Doctoral Dissertation
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Development of an innovative procedure to assess the crashworthiness of composite materials

By

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Abstract

The crashworthiness of a vehicle is defined as the capability of protecting the passengers from injuries due to high decelerations occurring in case of crash. This is achieved including specific structures (called crash boxes or crash absorbers) in the body-in-white with the aim of absorbing the kinetic energy of the vehicle by deforming in a controlled way. While these structures are today manufactured mainly with ductile metals, composite materials are progressively substituting them in high performance structures for crashworthiness applications thanks to the high Specific Energy Absorption (SEA), that allows for a significant reduction of the weight of the vehicle. Some composite structures show very high SEA, in many cases higher than metals, but their diffusion in crashworthiness applications is slowed down by their complex behavior during crash failure.

From many researches carried out in last decades it is known that different structures made of the same material can show, in a crash test, very different failure modes and levels of energy absorption. This is due to the complexity of failure mechanisms occurring during crash, that involve delamination, fiber fracturing and interface debonding.

In this work, the development of an innovative testing procedure to assess the crashworthiness of composite materials is reported. The test is based on the use of flat specimens to characterize the crash behavior of the material applying an in-plane load using a drop tower testing machine. The design and development of a clamping device to avoid the buckling of the specimen is presented together with many experimental results that prove the effectiveness of the testing procedure. Results are then compared to those obtained with specimens made of the same material but with different geometries to investigate the effect on the failure mode and the level of energy absorption of the material.

The testing procedure has two main objectives: first, have a standard method to measure the SEA and other properties of the material with the aim of material screening and properties comparison; second, to have useful experimental results to feed the material cards of finite element software with the aim of predicting the behavior of complex components by simulation. For this reason, part of the work involved the use of finite element models to investigate in depth the behavior of the material and to test the predictive capabilities of material cards optimized with the results of the crashworthiness test on flat coupons.

The outcome of this work is a testing procedure able to evaluate the SEA of composite flat coupons in splaying or tearing failure mode. The results obtained with the tearing failure mode are higher than those obtained with the splaying failure mode, but lower than those obtained on self-supporting sinusoidal specimens with small curvature radii; this means that a different failure mechanism is taking place, but even more effective failures can happen in different structure geometries, thus signifying that both the splaying and tearing test can give a conventional result useful for materials comparison and material card optimization but not representing the maximum or minimum SEA achieved by the material.

The predictive capabilities of the finite element models after the calibration of parameters based on the experimental results are not satisfactory and require deeper investigation to obtain good predictions on the behavior of complex components. This is due to the high complexity of the failure mechanisms that have been observed experimentally and strongly influence the energy absorption level of the material. Further work will be aimed at finding more complex material models and more advanced techniques for material parameters identification able to reproduce the experimental observations more accurately.