LOW TEMPERATURE IMPACT OF COMPOSITE HULL WALL WITH FLOATING RIGID BODY

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ABSTRACT

An experimental activity conducted in order to assess the impact behavior, at room and low temperature, of 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 the bag containing water. A falling weight machine equipped with an instrumented steel impactor and a thermal chamber was adopted for the experimental tests.

Laminates made by vinyl ester matrix and carbon fibres were considered during the tests, and the results in terms of impact behaviour in hostile environments were compared to what obtained at room temperature. The data obtained under a distributed load were also compared with the results of impacts at concentrated loads.

1 INTRODUCTION

An environmental condition critical for structures made of composite material is related to low temperatures, especially in presence of dynamic loads. This problem is really important in the Artic Ocean navigation. Navy ships must operate safely in different regions of the globe withstanding and surviving harsh environments and explosive threats surviving if subjected to extreme dynamic loads such as impact.

At the same time, the structures for naval applications, as well as for aerospace ones, must be light to save costs.

For the above mentioned reasons, good properties and low weight, composite materials are finding more and more widely used in that areas.

However, composite materials are non homogeneous and anisotropic. As a consequence, they can fail in a variety of damages not always visible. In particular, under dynamic loads, starting from matrix cracks that causes delamination and going ahead through fibre failures, the damage can start and propagate until the complete collapse of the structure, without having any external signals.

For security reason, it is very important to know the behaviour of composite laminates under impact conditions at different impact energies. The latter, in fact, can cause different more or less critical damages [1-5].

Since the large interest of the aerospace industry in composite materials, in literature, a lot was done to investigate the impact behaviour of laminates under concentrated dynamic loads [1-15]. The latter conditions, in fact, are very common on planes during the taking off and landing operation, as well as during the flight or maintenance operations. Few researches were, on the contrary, dedicated to distribute the dynamic load on the entire material surface to simulate the navigation in water.

In order to develop a basic insight into the problem and formulate material/structure concepts for the optimal design of ships operating under extreme conditions, an experimental campaign of impact tests on dry composite laminates with concentrated and distributed loads, were organized at University of Naples "Federico II".

Carbon fibre dry fabric laminates in vinylester resin from NSWC, were impacted at room and low temperatures with concentrated and distributed loads. During the experimental tests, all the load-displacement curves were recorded, analyzed and compared at the aim to obtain information on the impact behaviour of the laminates in the different test conditions.

A different behaviour was noted between concentrated and distributed load conditions but no big differences in terms of maximum loads and initial rigidity were noted between room and low temperature in concentrated impact loads. It means that the viscoelastic behaviour of the liquid could probabily play an important role in the responce of the material.

2 MATERIAL

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

The impact behaviour was analyzed carrying out dynamic tests by a falling weight machine Ceast Fractovis. The rectangular specimens, 100x150mm, suggested by the EN6038 Standard and cut from the original laminate by a diamond saw, were impacted at three different impact energies. A cylindrical shape and hemispherical nose instrumented tup geometry with a diameter of 19.8 mm was used as impactor. The impact velocity of 4.0 m/s was measured.

Impact tests at concentrated loads were, first, carried out at room and the low temperature of -25°C on the laminates using the clamping device suggested by the above recalled Stardard .

After that, 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 located under the composite laminate. The aim was to obtain a load distribution on the entire surface of the specimen in order to simulate the impact of the ship on the water during the navigation.

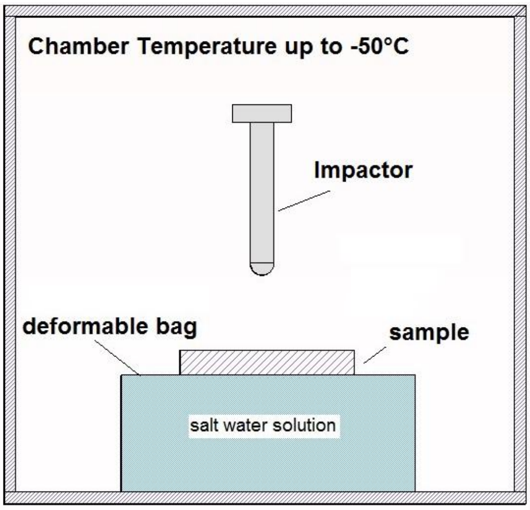


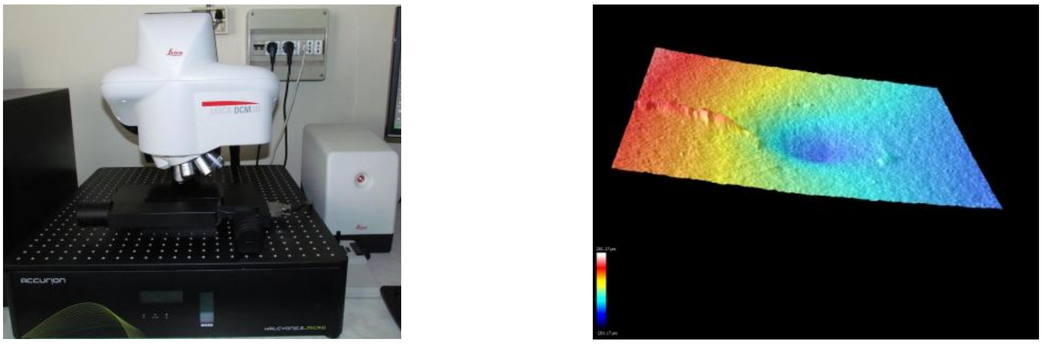
Figure 1: Schematic view of the apparatus.

The water was contained into a cylindrical pvc box without cover, 200 mm in diameter. A rubber bag in butyl, thin and deformable, was used to cover the box and was sealed to it. The water was injected into the box by one of the two valves on the bag. The other one was used to let the air out. The box has been filled with a quantity of water greater than that necessary to reach the edge so as to create a pillow of water and avoid any resistance of the sheath during the impact (Fig. 2). The rectangular specimens were placed on the pillow to allow the contact of the entire surface with the bag and they were impacted on the free side by the cylindrical impactor described above (see the scheme in Fig. 1). To avoid ice formation at T = - 25°C, an antifreeze liquid with a density similar to the water was added in 50% in weight.

Figure 2: Equipment for impact tests with distributed load.

During each test, the complete force-time and force-displacement curves, as well as energy and velocity ones, were recorded by the DAS16000 acquisition program and successively studied to evaluate the impact parameters like maximum forces and the correspondent displacements, the absorbed energy and the failure loads. All the parameters obtained in different conditions were then compared. Three different energy values were used for all the configurations, 5J, 10J and 25J, to study the damage initiation and propagation. The falling weight apparatus allows to vary the impact energy by changing the impactor mass and the drop height.

The indentation depth was measured by confocal microscope LEICA DCM3D (Fig. 3a) following the Standard EN6038 suggestions. Thanks to this instrument, it was possible to extract and record the three-dimensional shape of the surface (Fig. 3b) and to extract the section in correspondence of which derive the information about the profile and the measurement of the indentation depth left by the indenter.



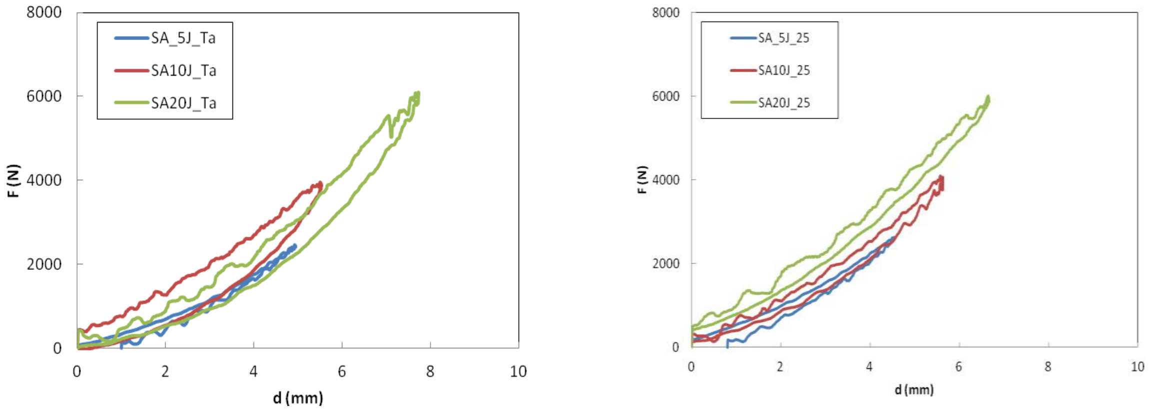
a) b)

Figure 3: Confocal microscope (a); microscopic image of the indented surface (b).

3 RESULTS

At the aim to characterize the behaviour of the laminates fabricated by NSWC and used in Naval field and to compare the results, the impact tests were first of all carried out with concentrated loads following the EN6038 suggestions. The different specimens, labeled as SA, were loaded by the same impact energies at the aim to allow the comparison at room and low temperatures.

In Fig. 4, the load curves obtained at room (a) and low (b) temperatures were overlapped. As expected, an increasing in maximum force was noted at the increasing of impact energy. No particular observation can be done about the initial rigidity.



a) b)

Figure 4: Load-displacement curves from concentrated tests at room a) and low b) temperature.

Interestingly, by the comparison between the curves obtained at room and low temperature, very little differences were noted, differently from what commonly observed [16] about initial rigidity and maximum load on laminates made by epoxy matrix. In the latter case, in fact, the differences observed were due to the more brittle behaviour of the material in extreme conditions. In Fig. 5, the load displacement curves at room and at low temperature were compared for laminates impacted at U = 20J for example. However, it is important to note 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 in specimens impacted at 5 and 10J of energy not reported here for brevity.

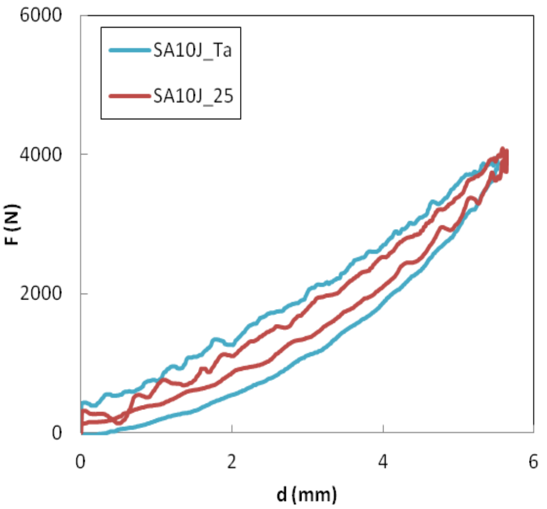


Figure 5: Comparison between room and extreme conditions. U = 20J.

As already said, the rectangular specimens were impacted at the same impact energies of the previously described concentrated tests, U = 5J, U = 10J and U = 20J, also when they were simply supported on a water pillow to obtain the load distribution, simulating the navigation.

In Fig. 6a), the complete load curves were compared at the different energy values used. As clear and expectable, the shape of the curves is different from what always observed in concentrated 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 a minimum value and then increases again up to a second maximum load higher than the first one; at this point, the load decreases at the decreasing of the displacement.

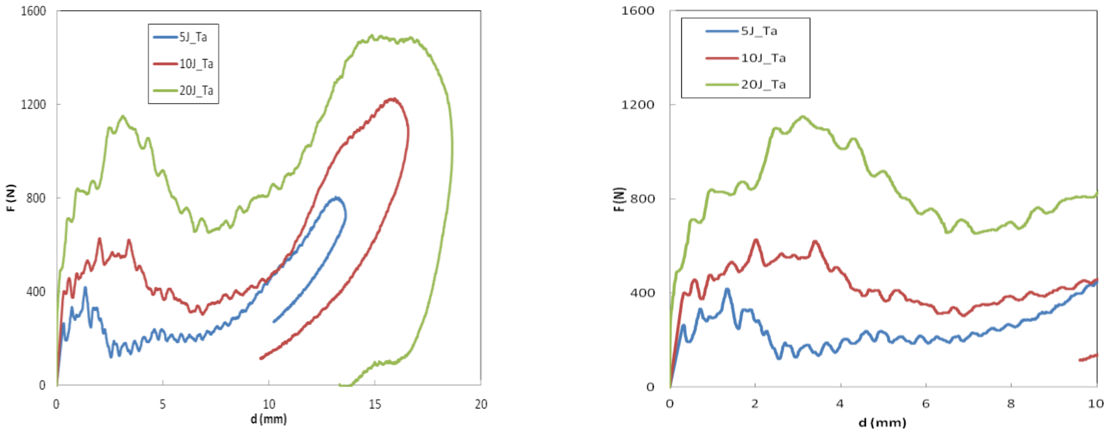
The explanation of this particular behaviour could be given as follow: the first increment is common to all the impact tests, showing the characteristic load drops probably due to the impact damage creation; it is due to the local event for the first local contact between the impactor and the central point of impact on the impacted surface; after that, the load decrease should be due to the distribution of the load on the entire surface of the specimen due to the water action as distributed support; it could represent a sort of water distributed reaction higher than the action load that makes the specimen as if it felt unloaded.

However, it is very important to understand the way of vibration of the system that, on contrary to what happens for concentrated impacts, in this particular case is not negligible. It is, in fact, important to understand if the vibrations are small but with high frequency, that appears like small load drops on the entire profile of the curve, or if the frequency modifies the entire shape of the load curve. In the latter case, the first decreasing trend could be due to a big oscillation of the system with low frequency. If it is, it has not to take into account and the real profile to consider is the increasing one up to the second maximum force value.

What said could be a possible explanation of a phenomenon completely new. So, contrary to what it is done in the case of concentrated loads, in the present case it could not be possible to neglect the vibrations of the system. The problem is to understand which is the effect of the vibrations on the load curve: the vibrations could get the curve dirty in each point but the general trend is saved, with the decreasing part due to the unloading effect of the impactor during the vibration; the vibrations could compromise the shape of the load curve causing the first load peak that on the contrary there would not be present. In the latter case, the maximum load to consider and to compare is the value in correspondence of the second load peak.

The only way to verify what supposed is to carry out static load tests in order to avoid vibrational effects. This will be the objective of the further work.

As it is simple to understand, the displacement in correspondence of the minimum load after the first decreasing is higher the higher the impact energy is. The latter is more clear in Fig. 6b) where a particular from Fig. 6a) up to a displacement of 10 mm, was reported for clarity.



a) b)

Figure 6: Load-displacement curves from distributed loads. $T=T_a$.

The same behaviour was observed at low temperature (Fig. 7)

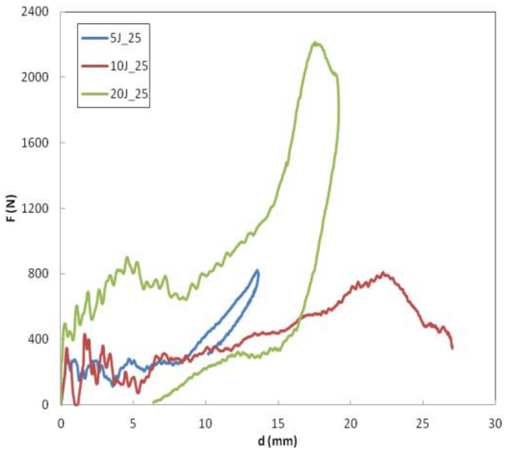
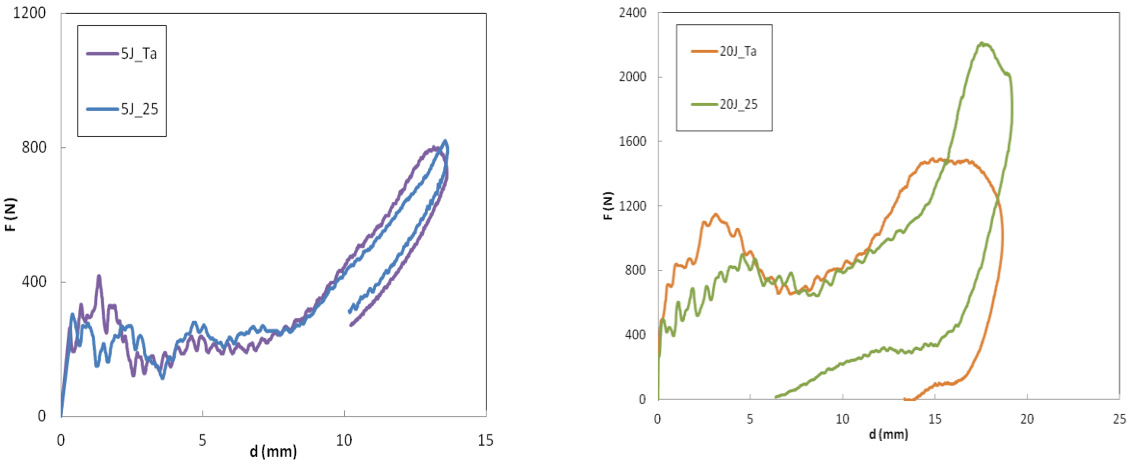


Figure 7: Load-displacement curves at low temperature.

By comparing the different curves at room and low temperature (Fig. 8a) and b)) it is possible to note the similar behaviour denoted by the similar shape of the curve. However, contrarily to what happens under concentrated loads, the first maximum load is higher in room conditions whereas the contrary happens for the second peak. The latter difference was noted only for an impact energy of 20J as it will be possible to confirm hereafter. Since no differences were noted between room and low temperature in concentrated impact tests, the differences noted about impact tests on water, could be due to a viscoelastic different behaviour of the liquid (water plus antifreeze) contained in the box. Static characterization tests at different velocity and/or different temperatures could clarify this point too.

It is also important to note that the minimum value of the load decreasing is the same in the two different test conditions that could support the hypothesis that it is due to vibration effects.



a) b)

Figure 8: Comparison between room and low temperature distributed load behaviour.

Plotting in a bars graph (Fig. 9) 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. 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.

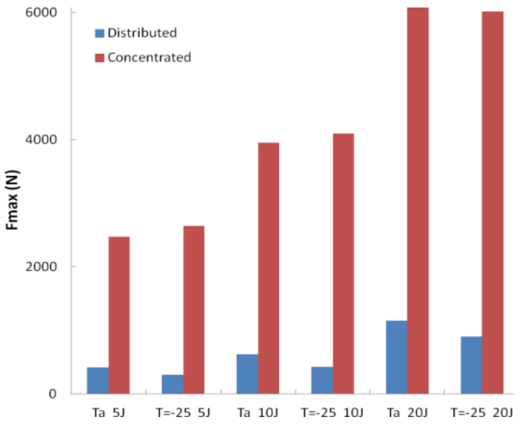


Figure 9: Maximum loads, F_{max}, comparison.

Of course, if the static tests confirm the effect of the vibration as a wave in the diagram, the maximum load to consider is the second peak of the curve. Plotting these values on the same bars graph used for Fig. 9, similar results were obtained (Fig. 10).

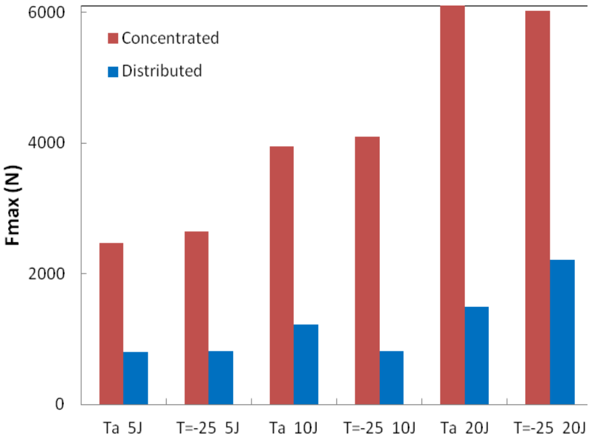


Figure 10: Maximum loads comparison: second peak.

In this graph it is possible to note that only in correspondence of an impact energy of 10J, F_{max} at room temperature is higher than T=-25°C. Similar values were observed at 5J and, as already previously noted, at 20J the higher value was obtained at T=-25°C.

4 INDENTATION

Indentation measurements were carried out by the confocal microscope described in the materials paragraph. In [17, 18], 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. Moreover, the possibility of a correlation between external and internal damage, get higher the interest in indentation measurements.

Unfortunately, in the research here discussed no significant indentation measurement was possible to obtain. In the tests on the water, in fact, the distribution of the load didn't allow any local plastic deformation on the surface of the specimen. Very surprisingly, no significant dent depth was found on specimens impacted at concentrated load at room and low temperatures by 5 and 10J of energy, whereas something deeper but not significative too, was noted at U=20J. It is probably due to a strong recovery of the material after the tool-material contact since the large bundle of fibre weaving (Fig. 11a).

The latter result represents a disadvantage since on the opposite side respect to the impacted one, a clear damage was observed (Fig. 11b): it means that the internal damage was not reported by any external sign.

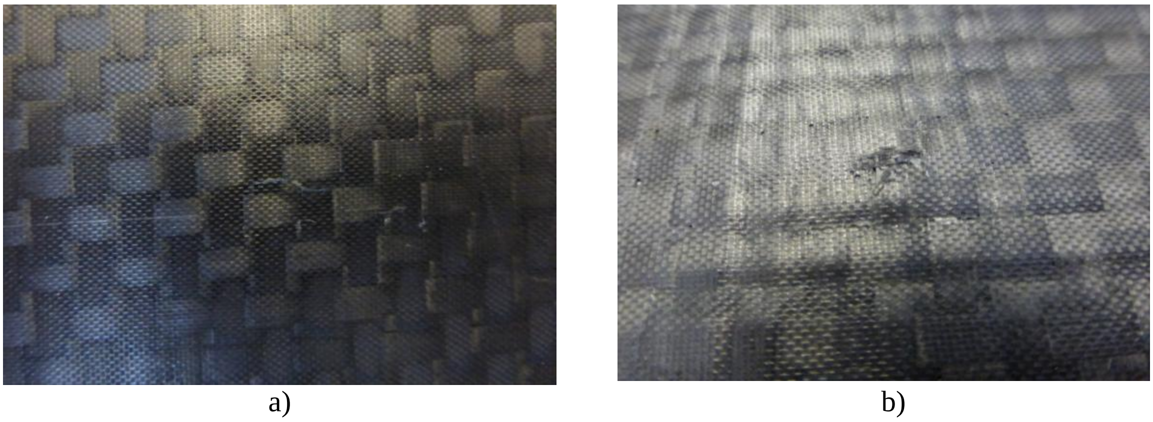

a) b)

Figure 11: Impacted surface a) and opposite side b). U=10J. Concentrated load.

5 CONCLUSIONS

With the continuously increasing interest in the use of composite materials for structural applications, at the aim to understand and improve the response of carbon composite systems applied in naval field to impact under extreme loading conditions, the results of an experimental activity at room and low temperature on 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 and the results were compared to what obtained at room temperature and by concentrated loading conditions.

The main aspects are evidenced as follow:

- no big differences, in terms of maximum loads and initial rigidity, were noted between room and low temperature in concentrated impact loads;
- a different behaviour was noted between concentrated and distributed load conditions: the load-displacement curve shows two maximum peaks in the latter conditions and the maximum load is sensibly higher in the impact on water;
- the vibration of the system cannot be neglected;
- the viscoelastic behaviour of the liquid could probabily play an important role in the responce of the material;
- no significant indentation was found on the surface of the laminate in both concentrated and distributed load conditions at room and low temperatures.

It could be very interesting, in the next future, to characterize the behaviour of the system in water under static conditions: it would be to avoid all the vibrational effects and to obtain a cleaned curve that reflect the pure impact phenomenon.

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