Delamination On GFRP Laminates Impacted at Room and Lower Temperatures: Comparison Between Epoxy and Vinylester Resins.

Valentina Lopresto[a], Antonio Langella[b], Ilaria Papa[c]

[1]*Department of Chemical, Materials and Production Engineering, University of Naples "Federico II", Piazzale Tecchio 80, 80125, Naples, Italy*

[a]Corresponding author: lopresto@unina.it
[b]antgella@unina.it
[c]ilaria.papa@unina.it

Abstract. Low velocity impact tests at three different impact energy values and three different temperatures, were performed on glass fibre composite laminates made by infusion technology. Two different resins, epoxy and vinylester, were considered to impregnate the fibres: the first is mainly of aeronautical interest whereas the second one is mainly applied in Naval field. The specimens were first completely destroyed to obtain the complete load-displacement curve. The latter allowed the evaluation of the increasing impact energies, 5, 10 and 20J, used to investigate about the start and propagation of the damage inside the laminates. The delamination was investigated by the very commonly used Ultra Sound technique and the results obtained on the different materials at different temperatures were compared. A general better behaviour of vinylester resin was noted.

INTRODUCTION

Composites laminates made by glass fibers reinforcements in an epoxy resin, is a very common composite material characterized by good physical, chemical, thermal, and mechanical properties. Epoxy resin is the most commonly used, in particular for aerospace applications, since its good resistance to higher temperatures, good corrosion resistance, mechanical and electrical properties, no styrene emission and more compact failure modes respect to vinylester. On the other side, the latter is very simple to use and shows a better moisture absorption. For these reasons, composite laminates made by carbon or glass fibres in vinylester resin are very appreciated and applied in Naval field.

However, since the anisotropic nature of composites and the subsequent particular mechanism of damage formation, the dynamic properties of both the cited laminates are deeply under attention. A lot of naval and aerospace construction parts are, in fact, subjected to mechanical shock: in these conditions, the toughness of the material changes causing different damage mechanisms. It is very important the understanding of these mechanisms and to compare the impact response of laminates made by different constituents in extreme temperature conditions too. The Artic Ocean navigation represent, for example, a very interesting point to investigate on.

Composites are characterized by several interacting failure modes such as matrix breakage, fiber failure and delaminations. These failure modes, which can be simultaneously induced by low velocity impacts [1], can be very difficult to be detected by visual inspections of the structure. Hence, time and cost consuming non-destructive techniques, such as ultrasound based techniques, must be adopted for the inspection of composite materials.

The changes in the properties of the materials with changing temperatures was studied in [2] by Howard and Hollaway whereas in [3], Shindo et al. studied the thermal mechanical response of non-metallic woven composites with temperature-dependant properties. In general, many scientists analyzed the properties of polymer composite materials at different temperatures but only a few of them tested their properties under impact loading and studied the changing of their impact properties with changing temperature.

In this paper, low velocity impact tests at three different impact energy values and three different temperatures, were performed on glass fibre composite laminates made by infusion technology. Two different resins, epoxy and vinylester, were considered to impregnate the fibres. The delamination was investigated by the very commonly used Ultra Sound technique and the results obtained on the different materials at different temperatures were compared. A general better behaviour of vinylester resin was noted.

MATERIALS AND EXPERIMENTAL SET UP

Dry unidirectional layers of E-glass fibre were overlapped following the stacking sequence $[(0), (90)]_n$, with n = 5, 7 and 8. Epoxy resin SX10 from Mates srl and vinylester Reichhold Hydrex 100 HF series (33375-00) were used to impregnate the glass fibre by infusion. The final laminates have nominal thicknesses in the range 2.8 - 4.6 mm. The fibre volume fraction was $V_f = 48\%$.

The experimental low velocity impact tests have been performed by a Ceast Fractovis drop weight machine, allowing to vary the impact energy by changing the impactor mass and the drop height. The instrumented steel impactor, with a total minimum mass of 3.6 kg, is cylindrical with hemispherical nose, 19.8 mm in diameter.

The maximum falling height of the drop weight testing machine is 1 m, corresponding to a maximum impact energy U = 35.7 J combined with the minimum mass of the impactor. Different impact energies for the so called indentation tests, useful to investigate the damage start and propagation, were obtained adding masses up to 10.6 kg, and varying the falling height. DAS 16000 acquisition program allows to record all the impact parameters like contact load and impact energy. The impact velocity of 4m/s was measured by an optoelectronic device. The data were stored after each impact and the impactor was catch by an antirebound system to avoid multiple impacts. Impact tests were carried out up to the complete penetration of the rectangular specimens, 100x150mm, clamped following the EN6038 Standard suggestions.

The updating of the machine by a thermal chamber allowed the tests at low temperature. Liquid Nitrogen was used to lower the temperature. From10 to 15 minutes were necessary to get -25°C and -50°C.

The complete load displacement curves were recorded during each test mentioned acquisition program. They were accurately studied since they represent a map of the dynamic behaviour of the laminates. It was possible [4], in fact, to correlate the damage evolution during an impact with the characteristics points, like load drops or change in slope. From them it was possible to measure the penetration energy and the different energy values, 5J, 10J and 20J, used to perform the indentation tests. The different energies were obtained in correspondence of characteristic points on the force - displacement curve clearly evidencing a change in material behaviour as a consequence of a damage. From the indentation tests the study of the damage initiation and propagation was possible.

After each test, each specimen was inspected: since the transparency of the glass fibre laminates, the delaminated areas were first measured by visual inspections and then inspected by US Multi2000 Pocket 16x64 system by M2M. Each sample was, so, first, photographed on the side opposite to the impacted surface with a light source placed on the other side (surface with the impact indentation). Each photo was, then, imported in a cad software where the delaminated area was bordered and measured. The results were then compared to the investigations by US technique. Since a good agreement was found, in the following no distinction will be done.

Ultrasounds scans were performed with a US Multi2000 Pocket 16x64 by M2M.

C-scan inspections provided a plane view of the specimen. The software controlling and analyzing the probe provides a total image of the damage. The acquisition system is calibrated using an undamaged sample. A typical example is represented in figure 1: the damaged areas are represented with different colors and they can be easily identified and measured.

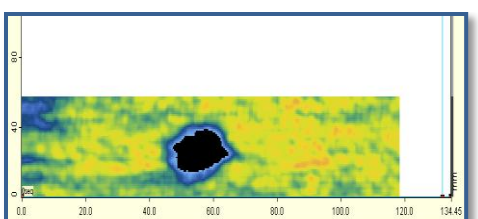
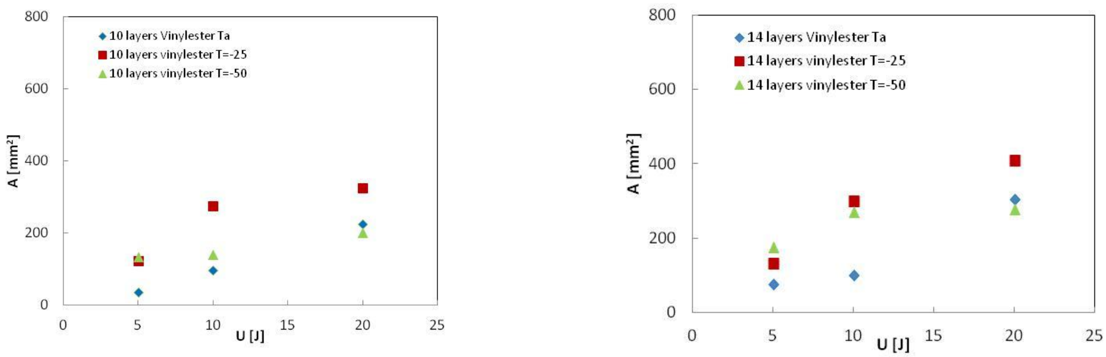


FIGURE 1. Example of US damage detection.

RESULTS

In [5], a more brittle behaviour was found on laminates impacted at lower temperature respect the room one. About delamination, in general, at the decreasing of the temperature, an increasing of the damage extension was observed and, as expected, the increasing was more at the increasing of the impact energy.

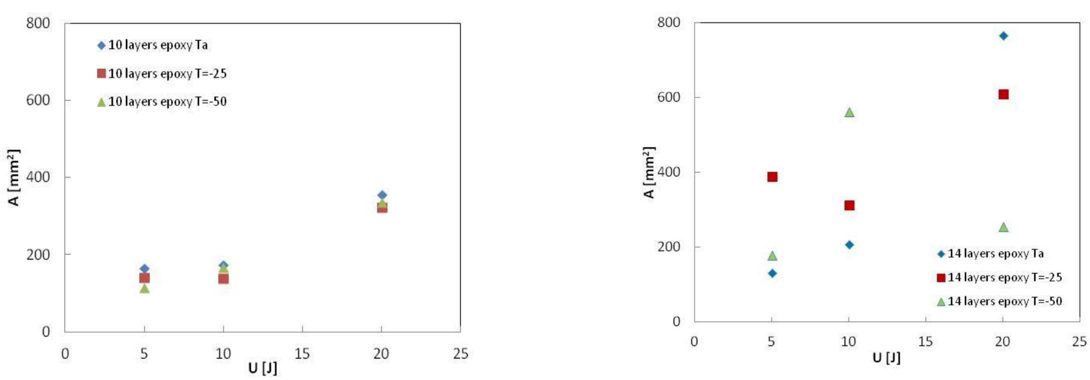
In the present research, as it is possible to observe in Fig. 2, when vinylester resin was adopted, the worst behaviour in terms of larger delaminations at higher impact energies, was performed at a temperature of -25°C and no big differences were noted between the different thicknesses analyzed. The trend is quite linear at the increasing of energy.



(a) (b)

FIGURE 2. Delaminated area vs impact energy: influence of the temperature on vinylester laminates. (a) 10 layers; (b) 14 layers.

By observing Fig. 3 (a), on the contrary, it was noted that by using epoxy resin as matrix, similar delaminated areas were found on laminates made by 10 layers, independently of the temperature. Results that need to be confirmed by more experimental tests were obtained on thicker laminates. However, by comparing these results with what observed on vinylester laminates, a different influence of the resin was evidenced.



(a) (b)

FIGURE 3. Delaminated area vs impact energy: influence of the temperature on epoxy laminates. (a) 10 layers; (b) 14 layers.

In Fig. 4, the comparison between epoxy and vinylester resin was reported for laminates 3 mm in thickness (14 layers) impacted at room (a) and -50°C (b). A better general behaviour of the vinylester was noted except for laminates impacted at an energy of 20J at -50°C. This result needs to be confirmed with additional tests at low temperatures and higher impact energies.

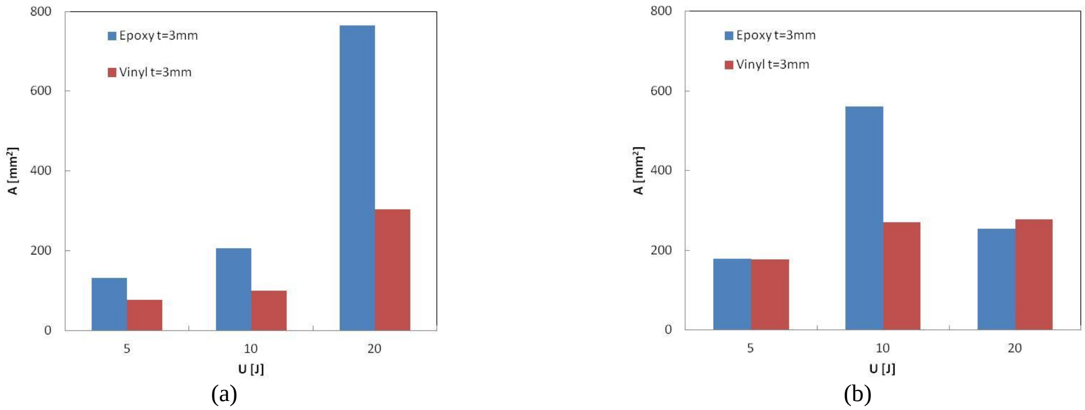


FIGURE 4. Delaminated area vs impact energy: influence of the resin. (a) room temperature; (b) T=-50°C.

CONCLUSIONS

After a comparison on impact behaviours in terms of delamination propagation at room and lower temperatures of laminates made by epoxy and vinylester resin, the following results were obtained.

- The temperature of -25°C was revealed to be crytical when vinylester resin was adopted: larger delaminations were measured at the higher impact energies; no big differences were noted between the different thicknesses analysed.
- Similar delaminated areas were found on laminates made by epoxy 10 layers, independently of the temperature. Additional tests are necessary on thicker laminates.
- The comparison between epoxy and vinylester resin denotes a better general behaviour of the vinylester.

AKNOWLEDGEMENTS

The authors gratefully acknowledge the ONR Solid Mechanics Program, in the person of Dr. Yapa D.S. Rajapakse, Program Manager, for the financial support provided to this research.

REFERENCES

1. Faggiani, A., Falzon, B.G. Compos. A: Appl. Sci. Manuf. 41(6), 737–749 (2010)
2. M. Howard, L. Hollaway, Composites, Vol. 18, 1987, 317.
3. Y. Shindo, S. Ueda, Y. Nishioka, Fusion Engin. Design, Vol. 20, 1993, p. 469.M. P. Brown and K. Austin, Appl. Phys. Letters **85**, 2503–2504 (2004).
4. G. Caprino, V. Lopresto, C. Scarponi, G. Briotti, Comp. Science and Tech., Vol. 59 (1999), 2279-2286.
5. V. Lopresto, A. Langella, Procedia Engineering, Vol. 88 (2014), 173-179.