Low velocity impact analysis on glass fiber reinforced composites with varied volume fractions

Rakesh Reghunath¹, Mahadevan Lakshmanan², K M Mini

¹Asst. Professor, Department of Mechanical Engineering, Amal Jyothi College of Engineering Kottayam, Kerala, India
E-mail: rreghunath11@gmail.com

²Asst. Professor, Department of Mechanical Engineering, Amrita School of Engineering, Amrita Vishwa Vidyapeetham, Amrita Nagar, Coimbatore, Tamil Nadu, India
E-mail: mlakshmanan90@gmail.com

³Professor, Department of Civil Engineering, Amrita School of Engineering, Amrita Vishwa Vidyapeetham, Amrita Nagar, Coimbatore, Tamil Nadu, India
E-mail: minikmadhavan@gmail.com

Abstract. This paper presents an experimental study to assess the impact response of bidirectional woven type of glass fiber reinforced composite material with varied volume fractions and hence to find out the optimal volume fraction which gives better impact resistance. The specimens are prepared using vacuum bagging process and the volume fraction is estimated by resin burn off method. For getting information regarding surface topography of the impacted specimen, scanning electron microscopy is conducted. The study is done by slightly varying the velocities and it is found that a volume fraction of 43-44% gives a better impact resistance which is also confirmed by the scanning electron microscopy test. From the SEM results it is observed that matrix cracking, fiber breakage, debonding and fiber pull out are the major modes of failure during the impact, which reduces the structural strength and stability of the structure.

1. Introduction
Composites are used as an alternative to metallic material structures where weight is a major consideration. During the last decade fiber reinforced composites have been established as a competitive material for naval, automotive and aerospace industry. Their behavior under impact loading is a major concern, since impacts do occur during manufacture, normal operation, maintenance and so on. The impact behavior of FRP materials is so diverse and complex and the present knowledge is far from complete. The resulting damage due to impact, often in the form of delaminations, matrix cracking and fiber failure may severely reduce the structural strength and
stability. Therefore, a current and important design requirement in load bearing composite structures is the ability to tolerate the impact damage. Impact may be defined as a relatively sudden application of an impulsive force, to a limited volume of material or a part of structure.

The impact responses of the composite structures have been studied extensively over the years since the impact damage caused by foreign objects can reduce the load carrying capacity of the composites significantly. Based on different velocity ranges in the impact events, categorization of impact events are reported by Roger L Ellis [1] as low, high, ballistic and hyper velocity impact. Rajesh Mathivan and J Jerald [2] characterized the type and extent of the damage observed in the laminate for a range of thickness subjected to different impact velocity. Studies on fiber reinforced composite plates impacted by standard drop weight with different impact energies are reported by Ramin et al [3], AhmetYapici [5] and Mitrevski et al [4] investigated the effect of impactor shape on the impact response of thin woven carbon/epoxy laminates. Low velocity impact tests are further reported by Giovanni Belingrdi & Roberto Vadori [6]. Kishore. ZY Zhang and Richardson [16] conducted low velocity impact induced non penetration damage in Pultruded glass fiber reinforced polyester composites material using a instrumented falling weight impact testing machine. A series of low velocity impact test have been carried out on a (0°, 90°) glass fiber reinforced epoxy resin by Yang and Cantwell [9] in order to investigate the influence of varying key parameters on the damage initiation threshold. Energy absorption mechanism in Kevlar multiaxial wrap-knit fabric composite under impact loading is presented by Tae Jin and cheol Kim [11]. Characterization techniques of the impact damage such as cross sectional fractography and scanning acoustic microscopy were employed quantitatively to assess the internal damage of the composite laminate at the subsurface under impact, reported by M S Sohn et al [10]. The repeated impact behavior of self reinforced poly propylene composite has been characterized by tensile impact and instrumented falling weight test by J Aurrekoetxea et al [24].It was reported that near surface damage in glass/epoxy composite beam is sensitive to tensile stress arising from repeated impact load on the undamaged surface by J M Lifshitz and Gandelsman [12]. Indentation and penetration of carbon fiber reinforced laminates under low velocity impact was studied by G Caprino et al[13]. An Overall view of the impact response of woven fabric composite plate is presented by Cesim and Onur Sayman [26]. Evaluation of in plane dimensional effect of the glass fiber/Epoxy composite under low velocity impact was conducted by Zuleyha Aslan et al[14]. Young Shin Lee [15] and his group did numerical analysis using FEM method to predict impact response of laminated composite plates subjected to low velocity impact. It was also found that the orientation of the damage during impact also have a significant role in determining CAI strength, presented by Mehmet Aktas and Yusuf Arman [17]. G Zhou and O Davies [18] analyzed impact response of thick glass fiber reinforced polyester composites and energy absorbing characteristic have been determined by impact force and absorbed energy histories and by force displacement relations. J N Baucom [20] has conducted an experimental study to obtain a detailed understanding of the effect of reinforcement geometry on the damage progression in woven composites panels under repeated drop weight impact loading conditions. A study of damage mechanism and delamination which are the principle mode of failure and energy absorption in a composite shell and their influence on the impact performance of the helmet was reported by Praveen K Pinnoji and Puneet Mahajan [21]. Low velocity impact damage to composite laminates caused a complicated pattern of matrix cracks, fiber cracks and delamination and was reported by M J Pavier and P Clark [22]. The effect of laminate thickness on the composite strength to repeated low energy impacts has been studied by W A de Morias et.al [23]. His studies proved that below a certain energy
level the cross section of the laminate is the most relevant variable that determines the impact resistance. The glass fabric reinforced composite laminates shows the steepest increase in impact resistance with increasing laminate thickness.

Present paper focuses on studying the effect of volume fraction of fibers on the impact strength of GFRP composites under low velocity impact. Composites of different volume fractions are manufactured by vacuum bagging process and percentage of fiber content is determined by resin burn off method. The specimens are subjected to low velocity impact by using the drop/falling weight impact test.

2. Experimental Investigation

Among the different methods available for conducting low velocity impact tests, the drop/falling weight impact test is the widely used one, where the testing can be done under low acceleration. Falling weight impact testing enables to simulate a wide variety of real world impact conditions and collect the detailed performance data.

In the present study, specimens are prepared by using vacuum bagging process [25], which is a clamping method that uses atmospheric pressure to hold the adhesive or resin – coated components of a lamination in place until the adhesive cures. Specimens are manufactured using 310GSM bidirectional E-glass mats. Volume fraction of the prepared specimen is estimated using resin burn off method (ASTM D2584) where specimens of 25 mm × 25 mm size is burned in a muffle furnace to a temperature of 600°C to burn off the resin, and thus to find the weight of fiber from which the volume fraction of specimen can be calculated. Volume fractions of 41%, 43%, 47%, 48% and 56% are obtained in the present study, thus varying the volume fraction from 40% to 60%. Volume fraction is an important parameter which determines the load carrying capacity of the material. As the volume fraction of composite increases the load carrying capacity by fibers also increases. Rule of mixture [7] is used to plot the effect of varying volume fraction on the load carrying capacity of fibers (figure1) where $E_f$ and $E_m$ represents the Young’s Modulus of fiber and matrix respectively.

From Figure1 it is observed that for a given value of $E_f/E_m$, as the volume fraction of fiber increases the load carrying capacity increases. But practically as the volume fraction of fiber increases beyond a limit, the percentage of matrix phase will go down and the interlaminar shear strength of material will come down and so the load carrying capacity should come down. The present paper focuses on this aspect and hence to find the optimum volume fraction.

The tests are conducted on an instrumented falling weight testing machine (figure2) where the impact energy can be controlled by either adjusting the falling height or by adjusting the mass of the falling steel dart. For the present investigation, the maximum height is set as 500 mm and the maximum mass as 2.5 kg which gives maximum impact energy of 15 J approximately. On increasing the mass or height, the potential energy of the dart will keep increasing and on releasing it, the potential energy will be converted to kinetic energy. For the experimental investigation a minimum of three square samples of size 150 mm × 150 mm are tested ASTM D 3029 [8]. Specimens are clamped on a fixture having a central slot of 100 mm × 100 mm which forms the area available for assessing the impact strength and the steel dart is having a hemispherical head of 10 mm radius. Specimen clamping apparatus is specially designed to ensure the constancy of clamping force, through a preloading of hemispherical springs.
3. Results and Discussion

GFRP composite specimens having a constant thickness of 2mm and volume fractions ranging from 40% to 60% are manufactured using vacuum bagging process. The specimens are clamped on the fixture having a central slot of 100mm × 100mm. The falling height of the impactor is adjusted such that the velocity of impact is attained a value of 2m/s, 2.5m/s and 3m/s. The load taken by the specimens of different volume fractions corresponding to varying velocities are compared and presented in Fig.3.
From Fig. 3 it is observed that as the volume fraction of fiber increases, the load carrying capacity also increases up to a limit and then it starts decreasing. When the volume fraction is 43-44% of fibers it is observed that the load taken by the material is maximum in all the three cases. When fiber content increases beyond a limit the interlaminar shear strength of the fiber will come down so the load taken by fibers will also come down at higher volume fractions. In the present investigation it is observed that a volume fraction 43-44% is the optimum for the load carrying capacity.

Fig. 4 shows effect of volume fraction on the energy absorbed by the specimen. From Fig. it is found that as the volume fraction of the fibers increases the amount of energy absorbed by the specimen increases and reaches a maximum value and then starts decreasing. Same trend of variation is followed for the entire volume fraction. At higher volume fraction more amount of energy is needed for fiber breakage and therefore the amount of energy absorbed by specimen is coming down. At 2m/s maximum amount of energy absorbed by specimen is near to the volume fraction of 43% and as the velocity moves to 2.5m/s and 3 m/s the amount of energy absorbed by specimen is maximum around 49% volume fraction and when impact velocity increases the volume fraction at which max amount of energy is absorbed also increases.
Fig. 5 Effect of Volume Fraction on Retardation

Fig. 5 shows the effect of retardation of the indenter on the specimen for varying volume fractions at maximum load, corresponding to varying velocity. From the graph it is observed that retardation offered by the specimen is maximum around 43% which can be considered as the volume fraction of the material which gives better impact resistance. After 43% volume fraction, the retardation offered by specimen is decreasing drastically in all the three cases.

Fig. 6 shows the effect of velocity on the load taken by GFRP composites at different volume fractions. From Fig. it is found that for a volume fraction of 41%, maximum load taken by specimen is 315 N, that is even for the lower velocity of 2m/s velocity, the impactor is completely pierced and the specimen could not take any further load. As the volume fraction is increased to 43% maximum load taken by specimen increases as the velocity increases and it has taken a load of 600N at higher velocity. Load carrying capacity varies slightly linearly in this case. For higher volume fractions of 48% and 56% maximum load taken by material has come down at higher velocity. In this case as the velocity is increasing the load carrying capacity will first increase and then started decreasing.

Conclusion

The present study focused on assessing the impact strength of glass fibre reinforced composite with varying volume fraction and hence to find the optimum volume fraction which gives the maximum impact resistance, for different velocities of impact. Composite specimens of 2 mm thickness are prepared by using vacuum bagging process by varying the fibre content. The volume fraction of the prepared specimens is found using resin burn off method. The specimens are subjected to low velocity impact in a falling weight impact testing machine. By changing the height
of the impactor the velocity of impact is varied. Since the investigation is focused on finding the optimum volume fraction corresponding to maximum impact resistance, the velocity of impact is varied slightly from 2 m/s to 4 m/s. From the study it is found that optimal value of fiber volume fraction is around 43% where the composite material is taking maximum load and maximum retardation to the indentation is also found to be around 43%.

Acknowledgment
The authors are very much thankful to Dr. V P Rahupathy and Mr. Rajesh M Mathivan, Professor, PES College of Engineering, Bangalore for their support in conducting the experiments.

References
1) Ballistic impact resistance of graphite epoxy composite with shape memory alloys and Extended chain polythene spectra Hybrid composite (Rigger L Ellis 1996, Thesis report submitted at Blacksburg University, Virginia.
2) N Rajesh Mathivan, J Jerald (2010) ‘Experimental Investigation of low velocity impact Characteristics of woven glass fiber epoxy matrix composite laminate’, ‘Journal of materials and design’, Vol 31, pp.4553-4560.
3) Ramin, Mahmoud Larry (2010).’Damage behavior of fiber reinforced composites plate subjected to drop weight impacts’ Journal of Composite Science and Technology, Vol 66 pp61-68
4) T Mitrevski et al (2005) ‘The effects of impactor shape on the impact response of Composite Laminate’ Journal of Composite structures Vol. 67 pp139-148.
5) AhemetYapici, Mehmet Metin.‘Effect of Low velocity Impact Damage on the Buckling Properties Journal of Scientific Research, 2009 pp 161-166
6) E Milli, B Necib Effect of stacking sequence on the impact induced damage in the cross ply E-glass/ Epoxy Composite Journal of applied Mechanics (2009) Vol 79 pp1019-1031.
7) Giovanni Belingrdi & Roberto Vadori’ Low velocity impact test of laminate glass fiber epoxy matrix composite material plate’. International journal of Impact engineering, 27(2002) Pp-213-229
8) Kishore, Ramanthan ‘Repeated Drop Weight impact test and post impact ILSS on Glass EpoxyComposite materials ‘Bull Mater Sci Vol 19 PP no 1131-1141
9) Westely J Cantwell et al. Impact response characterization of composite structures –Applied composite materials (2010) pp 463-472
10) P K Mallik- Taylor and Francis group 2007.’Fiber reinforced composites Materials Manufacturing and Design’.
11) Arthur K Kaw –Taylor and Francis Group 2006 ‘Mechanics of Composite Materials’
12) S R Reid and G Zhou–‘Impact behavior of fiberreinforced composite material and structures, CRC Press Washington D C 2000
13) P Gougeon- ‘A guide to Vacuum Bagging Methodology’ CRC Press, Washington D C 7th Edition 2010

14) ASTM D3029- Standards Testing method for impact resistance of flat rigid plastic specimen by means of a Tup or a falling Weight.