IMPACT BEHAVIOR OF AUTOMOTIVE SHOCK ABSORBING BEAM: EXPERIMENTAL AND NUMERICAL REPRESENTATION

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ABSTRACT

In this study, impact behavior of an automotive shock absorbing beam is studied in both experimental and numerical way. A characterization of constitutive material gives the engineer parameters in order to feed a LS-DYNA simulation. Consequently, a comparison between the real behavior and simulation is carried out. The material is regarded as linear elastic until failure considered by the TSAI criterion. Indeed reaching this criterion for an element involves its disappearance during calculation. The main difficulty lies in the representation of the kinematics of the destruction of the structure: the computing strategy presented in this document does not reproduce the global folding up of the structure. Thus whereas the destroyed simulated elements disappear, real damage occurs gradually. The global folding up of the structure induces an accumulation of material increasing the rigidity of the structure whereas calculation cannot represent any more.

KEYWORDS: impact behaviour, shock absorbing beam, drop weigh testing, behavior law, numerical simulation

INTRODUCTION

To ensure the car passenger security, absorbing parts is usually proposed using a weakened structure which will yield during impact. The use of composite allows a huge dissipation of energy by the degradation of the material. Damages such as cracking and delaminating are very large-scale energy consumers and the composite shock absorbing beam use this dissipative phenomena.

Previous studies [1, 2] showed the interest of such structures of security from an experimental point of view. In industrial conditions where the production rate imposes limited cycle times, using thermoplastic composites appears quickly as evident. Consequently, the viscoelastic behavior under fast dynamic stresses imposes the installation of thorough studies of the ruin phenomena of the structure.

Figure 1 shows the principal results from the project MOZAIC [1] which aimed to the realization of a composite car. This study showed the degradation chronology of the absorbing BMC cones.

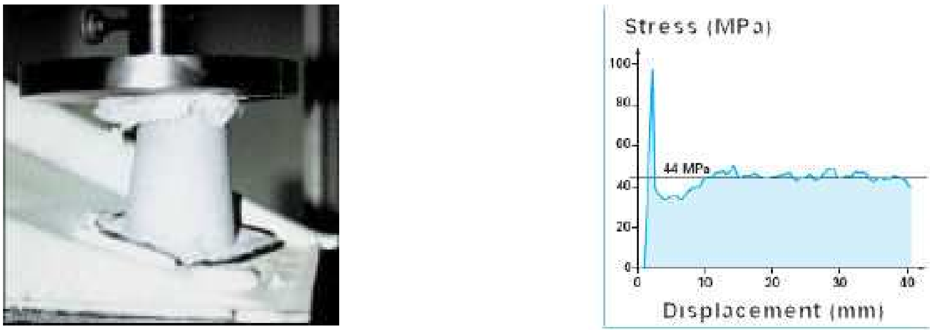

Fig. 1: MOZAIC quasi-static compression testing

A progressive destruction of the structure starts at the top of the cone and continues during all the duration of test. The curve forced according to displacement presents two characteristics:

- An initial peak caused by the starting of the failure (it can be reduced by machining a chamfer at the top of the cone)
- A maintain throughout all compression

The aim of the present study is first to understand the damage mechanisms intervening in such a material in terms of material. Second, a behaviour law is then introduced in a numerical simulating of an impact on an absorption cone composing the ends of the beam. A particular attention is then given to the damage scenario during impact and the correlation between experimental and numerical results.

STRUCTURE PRESENTATION

The study is limited to two substructures ending the beam. Figure 2 shows a beam and a representation of the cone. A TRE process allows the production of such structure in industrial conditions.

The whole structure is composed of polypropylene/random short glass fibers. The cones are regarded as individual entities of the rest of the global structure

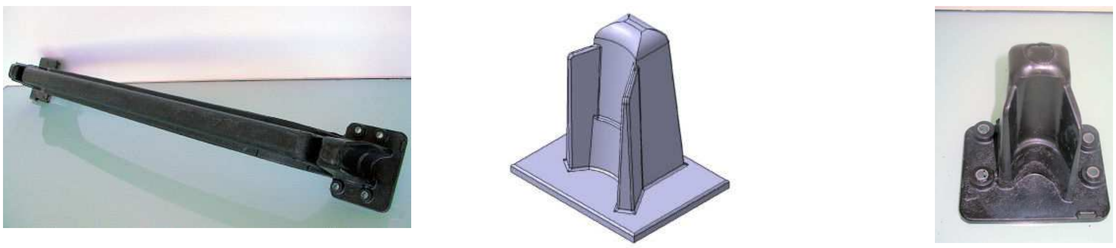

Fig. 2: shock absorbing beam (left), representation of a cone (right)

The central part will only be used to identify the behavior law of such material from classical tests in a large scale strain-rate.

MATERIAL BEHAVIOR

From the central part of the bar, tensile and compression specimens were extracted. The aim of this part of the study is to determine the mechanical properties of material composing the whole beam. Nevertheless, an approximation was posed: it was considered that the material is homogeneous on the totality of the structure. It is rather improbable that the fiber orientations and fiber rate are identical on the central part and the cones. However, these material data will be considered as representative for the rest of the study.

Moreover, two velocities are planned in order to determine the viscous effects of the polymeric matrix. Quasi-static tests are thus led to 5 mm/min and the higher speed tests are carried out with a 500 mm/min speed. It is clear, there too, than the scale speed is not completely comparable with the probable speed range of the impact tests carried out later. Nevertheless, this velocity range gives a main tendency.

Figure 3 shows the classical evolution of the constraint according to the axial deformation according to two request velocity. It shows a very low sensitivity according to the solicitation velocity.

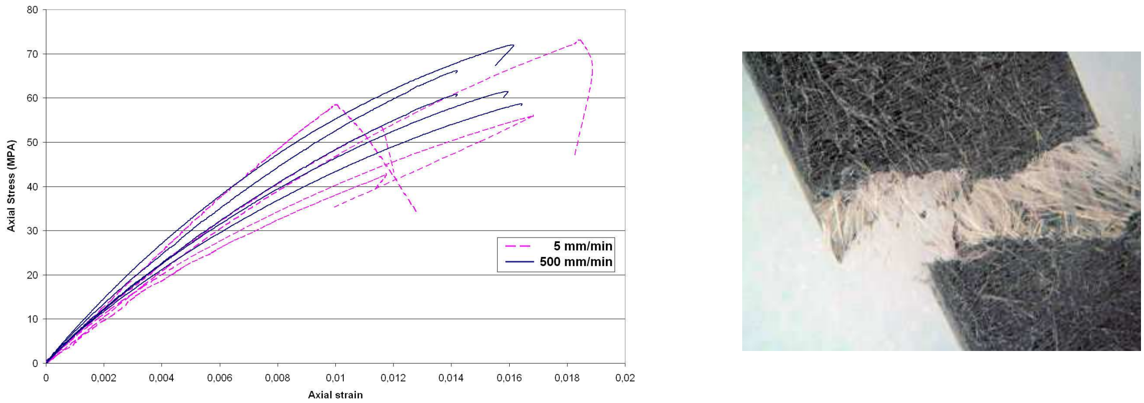

Fig. 3: tensile test on component material: curves and failure mode

We have thus considered in this first approach that this material is not sensitive at the velocity request; this constitutes a huge working hypothesis. (A deepening of this effect is currently in progress). Table 1 thus gathers the remarkable values used in the rest of the study.

Ex = Ey (MPa)	**νxy =νyx**	**Gxy = Gyx (MPa)**	**Xt = Yt (MPa)**	**Xc = Yc (MPa)**
$7622^{\pm 651}$	$0.293^{\pm 0.065}$	$6482^{\pm 541}$	$63.7^{\pm 5.3}$	$56.6^{\pm 10.8}$

Table.1: mechanical parameters of the material

STATIC COMPRESSION TESTING

The comprehension of the failure scenario is approached by a first phase of static stress. The idea is to establish the link between the damage mechanism and the load evolution during testing. The main tendencies will be thus released at slow velocity and will be used as a basis to understand the damage at higher speeds. Figure 4 gives a visualization of the failure mode according to this stress. Moreover, the cross section of the structure after the test shows an accumulation of composite near of the upper plate of compression.


Fig. 4: failure mechanism during axial compression

The load evolution according to the penetration of the upper plate is represented further in the part dedicated to the behavior with the impact. The figure 7 compares the curve evolution according to the travel rate of the compression plate.

It can be noted that the global evolution of the curve corresponds to what was awaited, i.e. an increasing curve: it becomes increasingly difficult to maintain a penetration speed in the structure because of the increase of the projected section of the part. The "conical shape" allows a good control of the penetration depth for a given stress.

IMPACT TESTING

Impact testing was performed using an IMATEK instrumented drop weight impact system. A total falling weight of 100 kg includes the plane indenter head, the load cell and the crossbeam. The mobile is then raised to the height that produced the desired initial energy for impact testing. Different energies were chosen to perform the test from 1000J and 3600J.

Fig. 5: ESTACA – LSM drop weight testing device (maximum capacity 4000J: 100kg and 4m)

Figure 6 shows the damages induced by such impacts. The structure undergoes strong degradations by a phenomenon of folding up and peeling absorbing the totality of initial energy.

Fig. 6: evolution of damage due to impact (left to right: 0J, 1000J, 2000J, 3000J, 3600J)

Figure 7 shows a superposition of the loads/displacement curves during static and dynamic tests. It clearly shows the quite independence of structure behavior compared to initial energy. Moreover, the test at low speed and infinite mass (static test) do not involve modification in the failure mode. The equivalence of an Iso-mass or Iso-speed work could be estimated.

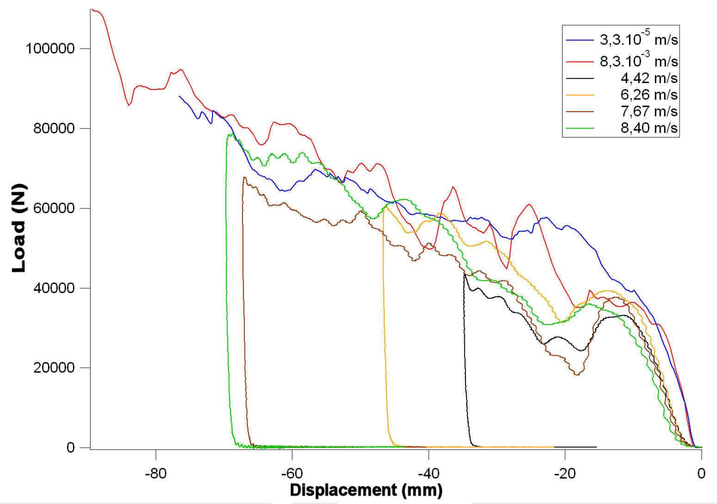

Fig. 7: static and dynamic compression comparison

NUMERICAL SIMULATION

To represent under impact behavior of the structure, a numerical modelling is proposed using the LS-DYNA code. The different parts of the structure will be modelled in Q4 shell elements. For that purpose, an initial drawing representing neutral fiber was carried out under CATIA (figure 8). Pre processing and Post processing will be carried out with LS-PrePost.

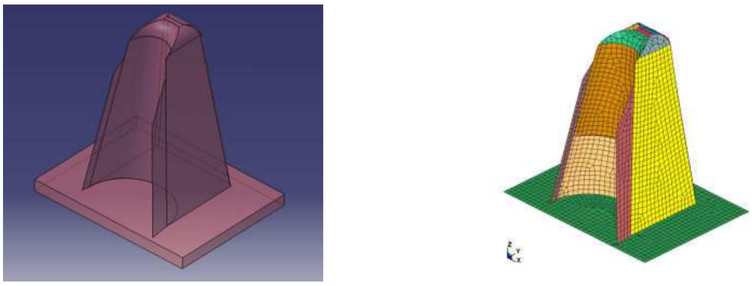

Fig. 8: cone drawing en CATIA and meshing in LS-DYNA

Each surface is defined separately by creating different entities with different thicknesses and mechanical properties independent from each other. The junctions between the various portions of a piece were considered as perfect.

The impactor is represented by a parallelepiped made up of a rigid material. The condition of contact between the structure and the impactor was represented by an ERODING_NOTES TO _SURFACE. Failure of the elements according to a criterion of the type TSAI will then be represented. The base of the cone is embedded. The impactor is animated a controlled initial velocity.

The material for every part follows the composite law 54-55 of LS-DYNA (ENCHANCED-COMPOSITE MAT.). This material has the advantage of the TSAI criterion coupled with the elements erosion conditions.

For the impactor, a 20 law (RIGID MAT.) is used representing steel behaviour (E = 210GPa). The density is adjusted to obtain the mass of the impactor (100kg) from the volume defining the impactor.

NUMERICAL AND EXPERIMENTAL COMPARISON

Figure 9 represents the load/displacement evolution for a 3000J impact test. It compares the numerical results and the experimental test.
Initially, a relatively good representation of rigidity can be observed. The difference is mainly due to the difference between the material characterization testing speed and the impact testing one. This too large variation does not give real apparent modulus at the impact speed. Moreover, this material characterization was carried out on the central bar and not on the cone; variations of fibers' orientation are possible.

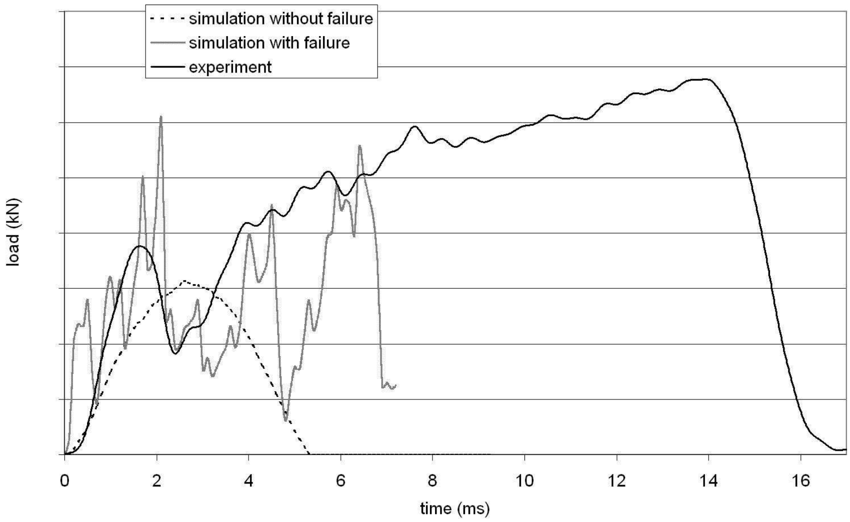

Fig. 9: static and dynamic compression comparison

Failure initiation and propagation representation diverges from reality. The mode of representation seems not to be adapted. Disappearing elements (figure 10) does not correspond to the physical phenomena where the material is folded up on itself and still add rigidity to the damaged structure.

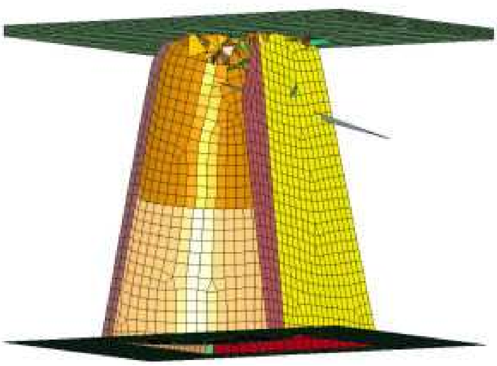

Fig. 10: static and dynamic compression comparison

CONCLUSION

Many applications for composite materials fulfil the economic requirements of the automotive industry. However, the security requirements of this market are important. Thus, the structural parts are subjected to many stress types (static or dynamic), and it is important and necessary to envisage their reaction under this different loading cases. The uncompleted knowledge of the dynamic behavior and the limited number of models available to simulate composite materials constitute an actual barrier to the development of these applications.

This work aims to contribute to better understand and model material composite behavior subjected to an important speed range of deformation and in particular to dynamic stresses. A general methodology modelling is proposed in three steps:

- **Analysis of material** from the structure to understand the mechanical behavior under simple stress with various speeds. The results showed an almost independant behavior under tensile stress according to the speed of request. This is enough surprising because of the preponderance of the viscosity behavior of the matrix. In fact, requests speeds are relatively limited compared to speeds during impact.

- **Study of the whole structure in static and dynamic compression.** For the dynamic tests, a study of the influence of initial energy is conducted. Behavior of the structure seems to be independent from the request speed (i.e. independent from the initial energy). A dynamic/static equivalent could be proposed.

- **Modelling of the behavior of the structure under impact**: From the material parameters determined previously on specimens, a homogenized material is created: the behavior is considered, in this first approach, as linear until rupture. The TSAI criterion is used. A shell model is then created. Impact tests were used as reference in terms of load evolution according to impactor penetration.

The results show a relatively good adequacy as regards as rigidity: the difference is due to the difference in speed between the tests on materials and impact on structure. On the other hand, the representation of the failure does not correspond to reality. The approach using elements erosion as soon as the local TSAI criterion is reached cannot represent the global folding up of the structure.

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