Distributed Dynamic Load on Composite Laminates

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Abstract. An experimental activity conducted in order to assess the impact behavior at room and low temperature of carbon fibre in vinylester resin laminates used in the shipbuilding industry, was reported. The conditions which reproduce the impact of a hull at low temperature with a solid body suspended in the water was reproduced.

A test equipment was designed and realized to reproduce the real material behaviour in water to obtain a load distribution on the entire surface of the specimen.

The results were obtained impacting the laminates placed between the cilyndrical steel impactor and a bag containing water. A falling weight machine, equipped with an instrumented steel impactor and a thermal chamber, was adopted for the experimental tests.

The impact behaviour in hostile environments was compared to the behaviour at room temperature and the data obtained under distributed load conditions were compared with the results from concentrated loads: a completely different behaviour was observed between the two different loading conditions in terms of load-displacement curve.

The effect of the impact on the laminates has been related with the delaminations, evaluated by ultrasonic scanning, and the indentation.

Keywords: dynamic load, composites, low temperature, Naval field, distributed load.
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Introduction

The low temperature represents an environmental condition critical for structures made of composite material in particular under dynamic loads. This problem is really important in the Artic Ocean navigation since Navy ships must operate safely in different regions of the globe surviving if subjected to extreme dynamic loads such as impact.

Composite materials are non homogeneous and anisotropic and they can fail in a variety of damages not always visible. For security reason, it is very important to know the behaviour of composite laminates under impact conditions at different impact energies. A lot was done to investigate the impact behaviour of laminates under concentrated dynamic loads [1-5]. The latter conditions are very common also during maintenance operations. Few researches were, on the contrary, dedicated to distribute the dynamic load on the entire material surface to simulate the navigation and so the water-material interaction.

Material and Experimental Set Up

A balanced laminate (0°/90°) made by the overlapping of seven T700 carbon fabric plies 300 g/sqm, resulting in 2.4 mm thickness, was studied under dynamic loading conditions. The panel, 600x600mm, was fabricated at Naval Surface Warfare Center (NSWC) by vacuum infusion process using the Ashland Derakane 510A vinyl ester resin. The volumetric fibre percentage V_f was 48%.

The impact behaviour was studied performing dynamic tests by a falling weight machine Ceast Fractovis, impacting the rectangular specimens, 100x150mm, suggested by the EN6038 Standard and cut from the original laminate by a diamond saw. A cylindrical instrumented tup with hemispherical nose 19.8 mm in diameter, was used to impact the specimens. The impact velocity was 4.0 m/s.

The specimens were, first, impacted under concentrated loads at room and the low temperature of -25°C. The clamping device was the one suggested by the above recalled EN Stardard .

Then, dynamic tests with distributed loads were carried out on similar specimens simply supported by a water layer. The scheme of the experimental equipment used during the tests is shown in Fig.1 where it is possible to note that a deformable bag containing water solution, was placed under the sample. The aim was to obtain a load distribution on the entire surface of the specimen in order to simulate the impact conditions of the ship on the water during the navigation.

The water was contained into a cylindrical pvc box without cover, 200 mm in diameter. A rubber bag, thin and deformable, was used to cover the box and was sealed to it.

During each test, the complete force-time and force-displacement curves were recorded by the DAS16000 acquisition program and successively studied. Three different impact energy values were used for each configuration, 5J, 10J and 25J, to study the damage initiation and propagation.

The indentation depth was measured by confocal microscope LEICA DCM3D following the Standard EN6038 suggestions whereas an Ultra Sound apparatus, Multi2000 Pocket 16x64 by M2M, was used to investigate the internal delamination.

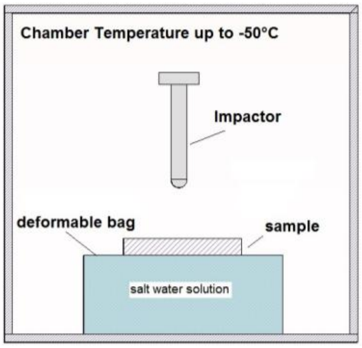
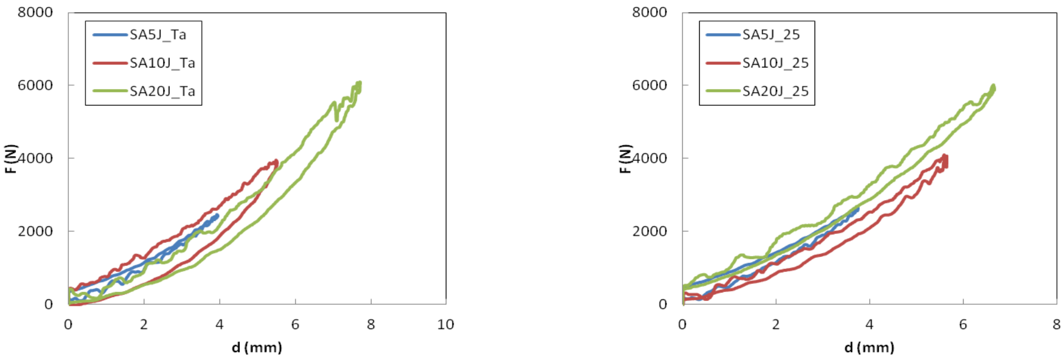


FIGURE 1. Schematic view of the apparatus.

Results

In Fig. 2, the load curves obtained at room (a) and low (b) temperature under concentrated loads, were overlapped. As expected, an increasing in maximum force was noted at the increasing of the impact energy. Any particular observation can't be done about the initial rigidity.



a) b)

FIGURE 2. Load-displacement curves from concentrated impact tests at room a) and low b) temperature.

Interestingly, by the comparison between the curves obtained at room and low temperature (Fig. 3), very little differences were noted about initial rigidity and maximum load, differently from what commonly observed [6] on laminates made by epoxy matrix. In the latter case, the higher rigidity and maximum force at low T were due to the more brittle behaviour of the material in extreme conditions. However, it is important to note in the same figure that at T = -25°C, a reduced amount of energy was absorbed since the smaller area between the loading and unloading part of the curve. The same happened also at 5 and 10J of impact energy, U, not reported here for brevity.

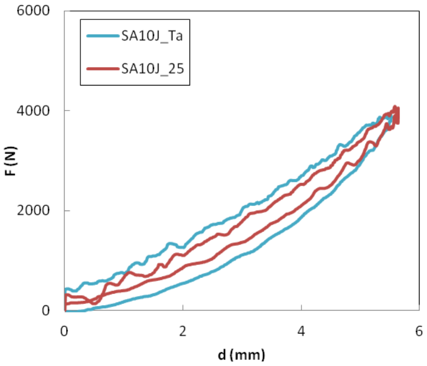
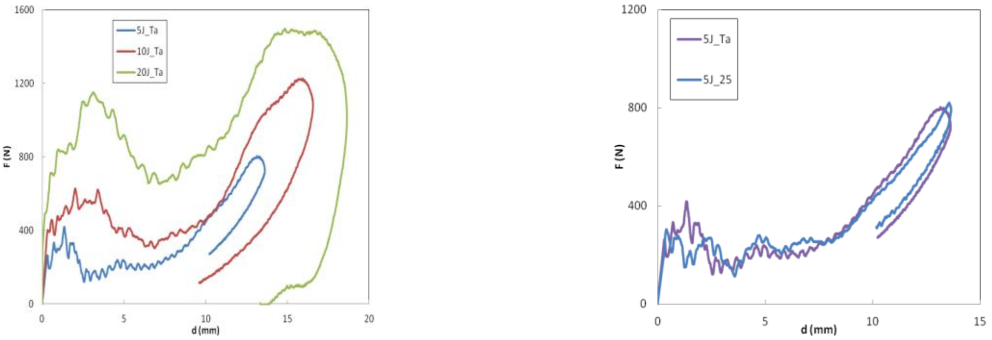


FIGURE 3. Comparison between room and extreme conditions. U = 20J.

As already said, the rectangular specimens were impacted by the same impact energies of the previously described concentrated load tests, U = 5J, 10J and 20J, also when they were simply supported on a water pillow adopted to obtain the load distribution. In Fig. 4a), the complete load curves were compared between the different energy values used. As clear and expectable, the shape of the curves is different from what always observed in concentrated load impact tests: after an increasing up to the maximum load, the unloading part of the curve decreases even if the displacement of the specimen continue to increase; the decreasing reach, then, a minimum value and increases again up to a second maximum load, higher than the first one; in the final part, the load decreases at the decreasing of the displacement. Different explanations of the particular behaviour will be given in the full paper but it is possible to anticipate here the very important understanding of the vibrations of the system that could be here not negligible, contrarily to what demonstrated [7] in concentrated load impacts. It is, in fact, important to understand if the vibrations are small but with high frequency or if the frequency modifies the entire shape of the load curve. The problem is to understand which is the effect of the vibrations on the curve.



a) b)

FIGURE 4. Load-displacement curves from distributed load tests: a) different impact energies; b) different temperatures.

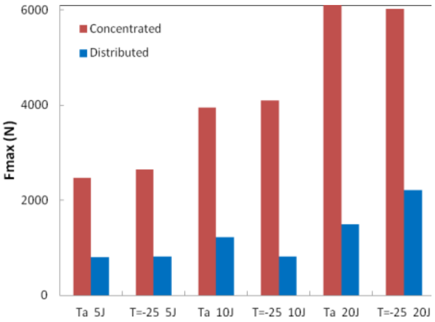


FIGURE 5: Maximum loads, F_{max}, comparison between concentrated and distributed load test.

The same behaviour was observed at low temperature. By comparing the different curves at room and low temperature (Fig.4 b)) it is possible to note the similar behaviour denoted by the similar shape of the curve.

Plotting in a bars graph (Fig. 5) all the maximum loads obtained in all the tests carried out on carbon-vinylester laminates, it is possible to clearly see the different values between concentrated and distributed load conditions. In the latter case, the second higher peak was considered. The concentrated maximum loads are sensibly higher than the ones obtained distributing the impact. It is also clear what said above about the higher values obtained at room temperature respect the extreme conditions in water.

Indentation and delamination

Indentation measurements were carried out by the confocal microscope. In [8, 9], the importance to know the dent depth was highlighted since the possibility to predict the impact energy and thus the residual strength of an impacted laminate. Unfortunately, on these laminates, no significant indentation measurement was possible in distributed load conditions nor in concentrated ones at all the impact energies. The reason could be found in the particular fabric adopted for the laminates presenting large bundle of fibre weaving that probably allowed the recovery of the indentation. It represents a not good aspect since the presence of the internal damage confirmed by the visual inspection on the surface opposite to the impacted one, and the ultra sound inspection. By the latter, a larger internal damaged area was observed after concentrated load tests, as it will be showed in the full paper.

Conclusion

As a conclusion it is possible to assert that under distributed loads, the carbon fibre in vinylester resin laminates evidenced a completely different behaviour respect to the concentrated ones, in both load displacement curve shape and damage formation. The importance of the vibrations was evidenced while the effect of the temperature seems to be negligible.

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