24% reduction percentage. This decrease in the impact strength of the composite is due to the degradation of the composite due to the environment to which it is subjected to. On further treating the specimens for 60 days, the impact strength further reduced to a large extent. The reduction in the impact strength is from a minimum of 1.5J to a maximum of 2.96J. Here also the maximum decrease in the impact energy value is observed for 40% fibre volume specimen. This shows the strong dependency of fibre volume on the impact strength of the composite. Over a
large period of exposure of composites to liquid environment, the composite strength decreases and hence there is a decrease in the impact energy strength of the composite.

In Fig. 8.3(b) the variation of impact energy with fibre volume for specimens having a notch length of 2mm is presented. Untreated specimens showed the same behavior of increase in the impact strength as the fibre volume increased. For specimens treated for 15 days, the impact energy increased for all the specimens. Increase in the impact energy ranged from 0.15J to 0.8J. The maximum increase was shown by 40% fibre volume specimen. This increase in the impact strength is due to the reasons discussed in section 8.1. Water uptake by the specimen initially increases and all the voids and micro cracks are filled by the water molecules. This makes the composite laminate a more entirety. This is also a possible reason for increase in the impact strength. On further soaking the specimens for a period of 30 days, the impact energy decreased. The decrease in the impact energy varied from 0J to 0.8J. Maximum decrease was observed for 40% fibre volume specimen which is around 19% percentage reduction. Further treating the specimens for 45 days, the impact strength further reduced. The reduction in impact energy varied from 0.2J to 1J. The maximum reduction was observed for 40% fibre volume specimen. This reduction in the strength is due to the reasons discussed in section 8.1. The specimens treated for 60 days exhibited further decrease in the impact strength to a large extent. The reduction in the impact energy values ranged from 1.65J to 2.2J. The maximum reduction in the impact strength was observed for 40% fibre volume specimen having the highest fibre volume.

Figure 8.3 (c) shows the variation of impact energy with fibre volume for specimens having the notch length of 3mm. Untreated specimens exhibit the same trend as discussed above. For specimens treated for 15 days the impact energy increased and the increase in impact energy is from a minimum of 0J to a maximum of 0.4J. Maximum increase in the impact strength was observed for 25% and 30% fibre volume specimens. The increase in impact energy is due to the reasons discussed in the section 8.1. On further increasing the soaking period to 30 days the impact strength reduced well below the untreated specimens. The decrease in the strength was from 0.2J to 0.6J. Maximum decrease was observed for 40% fibre volume specimen. The decrease in impact strength is due to the start of degradation process of
the composite. For specimens treated for 45 days the impact energy further reduced except for 20% fibre volume specimen. This non reduction in the impact strength for 20% fibre volume specimen may be due to improper testing. The decrease in the strength of other specimens is due to the deterioration of the composite when subjected to liquid environment. The decrease in impact strength varied from 0J to 0.8J, and the maximum decrease was shown by 40% fibre volume specimen. Further treating the specimen for 60 days, the impact strength reduced further to a large extent. The reduction in impact energy was from a minimum of 1.6J to a maximum of 2.3J. The maximum decrease in the impact strength was exhibited for 40% fibre volume specimen with highest fibre volume.

In Fig.8.3 (d) the variation of impact energy with fibre volume for specimens having a notch length of 4mm is shown. Untreated specimen showed the same behavior as discussed above. The specimens soaked for 15 days time period exhibited increase in the impact energy values. The increase in the impact energy values ranged from 0.1J to 0.4J. The maximum increase in the impact energy was shown by 20% and 35% fibre volume specimens. This increase in the impact energy can be attributed to the reasons discussed in the above paragraphs. On further increasing the soaking period for 30 days, the impact strength reduced well below the untreated specimens. The decrease in the impact strength varied from 0J to a maximum of 0.3J. Maximum decrease in the impact energy value is for 35% fibre volume specimen which is around 10% reduction. For specimens treated for 45 days, the impact energy further reduced. This reduction in the impact energy is due to the degradation of the composite due to exposure to liquid environment. The decrease in impact energy ranged from 0.2J to 0.4J. The maximum decrease in the impact strength was observed for 25%, 30% and 40% fibre volume specimens. Specimens treated for 60 days time period showed further reduction in their strength to a large extent. The decrease in the impact strength varied from 1.4J to 1.6J. The maximum decrease in the impact strength was observed for 40% fibre volume specimen. This decrease in the impact energy is due to the reasons discussed in the above section.

Figure 8.3 (e) shows the variation of impact energy with fibre volume for specimens having a notch length of 5mm. For untreated specimens the impact energy increased as the fibre volume increased. For specimens treated for 15 days the impact energy
increased and varied from 0.04J to 0.5J. The maximum increase in the impact energy was shown by 20% fibre volume specimen which is around 33%. The increase in the impact energy is because of the reasons discussed in the above section. For specimens soaked for 30 days the impact energy decreased well below the untreated specimens. The decrease in impact strength varied from 0.1J to 0.4J. Maximum decrease in impact strength was observed for 40% fibre volume specimen. This decrease in impact energy is due to starting of the degradation process in the composite. On further treating the specimens for 45 days, the impact strength further reduced and varied from 0.1J to 0.5J. The maximum decrease in the impact strength was observed for 30% fibre volume specimen. The 60 days treated specimens showed further reduction in the impact strength largely. The reduction in the impact strength varied from 1.1J to 1.7J. The maximum reduction in impact energy was shown by 25% fibre volume specimen which is around 77%. This decrease in the strength is due to the degradation of the composite when it is subjected to liquid environment.

The following important observations were made regarding the impact behavior of specimens treated with saline water:

- All specimens treated for 15 days exhibited increase in the impact energy values except for specimens having notch length of 1mm where the variation was very small. This variation may be due to the improper testing of the specimens. The maximum increase in the impact strength is of the order of 33%.
- Specimens treated for 30 days exhibited decrease in the impact strength well below the untreated specimens. The decrease in the impact strength is from 0-0.96J. The maximum percentage reduction is of the order of 20%.
- For specimens treated for 45 and 60 days, there was a large reduction in the impact strength. Specimens treated for 45 days showed a reduction in the impact energy from 0%-24% and for specimens treated for 60 days the reduction is from 46%-77%.
(a) 1mm notch length  (b) 2mm notch length  (c) 3mm notch length

Fig. 8.3. Variation of Charpy impact energy with fibre volume for specimens treated with Saline water.
Fig. 8.3. (contd...) Variation of Charpy impact energy with fibre volume for specimens treated with Saline water.

(d) 4mm notch length   (e) 5mm notch length
8.4. Comparative study of the Charpy behavior of GFRP composite treated with normal, sea and saline water for 15 days.

Figures 8.4 (a)-(e) show the variation of Charpy impact energy with fibre volume for specimens treated with different liquid mediums for 15 days and for different notch lengths. Fig.8.4 (a) shows the variation of impact energy with fibre volume for specimens having notch length of 1mm treated with different liquid mediums. Seawater treated specimen exhibit very good increase in the impact strength when compared with other treated specimens. There is a small decrease in the impact strength for specimens treated with saline water. The percentage increase in the impact energy values for sea water treated specimens is from 5%-15%. This case is different from other cases where the impact energy increased for all specimens irrespective of the treating medium. The reason for this is being investigated. The increase in the impact energy for the normal water treated specimens was from 0.8%-7.7%. The decrease in the impact strength for the saline water treated specimens was from 0%-11%.

Figure 8.4 (b) shows the variation of impact energy with fibre volume for specimens having a notch length of 2mm. The entire specimens exhibit increase in the impact strength. Both saline water and normal water treated specimens showed maximum increase in the impact strength followed by sea water treated specimens. The percentage increase in the impact strength for normal water ranged from 0%-25% and for saline water treated specimens from 4%-19%. The sea water treated specimens showed an increase in the impact strength from 0%-8%. This increase in the impact strength is due to the reasons discussed in sections 8.1, 8.2, and 8.3.

In Fig. 8.4 (c) the variation of impact energy with fibre volume for specimens having a notch length of 3mm is shown. All the specimens show an increase in the impact strength irrespective of the treating medium. Saline water treated and normal water treated specimens exhibit the highest increase in the impact strength followed by sea water treated specimens. The increase in the impact energy values ranged from 0%-15% for saline water treated specimens. An increase of 0%-9% impact energy values were found for sea water treated specimens. Normal water treated specimens showed an increase of 5%-15% impact energy values. This
increase in the impact strength is due to the reasons discussed in sections 8.1, 8.2, and 8.3.

Figure 8.4 (d) shows the variation of impact energy with fibre volume for specimens having a notch length of 4mm. The same trend continued in the behavior of all the specimens as discussed above. Saline water treated and normal water treated specimens exhibit maximum increase in the impact strength followed by sea water treated specimens. An increase from 4%-20% impact energy values was observed for saline water treated specimens. An increase from 0%-12% and 6%-20% impact energy values were found for sea water and normal water treated specimens respectively. The increase in the impact strength can be attributed for the reasons discussed in sections 8.1, 8.2 and 8.3.

Variation of impact energy with fibre volume for specimens having a notch length of 5mm is shown in Fig.8.4 (e). Seawater treated and normal water treated specimens show maximum increase in the impact energy values followed by saline water treated specimens. An increase from 1.5%-33% impact energy values were found for saline water treated specimens. For normal and sea water treated specimens an increase from 8%-46% and 9%-33% respectively was recorded. The reasons for increase in the impact energy values are discussed in sections 8.1, 8.2 and 8.3.

Following observations were made regarding the behavior of the specimens treated for 15 days.

- Saline water treated specimens showed good increase in the impact strength than other specimens treated with normal water and sea water. The maximum percentage increase in the impact strength was up to 33%.
- Normal water and sea water treated specimens exhibit almost same behavior. For specimens having notch length of 1mm, sea water treated specimens showed maximum increase. An increase in impact values up to 46% were recorded for normal water treated specimens. Sea water treated specimens showed an increase up to 33% in impact energy values.
- The above discussion shows that the impact energy values depend on the medium of immersion. This variation may be due to the variation of...
chemical structure of the molecules in each medium and their interaction with the composite material. The chemistry between the immersion medium and the composite plays a major role in deciding the impact strength of the composite.
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Fig. 8.4. Variation of Charpy impact energy with fibre volume for specimens treated with different mediums for 15 days.

(a) 1mm notch length  (b) 2mm notch length  (c) 3mm notch length
Fig. 8.4. (contd...) Variation of Charpy impact energy with fibre volume for specimens treated with different mediums for 15 days.
8.5. Comparative study of the Charpy behavior of GFRP composite treated with normal, sea and saline water for 30 days.

Figures 8.5 (a)-(e) show the variation of Charpy impact energy with fibre volume for specimens treated with different mediums for 30 days. In Fig.8.5 (a) the impact energy variation with fibre volume is presented for specimens having a notch length of 1mm. All the specimens irrespective of the soaking medium exhibit decrease in the impact strength. The highest decrease in the impact strength is shown by sea water treated specimens. The lowest decrease in the impact strength is observed for saline water treated specimens. The decrease in the impact strength for saline water treated specimens is from 0%-20%. The decrease in impact strength for other specimens is from 3%-16% and 3%-15% for sea water and normal water treated specimens respectively. This decrease in the impact energy values is due to the reasons discussed in sections 8.1, 8.2 and 8.3.

Figure 8.5 (b) shows the variation of impact energy with fibre volume for specimens having a notch length of 2mm. Specimens treated with saline water exhibit increase in the impact strength when compared to other specimens. All the specimens irrespective of the soaking medium exhibit decrease in the impact energy values. Almost all the specimens show similar variation in the decrease of impact strength. The decrease in the impact strength is from 7%-16% for sea water treated specimens and from 6%-10% for normal water treated specimens. For saline water treated specimens a decrease from 0%-19% was found for impact energy values. The decrease in the impact strength can be attributed to the reasons discussed in sections 8.1, 8.2 and 8.3.

Figure 8.5 (c) shows the variation of impact strength with fibre volume for specimens having a notch length of 3mm. All specimens irrespective of the soaking medium show decrease in the impact energy values. Almost all the specimens show same variation in the decrease of impact energy values. The decrease in the impact energy values for sea water and normal water treated specimens is from 0%-16% and 5%-9% respectively. Saline water treated specimens show a decrease in impact energy values from 7%-16%. The reasons for decrease in the impact strength for the specimens soaked for 30 days can be attributed to the reasons discussed in sections 8.1, 8.2, and 8.3.
In Fig. 8.5(d) the variation of impact energy with fibre volume is presented for specimens having a notch length of 4mm. The same trend shown by other specimens is also been showed here. All the specimens show decrease in the impact strength regardless the soaking medium. The variation between the impact energy values is small. Normal water treated specimens show a decrease in impact energy values from 6%-12%. A decrease from 4%-10% and 0%-11% was observed for sea water and saline water treated specimens respectively. The decrease in the impact strength is due to the reasons discussed in sections 8.1, 8.2, and 8.3.

The variation of impact energy with fibre volume for specimens having a notch length of 5mm is shown in the Fig. 8.5 (e). All the specimens show decrease in the impact energy values. Maximum decrease in the impact strength was observed for normal water treated specimens followed by sea water and saline water treated specimens. The decrease in the impact strength values is from 4%-14% and 4%-11% for saline water and sea water treated specimens respectively. A maximum decrease from 6%-19% was observed for normal water treated specimens. The reasons for decrease in the impact energy values are discussed sections 8.1, 8.2 and 8.3.

Some important observations made for specimens treated for 30 days of time period are:

- All specimens show a decrease in the impact energy values when compared to 15 days treated specimens well below the untreated specimens. The variation of the impact energy values between specimens treated with different liquid mediums is very small.
- Saline water treated specimens showed a decrease in impact strength from 0%-20%.
- Normal water treated specimens show a decrease in the impact strength values of the order of 0%-19%.
- Sea water treated specimens also show decrease in impact strength. These specimens exhibit almost same decrease in the impact strength for all the specimens. The decrease in the impact strength is from 0%-16%.
Fig. 8.5. Variation of Charpy impact energy with fibre volume for specimens treated with different mediums for 30 days.
Fig. 8.5. (contd...) Variation of Charpy impact energy with fibre volume for specimens treated with different mediums for 30 days.
8.6. Comparative study of the Charpy behavior of GFRP composite treated with normal, sea and saline water for 45 days.

Figures from 8.6 (a) to 8.6 (e) show the variation of Charpy impact energy with fibre volume for specimens having different notch lengths and treated for 45 days. In Fig. 8.6 (a), the variation of impact energy with fibre volume is presented for specimens having a notch length of 1mm. It is observed that the impact strength of all the specimens irrespective of the treating medium show decreasing trend with respect to the untreated specimens. The highest decrease in the impact strength is shown by saline water treated specimens. The least decrease in the impact strength was shown by the sea water treated specimens. The decrease in the impact strength for the saline water treated specimens is from 11%-24%. The decrease in the impact energy values for sea and normal water treated specimens is from 3%-28% and 5%-17% respectively. The decrease in the impact strength for all the specimens is due to the degradation of the composite due to exposure to the moisture environment for longer time period. The degradation process may occur due to leaching, hydrolysis, and swelling of the matrix. These processes weakens the bonding between fibre and matrix and results in the decrease in the strength of the composite. Other mechanisms may also be involved in the degradation process which has to be investigated further.

In Fig. 8.6 (b) the variation of impact strength with fibre volume for specimens having a notch length of 2mm is shown. The trend shown by previous specimens is also found here. All the specimens show decrease in the impact strength irrespective of the soaking medium. Saline water treated and sea water treated specimens show least decrease and specimens treated with normal water show minimum decrease. But the variation between each specimen treated with different medium is very narrow. The decrease in the impact strength for saline water treated specimens is from 8%-23%. For the specimens treated with sea and normal water the decrease in the impact strength is from 8%-29% and 7%-25% respectively. This decrease in the impact strength is for the reasons discussed in the above section.

The variation of impact energy with fibre volume for specimens having a notch length of 3mm is shown in Fig. 8.6 (c). All the specimens exhibit decrease in the impact strength values regardless of the environment to which it is subjected to. The variation in decrease of strength between the specimens treated with different mediums is very
small. Saline water treated specimens show a decrease in impact strength from 0%-18%. For sea water treated specimens the decrease in impact strength was from 9%-21%. Normal water treated specimens showed a decrease from 11%-23%. The decrease in the impact strength is due to the reasons discussed in the above section.

In Fig. 8.6(d) the variation of Charpy impact energy with fibre volume for specimens having a notch length of 4mm is shown. The trend exhibited by other specimens is also seen here. All the specimens show decrease in the impact strength regardless the medium of soaking. There is very small difference between the impact energy values shown by all the specimens. Saline water treated specimens show a decrease in impact energy values from 10%-17%. The specimens treated with sea water showed a decrease in impact energy values from 12%-20%. Normal water treated specimens showed a decrease in the impact energy values from 12%-20%. The decrease in the impact strength of the composite can be attributed to the degradation process involved between the composite and the exposure medium which are discussed in the above section.

Figure 8.6 (e) shows the variation of impact energy with fibre volume for specimens having a notch length of 5mm. All the specimens exhibit decrease in the impact strength irrespective of the medium of soaking continuing the same trend as before. The difference between the impact energy values between the specimens is very small. Saline water treated specimens showed a decrease in impact energy values from 6%-22%. The decrease in impact strength for specimens treated with sea water is from 13%-27%. The specimens treated with normal water showed a decrease in impact strength from 20%-27%. The decrease in the impact strength is due to the reasons discussed in the above section.

Some of the important observations made for the specimens treated for 45 days are:

- All the specimens irrespective of the soaking medium show decrease in the impact strength when treated for 45 days.
- Charpy test gave a decreased percentage reduction in impact strength compared to Charpy impact test for 45 days treatment period.
- Saline water treated specimens show decrease in impact energy values from 0%-24%.
➢ Sea water treated specimens show decrease in impact energy values from 3%-29%.

➢ Normal water treated specimens show decrease in impact energy values from 5%-27%.

➢ It observed that for almost all the specimens with high fibre volume show maximum decrease in the impact strength after exposure to the different mediums.
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Fig. 8.6. Variation of Charpy impact energy with fibre volume for specimens treated with different mediums for 45 days.

(a) 1mm notch length     (b) 2mm notch length     (c) 3mm notch length
Fig. 8.6. (contd...) Variation of Charpy impact energy with fibre volume for specimens treated with different mediums for 45 days.

(d) 4mm notch length   (e) 5mm notch length
8.7. Comparative study of the Charpy behavior of GFRP composite treated with normal, sea and saline water for 60 days.

Figures from 8.7 (a) to 8.7 (e) show the variation of Charpy impact energy with fibre volume for specimens treated for 60 days and for different notch lengths along with untreated specimens. In Fig. 8.7(a) the variation of impact energy with fibre volume is shown for specimens having a notch length of 1mm. All the specimens irrespective of the medium being treated show a marked decrease in the impact strength. The decrease in the impact strength for all the specimens is very large. Saline water treated specimens show large decrease in the impact strength than other specimens. Normal water treated specimens show a decrease in the impact strength from 20%-42%. A decrease from 23%-47% was observed for sea water treated specimens. For saline water treated specimens the decrease in the impact strength was from 50%-63%. The decrease in the impact strength is due to the degradation process of the composite when it is subjected to the moisture environment.

Figure 8.7 (b) shows the variation of Charpy impact energy with fibre volume for specimens having a notch length of 2mm. The same trend is observed as in the previous specimens. All the specimens exhibit decrease in the impact strength regardless the soaking medium. Also the variation between the different treated specimens is very small. All the curves are staggered together showing marginal variation between them. Normal water treated show a decrease in impact strength from 53%-62%. A reduction from 36%-67% of impact strength was observed for sea water treated specimens. Saline water treated specimens exhibit a decrease in impact strength from 47%-75%. This decrease in the impact strength is due to the reasons discussed in the above section.

The variation of impact energy with fibre volume for specimens having a notch length of 3mm is shown in Fig. 8.7 (c). The same trend is observed here also as before. All the specimens show a reduction in the impact strength regardless the soaking medium. All the curves for different specimens are clustered indicating the variation between them is very small. Normal water treated specimens show a decrease in the impact strength from 50%-77%. A decrease from 47%-72% of impact strength was observed for sea water treated specimens. Saline water treated specimens show a decrease in impact energy from 55%-77%. This decrease in the impact strength can be attributed
to the degradation process involved in the composite when it is subjected to liquid environment.

In Fig. 8.7 (d) the variation of impact energy with fibre volume for specimens having a notch length of 4mm is shown. All the specimens exhibit the same trend as shown by the previous specimens. All the specimens show a large decrease in the impact strength values when compared to the untreated specimens. The variation between the different treated specimens is small. Normal water treated specimens show a decrease in strength from 62%-75%. Sea water treated specimens show a reduction in the impact energy values from 50%-75%. A decrease in impact energy values from 50%-70% was observed for saline water treated specimens. The decrease in the impact strength is due to the reasons discussed in the above section.

Figure 8.7 (e) shows the variation of impact energy with fibre volume for specimens having a notch length of 5mm. All the specimens show a decrease in the impact strength values showing the same trend that is shown by other specimens. Irrespective of the soaking medium all the specimens show large decrease in the impact strength. For specimens treated with normal water, a decrease in impact energy values from 64%-73% was observed. Sea water treated specimens show a decrease in the impact energy values from 50%-77%. Specimens soaked in the saline water showed a decrease in impact energy values from 46%-77%. The reasons for decrease in the impact strength are due to the environmental effects on the composite. Exposure of composite to moisture causes loss of strength when exposed for longer duration due to degradation. Leaching and hydrolysis are two mechanisms primarily responsible for decrease in the impact strength of the composite. This was clearly observed in the soaking trays used to soak the specimens. The leached material was present in the liquid when observed even for naked eyes.

The following are the observations made for the specimens treated for 60 days of time period:

- All the specimens regardless the environment to which it is subjected to exhibit a large decrease in the impact energy values.
- The variation between the specimens treated with different mediums was very small.
Normal water treated specimens show a decrease in the impact strength from 20%-77%.

Sea water treated specimens show a decrease in the impact strength values from 23%-77%.

Saline water treated specimens show a decrease in the impact strength values from 46%-77%.

As seen from the above observation, the variation of impact energy between the specimens treated with different liquid mediums is very small. As the treating time increases all the specimens almost exhibit the same impact strength behavior.
Fig. 8.7. Variation of Charpy impact energy with fibre volume for specimens treated with different mediums for 60 days.
Fig. 8.7. (contd...) Variation of Charpy impact energy with fibre volume for specimens treated with different mediums for 60 days.

(d) 4mm notch length  (e) 5mm notch length
8.8. Variation of damping with Charpy impact energy for specimens immersed in Seawater for different immersion times.

Figures 8.8 (a)-(e) show the variation of Charpy impact energy with damping for specimens with different notch lengths and immersion times soaked in seawater. In Fig. 8.8 (a) the variation of damping with Charpy impact energy is presented for specimens having fibre volume of 20%. As seen from the figure, for immersion period between 0-15 days, as the damping factor increases the impact energy value also increases irrespective of the notch length. The increase in damping is around 0.00075 (9%) while increase in the impact energy is around 0.5J (33%). For immersion period between 15-30 days, there was increase in the damping value but impact energy values for all the specimens decreased regardless the notch length. For a time period between 15 to 30 days the damping increased by around 0.0022 (25%) and impact energy decreased by around 0.6J (30%) which was for 5mm specimen. Between 30 to 45 days of immersion time both the damping and the impact energy for all the specimens decreased. The damping decreased by an amount of 0.00257 (23%) and impact energy decreased by a maximum amount of around 0.2J (14%) which was for 5mm specimen. Specimen with notch length of 2mm showed slight increase in the impact energy value of the order of 0.2J. For time period between 45 to 60 days damping decreased by around 0.0026 (3%) while impact energy decreased by around a maximum of 1.4J (70%) which was for 3mm specimen. Except between the immersion time of 15 to 30 days, remaining soaking times showed similar trend between the damping and the impact energy of the specimens.

Figure 8.8 (b) shows the variation of damping with impact energy for specimens having different notch lengths with 25% fibre volume for different soaking times. For initial period of immersion time between 0-15 days, as the damping increased the impact energy also increased. Between 15 and 30 days of soaking time, the damping of the composite increased while impact energy decreased for all the specimens. For immersion time between 30 to 45 days both the damping and the impact energy values for all the specimens decreased. Finally between 45 to 60 days of time period both the specimens show similar trend. As the damping value decreased the impact energy value also decreased. For immersion time between 0-15 days, the damping increased by 0.00127 (14%) and impact energy increased by a maximum amount of
0.25 J (8%). Maximum increase in the damping value of around 0.00097 (11%) while the impact energy decrease of around 0.7 J (20%) was observed for the specimens for time period between 15 to 30 days. Decrease in damping of 0.0012 (12%) and impact energy by 0.4 J was observed for specimens soaked 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 impact energy value decreased by maximum of 1.4 J (70%).

Variation of damping with impact energy for fibre volume of 30% with different notch lengths is presented in Fig. 8.8 (c). For initial period of immersion between 0-15 days, the damping decreased by an amount of 0.00287 and impact energy value increased by a maximum amount of 0.46 J. Between 15 to 30 days of immersion time, the damping increased by 0.0046 (69%) while the impact energy value decreased by around a maximum of 0.6 J (16%). For immersion time between 30 to 45 days the damping decreased by an amount of 0.00132 (12%) and impact energy decreased by 0.3 J (11%) which was for 3 mm notch length specimen. Finally between 45 to 60 days of immersion time the damping decreased by an amount of 0.00124 (13%) while impact energy value decreased by a maximum of 1.3 J (52%). The specimens here also present similar trend as shown by the previous specimens.

In Fig. 8.8 (d) the variation of damping with impact energy is presented for specimens having fibre volume of 35% and for different notch lengths. The specimens behavior for both damping and impact energy for initial immersion period is different. For initial period of soaking between 0-15 days the damping value decreased while the impact energy increased by 0.0001 and 0.4 J respectively. For an immersion time between 15 to 30 days the damping value increased by around 0.00193 (24%) while impact energy value decreased by approximately by a maximum amount of 0.6 J (15%) and between 30 to 45 days soaking time the damping value decreased by 0.00105 (11%) and impact energy value decreased by around 0.4 J (12%). Between 45 to 60 days of immersion period the damping value decreased by 0.0009 (10%) approximately while impact energy decreased by around 1.3 J (46%) which was for 3 mm notch length specimen. Here again the same trend is observed as with the other specimens with different fibre volumes.

Figure 8.8 (e) shows the variation of damping with impact energy for specimens having fibre volume of 40% and different notch lengths for different immersion times.
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The initial immersion time between 0-15 days showed decrease in damping values and increase in the impact energy by 0.0006 (6%) and 0.4J (14%) respectively. For immersion time between 15 to 30 days the damping value increased by 0.00282 (30%) while impact energy value decreased by a maximum of 1J (20%) and between 30 to 45 days of time interval, damping value decreased by 0.0017 (14%) and impact energy value decreased by around 0.6J (17%). For time period between 45 to 60 days damping value increased by an amount of 0.0019 (18%) while impact energy value decreased by 1J (42%).

As seen from the above discussion both the damping and the impact energy values vary in a similar trend except for time period between 15-30 days of immersion time. The reason for this deviation is to be investigated. The following are the important observations made for specimens soaked in seawater with regards to impact energy and damping:

- For specimens with fibre volume 20% and initial immersion period between 0-15 days the damping value increased by 9% while impact energy increased by a maximum amount of around 33%. Between 15 to 30 days of time interval, the damping increased by a maximum amount of around 25% while impact energy decreased by 30%. For time interval between 30 to 45 and 45 to 60 days the damping values decreased by a maximum amount of around 23% while impact energy decreased by a maximum of around 70%.

- For the initial period of immersion between 0-15 days and 25% fibre volume the damping increased by an amount of 14% while impact energy increased by an amount of 9%. Between 15 to 30 days of interval, the damping increased by an amount of 11% while impact energy increased by an amount of around 20%. For time interval between 30 to 45 days the damping decreased by an amount of 12% while impact energy value decreased by a maximum of 20% and between 45 to 60 days of time interval, damping decreased by 2% while impact energy also decreased by a maximum of 75%.

- Between 0-15 days of immersion period and 30% fibre volume, the damping decreased by 30% while impact energy increased by a maximum of 14%. For specimens immersed between 15 to 30 days, the damping value increased by large amount of around 69% while impact energy value decreased by 16%.
Between 30 to 45 days of soaking time damping decreased by approximately 12% while impact energy decreased by around 11% and for immersion time between 45 to 60 days the damping decreased by 13% while impact energy decreased by around 60%.

Specimens with fibre volume 35% and immersion time between 0-15 days showed reduction in damping by 1% while the impact energy increased by 11%. Immersion time between 15 to 30 days show a increase in the damping value of 24% and reduction in the impact energy value of 15% and for immersion period between 30 to 45 days the damping value decreased by around 11% while impact energy value decreased by an amount of 12%. For soaking time between 45 to 60 days there was decrease in the damping value of around 10% and impact energy decreased by 50%.

For specimens with fibre volume 40% and immersion period between 0-15 days the damping values decreased by 6% while the impact energy increased by 14%. Between immersion time 15 to 30 days, the damping value increased by 30% and impact energy value reduced by a maximum of around 22% and for soaking time between 30 to 45 days, the damping value decreased by an amount of 14% and impact energy decreased by a value of 17%. For immersion time between 45 to 60 days the damping value increased by 18% and impact energy value decreased by 42%.
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Fig. 8.8. Variation of Charpy impact energy with damping for specimens immersed in Seawater with different notch lengths and fibre volume.

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

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8.9. Variation of damping with Charpy impact energy for specimens immersed in Saline water for different immersion times.

Figures 8.9(a)-(e) show the variation of impact energy with damping factor for different fibre volumes and immersion times for specimens soaked in saline water. Figure 8.9 (a) shows the variation of impact energy with damping for specimen with fibre volume of 20%. Initial period of immersion between 0-15 days showed decrease in damping and increase in impact energy values. Damping decreased by an amount of 0.0074 (9%) while impact energy value increased by a maximum amount of 0.5J (33%). Specimen with 1mm notch length showed increase in the impact energy value of the order of 0.1J. For immersion time between 15 to 30 days the damping value decreased by an amount of 0.00133(18%) and impact energy value by around 0.4J (17%) and between the time interval of 30 to 45 days the damping value increased by 0.00037 (6%) while the impact energy value for all the specimens decreased. The maximum decrease was of the order of 0.2J (12%). For immersion time between 45 to 60 days the damping again decreased by 0.00043 (7%) while impact energy decreased by a maximum of around 1.7J (77%) which was for 3mm notch length specimen. There was different trend between the damping and impact energy values between 0-15 days and 30-45 days of immersion period.

In Fig. 8.9 (b) the variation of impact energy 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 the damping decreased and the impact energy values increased. The damping value decreased by 0.00008(1%) while the impact energy value increased by 0.4J (15%). Specimen with notch length of 1mm showed reduction in the impact energy value of the order of 2%. For 15 to 30 days period of soaking the damping value decreased by an amount of 0.003 (39%) while impact energy decreased by a maximum amount of around 0.6J (20%) and for immersion time between 30 to 45 days, the damping value increased by an amount of approximately 0.00074 (16%) and impact energy value decreased by an amount of around 0.4J (13%) which was for 1mm notch length specimen. For soaking time between 45 to 60 days the damping value increased by an amount of 0.0014 (26%), while the impact energy value decreased by a maximum amount of around 1.4J (58%). There is a contrasting behavior between the damping and impact energy values in this case.
Figure 8.9 (c) shows the variation of damping with impact energy for specimens having a fibre volume of 30% and for different soaking times. Soaking time between 0 to 15 days showed reduction in the damping and increase in the impact energy values. The damping value reduced by 0.00076 (8%) while the impact energy value increased by 0.4J (14%). For immersion period between 15 to 30 days the damping value decreased by a substantial amount of 0.00368 (42%) and impact energy value decreased by a small amount of around 0.6J (19%) and 30 to 45 days of soaking time showed again an increase in the damping value of about 0.00133 (26%), while impact energy value decreased by a maximum of 0.4J (18%) which is for 5mm notched specimen. For an immersion time between 45 to 60 days the damping value increased by an amount of 0.0016 (25%), while the impact energy value decreased for all the specimens irrespective of the notch length. A maximum amount of 1.4J (54%) decrease was observed. The same trend exhibited by the 2mm notch length specimens were also shown here. Except for 15-30 days of immersion time remaining soaking time showed different trend between the damping and the impact energy.

In Fig. 8.9 (d) the variation of impact energy with damping for specimens having a fibre volume of 35% is presented. Soaking period between 0-15 days showed reduction in damping and increase in impact energy of the specimens continuing the same trend exhibited by other previous specimens. Here the 1mm notch length specimen showed no change in the impact energy value. The damping reduced by 0.0032 (38%) and impact energy increased by a maximum of 0.24J (8%) which was for 3mm notched specimen. For the period of soaking between 15-30 days the damping increased by an amount of 0.00219 (43%), while impact energy decreased by an amount of around 0.7J (22%). For immersion time between 30 to 45 days the damping value decreased by small amount of around 0.00052 (7%) and impact energy by an amount of approximately 0.2J (8%). Between 45 to 60 days of immersion time, the damping value increased slightly by 0.0003 (5%) and impact energy value decreased by a maximum of around 1.4J (44%). Here also between the soaking time 15-30days, there was a similar trend between damping and impact energy values. Remaining immersion times showed different behavior between damping and impact energy.
Figure 8.9 (e) shows the variation of impact energy 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 specimens previously was also observed. Damping decreased by an amount of 0.0016 (10%) while impact energy increased by 0.8J (21%). Specimens with 1mm notch length showed decrease in the impact energy value. For immersion period between 15 to 30 days, the damping value decreased slightly by 0.00036 (4%), while impact energy value decreased by around 1.6J (32%) and for soaking time between 30 to 45 days the damping value increased by an amount of 0.0006 (7%), while the impact energy value decreased by around 0.2J (7%). For 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 impact energy value decreased by an amount around 1.8J (50%).

The following are the important observations made for specimens soaked in saline water with regards to impact energy and damping:

➤ Soaking period between 0 to 15 days showed reduction in the damping and increase in the impact energy values. A maximum reduction of around 38% for damping and 33% increase for impact energy was observed. Some specimens showed decrease in the impact energy values also. There requires further investigation to explain the deviation of the trends between the specimens.

➤ For immersion period between 15 to 30 days, the damping and impact energy values decreased for almost all the specimens. A maximum decrease of 42% was observed for damping and a maximum decrease of around 32% was observed for impact energy. Some of the specimens did not show any change in the impact energy values.

➤ For soaking time between 30 to 45 days, the damping values for the composite increased while the impact energy values for all the specimens decreased. The maximum increase for the damping is of the order of 27% and maximum decrease for impact energy was around 18%.

➤ For immersion period between 45 to 60 days, most of the specimens showed increase in damping and decrease in the impact energy values. A maximum
increase of around 25% was observed for damping and 77% decrease was observed for impact energy values.

- In total for specimens soaked in saline water, except for the immersion time between 15-30 days, remaining immersion times showed different trends in both the damping and the impact energy values. This behavior is different from the seawater treated specimens where in most of the cases similar trend was observed for both damping and the impact energy values.
Fig. 8.9. Variation of Charpy impact energy with damping for specimens immersed in Saline water with different notch lengths and fibre volume.
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8.10. Variation of damping with Charpy impact energy for specimens immersed in Normal water for different immersion times.

Figures 8.10 (a)-(e) show the variation of Impact energy with damping for different fibre volumes and immersion times. In Fig. 8.10 (a) the variation of damping with impact energy for specimens with fibre volume 20% is shown. Soaking period between 0 to 15 days showed reduction in the damping value and increase in the impact energy of the specimen. Damping reduced by an amount of 0.00137 (16%) and impact energy increased by a maximum of 0.7J (47%). For the immersion period between 15-30 days, the damping value increased by an amount of around 0.00051 (8%) and the impact energy values decreased by a maximum amount of 0.8J (36%). For soaking time between 30 to 45 days the damping value decreased by an amount of 0.0011 (15%) while impact energy decreased by 0.4J (18%). 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 impact energy decreased by a maximum of around 1.3J (72%). Here except for 30-45 days of immersion time, remaining soaking time presents different trends for both damping and impact energy.

The variation of impact energy with damping for specimens having a fibre volume of 25% is shown in Fig. 8.10 (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 the damping and increase in the impact energy values. The damping reduced by an amount of 0.0015 (20%) and impact energy increased by a maximum of around 0.6J. For the soaking time between 15 to 30 days, the damping value increased by an amount of around 0.00197 (31%), while impact energy decreased by an amount of the order of 0.8J (24%). For the immersion time between 30 to 45 days, the damping value decreased by an amount of 0.00173 (17%), while impact energy decreased by an amount of around 0.4J (17%). For soaking period between 45 to 60 days, the damping value increased by an amount of 0.00173 (25%) while impact energy value decreased by around a maximum of 1.2J (60%). Again here also we see the same trend exhibited by the 20% fibre volume specimen being repeated.

In Fig. 8.10 (c) the variation of damping with impact energy for specimens having fibre volume of 30% is presented. Soaking time between 0 and 15 days showed reduction in damping and increase in the impact energy values continuing the same
trend exhibited by the other specimens explained above. The damping reduced by an amount of 0.00285 (30%) while impact energy increased by a maximum of 0.5J (20%). Between the immersion time of 15 to 30 days the damping values increased by an amount of around 0.00022 (3%) while the impact energy decreased by a maximum of 0.8J (27%). For the immersion time between 30 to 45 days, the damping increased by an amount of 0.0003 (4%) and the impact energy decreased by a maximum amount of the order of 0.6J. For the immersion period between 45 to 60 days, the damping value decreased by around 0.00048 (8%) and the impact energy value decreased by a maximum amount of 1.4J (70%). In these specimens the immersion time between 45-60 days showed similar trend between damping and the impact energy values.

Figure 8.10 (d) shows the variation of impact energy 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 impact energy increased by around 0.64J (20%). For the immersion time between 15-30 days, the damping value increased by an amount of 0.00196 (34%) while impact energy decreased by a maximum amount of around 0.8J (21%). For the soaking time between 30 to 45 days, the damping value decreased by an amount of 0.00193 (25%) while impact energy decreased by a maximum amount of around 0.2J (9%). Immersion time between 45 to 60 days showed an increase in the damping value by an amount of 0.00226 (39%) while the impact energy value decreased by a maximum amount of 1.7J (53%). These specimens also show similar trend shown by other specimens discussed previously. The time period between 30-45 days show similar trend between damping and the impact energy values.

In Fig. 8.10 (e) the variation of impact energy with damping value for specimens having fibre volume of 40% is presented. Immersion period between 0-15 days showed reduction in the damping and increase in the impact energy values. The damping of the specimen reduced by an amount of 0.0018 (18%) while the impact energy increased by a maximum of 0.4J (14%). For the soaking time between 15 to 30 days the damping value increased by an amount of 0.00045 (5%) while impact energy value decreased by an amount of around 0.8J (25%). For the immersion time between 30 to 45 days, the damping value decreased by an amount of around 0.00096 (11%)
while the impact energy values also decreased by a maximum amount of 0.5J (14%). For soaking period between 45 to 60 days, the damping value increased by an amount of 0.00092 (12%) and the impact energy value decreased by a maximum amount of 2J (56%). We can see from the discussion above that the trend shown by the previous specimens is also being shown by these specimens.

The following are the important observations made for specimens soaked in normal water with regards to impact energy and damping:

- The immersion period between 0 to 15 days showed reduction in the damping value and increase in the impact energy values irrespective of the fibre volume. The maximum reduction in the damping value is of the order of 31% while the impact energy values increased by a maximum of 47%.
- For an immersion period between 15 to 30 days, the damping value of the composite increased by a maximum amount of 40%, while the impact energy value decreased by an amount of approximately 36%.
- 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 impact energy value decreased by an amount of around 19%.
- Immersion period between 45 to 60 days showed increase in the damping value of about 39% while the impact energy value decreased by a maximum amount of around 72%.
- Except for the soaking time between 30-45 days, the remaining immersion times exhibit different trends for both the damping and the impact energy.
(a) 20% Fibre volume (b) 25% Fibre volume (c) 30% Fibre volume (d) 35% Fibre volume (e) 40% Fibre volume

Fig.8.10. Variation of Charpy impact energy with damping for specimens immersed in Normal water with different notch lengths and fibre volume.