Composite Structures 120 (2015) 483–495

Contents lists available at ScienceDirect

Composite Structures

journal homepage: www.elsevier.com/locate/compstruct

Alternative lightweight materials and component manufacturing technologies for vehicle frontal bumper beam

G. Belingardi [a], A.T. Beyene [a], E.G. Koricho [b,*], B. Martorana [c]

[a] Politecnico di Torino, Department of Mechanical and Aerospace Engineering, Italy
[b] Michigan State University, Composite Vehicle Research Center, USA
[c] Centro Ricerche FIAT, strada Torino 50, Orbassano Torino, Italy

ARTICLE INFO

Article history:
Available online 25 October 2014

Keywords:
Bumper
Crashworthiness
Lightweight design
Composite structures
Optimization

ABSTRACT

One of the vehicle subsystem where large advantage is expected in lightweight design is the bumper subsystems. Bumper subsystems are designed to prevent or reduce physical damage to the front or rear ends of passenger motor vehicles during collusion.

In this paper, detail design aspects and method of analysis with particular reference to the application of composite materials to automotive front bumper subsystem, crash box and bumper beam. Innovative design of integrated crash box and bumper beam has been considered for better crashworthiness; the proposed solution results to be of great interest also from the points of view of subassembly cost and effective production process.

Three materials have been characterized under quasi static and impact tests for this bumper beam application: GMT, GMTex, and GMT-UD. Major parameters, such as impact energy, peak load, crash resistance, energy absorption and stiffness have been taken as evaluation criteria to compare the proposed materials solutions with pultruded and steel solutions. Finally, the results predicted by the finite element analysis have been evaluated and interpreted in comparison with other existing solutions to put in evidence the effectiveness of the proposed innovative materials and design concept solutions.

1. Introduction

Automobile bumper subsystem is the frontal and rear structure of the vehicle that has the purpose of energy absorption during low velocity impact. Usually, bumper subsystem consists of bumper transverse beam, stays, impact-absorbing materials (such as foam or honeycomb) connected to the structural components (generally the bumper beam) and a cover, that has both aesthetic and protection purposes. Among those elements, the bumper beam is the main structural component; it is expected to be deformable enough to absorb the impact energy, in order to reduce the risks of injury for pedestrians and other vulnerable road users, but, at the same time, it should also have sufficient strength and stiffness to give place to small intrusion of the engine compartment and, therefore, to protect the nearby vehicle components.

Composite materials are characterized by high specific strength, both in static and impact loading conditions, and high specific stiffness; they could be an interesting candidate material for this type of component, posing as targets the lightweight together with the maintenance of at least the same level of safety performance in comparison with the present steel solution.

When designing with composite material, it is always needed not only to choice the appropriate material but to think composite (i.e. to not simply replace the metallic material with the new one, but to redesign the part) and to select the type of production technology that will be used in manufacturing, as this choice will affect deeply both the structural performance and the cost and the production rate [1]. Therefore material, design and manufacturing technology are strictly linked each other and should be considered all together.

From the point of view of manufacturing technology we have taken into consideration two different types: pultrusion and die forming. Both of them are cost-effective and fully automated and give high quality parts in terms of geometry accuracy and degree of consistency of mechanical property (mainly due to process automation).

Pultrusion has a number of advantages such as perfect fiber alignment and high fiber volume since polymerization takes place while the fiber is under tension, capable of producing both closed and open section with a variety of end profiles, etc. However, at the moment the technology is strongly limited to straight and

* Corresponding author.
E-mail address: koricho@msu.edu (E.G. Koricho).

http://dx.doi.org/10.1016/j.compstruct.2014.10.007
0263-8223/

constant section. Conversely, die forming composite manufacturing technology has also its own advantages, i.e. it allows producing structurally integrated crash box and beam, as shown in Fig. 1, that improve both manufacturing and assembling rate and eliminate connection between bumper beam and crash box. However, it is mainly limited to open section profiles that are generally less performing than the closed section profiles.

As the targeted component is designed for impact loading, prior to conduct numerical impact analysis at the component level, the impact performance of composite material are assessed. In general, impact responses and damage mechanisms for the whole group of composite materials are more complex comparing with the conventional metallic materials and depend on a number of different parameters: fiber and matrix type, section shape and dimensions, impact velocity, impact angle, shape of striker, target geometry and target material. Open literatures show that a composite tube is capable of absorbing significant impact energy by material fragmentation and large changes in the tubes cross-sectional geometry when the tube undergoes large flexural deformation [2–7].

In the current study six material were considered. For pultruded bumper beam solution, unidirectional pultruded E Glass/epoxy, a bidirectional fabric E Glass/epoxy and steel material were compared. The detailed mechanical properties documented [8]. For the case of die formed integrated crash box–beam solution, three materials were considered:

- A classic glass-mat-reinforced thermoplastics (GMT) i.e. an endless fiber glass mate reinforced PP with randomly oriented glass fibers,
- GMTex, i.e. a chopped fiber glass mat reinforced PP laminate with randomly oriented glass fibers and additionally reinforced with a fabric inside and
- GMT-UD, i.e. a chopped fiber glass mat reinforced PP laminate with randomly oriented glass fibers and additionally reinforced with unidirectional oriented glass fiber layers.

These three materials, supplied by Quadrant, were considered for front bumper application. Considering the novelty of the modified material, extensive material characterization had been conducted to obtain the main mechanical properties of the material and to understand the failure mechanism for the intended loading case and finally their capability for substituting the current steel material were numerically assessed.

2. Material characterization

The composite materials were characterized under a tensile (both longitudinal and transverse direction), compressive (both longitudinal and transverse direction), and a drop-dart tests. A brief summary of the test set-up and of the obtained mechanical characteristics of the tested materials are presented in the following sections.

2.1. Experimental setup for tensile test

Five specimens for each material type, in both longitudinal and transverse directions, were tested under tensile loading with a 100 kN capacity servo-hydraulic testing machine (INSTRON-8801), as shown in Fig. 2. Each specimen was clamped by means of hydraulic wedge grips. The machine was equipped with a standard load cell and a crosshead displacement measuring device.

During the mount phase of the specimen, the maximum preload was controlled and set lower than 0.2 kN in order to avoid specimen damage. According to ASTM D3039, specimens were subjected to monotonic tensile loading with a stroke rate of 2 mm/min. The specimens were instrumented by strain gages to measure Young's modulus and Poisson's ratio. To acquire the strain gages data, a NI WLS-9163 data acquisition board was used and to acquire load and crosshead displacement data from the machine, a NI DAQCard-6062E was utilized. All data were acquired with a sampling rate equal to 1 kHz. The main mechanical properties are reported in Table 1.

2.2. Experimental setup for compression test

Similarly, five specimens for each material, in both longitudinal and transverse directions, were tested under compressive loading as per ASTM D6641/D6641M and the found experimental results are presented in Table 2.

2.3. Experimental setup for the drop dart test

Prior to impact test, quasi-static indentation tests were performed on Zweck Roell 100 universal testing machine, to investigate perforation energy of the proposed composite laminates, Fig. 3. Main results are reported in Table 3.

Experimental impact tests were performed according to ASTM standard 3029 using an instrumented free-fall drop dart testing machine. The impactor has a carriage mass of 5.735 kg and an hemispherical head with a radius of 10 mm and the maximum falling height of the testing machine is 2 m (see Fig. 4). The drop-weight apparatus was equipped with a motorized lifting track. The collected data were stored after each impact and the impactor was returned to its original starting height. Using this technique, the chosen impact velocity was consistently obtained in successive impacts. By means of a piezoelectric load cell, force–time curves were acquired and, with a double integration of acceleration–time curve, force–displacement curves were obtained. Square specimen panels, with 100 mm edge, were clamped in the specimen holder with a 76.2 mm inner diameter, and fixed to a rigid base to prevent

(a)

(b)

Fig. 1. Integrated composite solution developed by Quadrant Plastic Composites International (a) and used on Mercedes for top class vehicle (b).