THERMOMECHANICAL BEHAVIOUR OF COMPOSITE SANDWICH PANELS OF POLYMER/METAL UNDER LOW-VELOCITY IMPACT

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Abstract

This work deals with the mechanical behavior under impact loading (5 m/s≤V0≤15 m/s) and different temperatures (15ºC and 100ºC) of the three-layered sandwich sheets: metal skins (2024 aluminum alloy) and polymer core (PEEK). This type of configurations are widely used in automobile sector. In order to conduct the perforation tests a drop weight tower CEAST INSTRON 9350 with climatic chamber has been used. Numerical analysis using Johnson-Cook (JC) plasticity for thermoplastic PEEK polymer has been implemented. This model considers temperature sensitivity between transition temperature and melting temperature. The amount of kinetic energy of the striker converted into plastic work is strongly dependent on the initial temperature.

1. Introduction

Currently, structural weight reduction has become in one of main the design objectives in automotive engineering. One of the most implemented ways to reduce the automobile’s weight is using an application of sandwich sheets which comprise of two faces sheets and low-density core materials. The main advantage of this configuration versus homogenous metal sheets is that metal-polymer-metal laminates offer a significantly lower density and a better sound and vibration damping characteristics. They also have the advantages of good surface finish comparing it with the one of a simple metal sheet of the same total thickness. Recently they have been implemented in vehicle structures in order to reduce in-cabin noise due to their excellent properties. So, sandwich materials systems can combine the advantages of miscellaneous materials (e.g. low density, high bending resistance, energy absorption, high load-capacity at low weight) with each other [1]. Hybrid systems, three-layered metal/polymer/metal or multi-layer sheets, offer a great potential for the automotive and even aeronautics. One example of three-layered of metal/polymer/metal sandwich systems is HYLITE, which is an aluminum/polypropylene/aluminum which was introduced into the automotive market through the Audi A2 [2]. Regarding to the polymeric core, it is important to study the influence of temperature especially when these polymers are used in applications in which they absorb large amounts of energy, and therefore heat. Some polymers show that temperature variations, whose intensity depends on the heat sources and heat conduction problem, can according to their intensity and the thermal softening of the material modify its flow and strain rate [3]. The aim of this study was to analyze the impact mechanical behaviour of a metal-polymer-metal sandwich configuration focusing the study on the temperature influence. The procedure following was to analyze the behavior of the sandwich structure (2024 aluminum- PEEK- 2024 aluminum) subjected to a low velocity perforation in range of temperatures from 15 ºC to 100 ºC.

2. Material

Two different materials have been used in order to make the composite laminate: metal skin of 2024-T3 aluminum alloy of 1 mm thickness and PEEK core of 3 mm. The 2024-T3 aluminum alloy is one of the alloys whose use is more prevalent in the industry. The main applications of this material are aeronautical structural components, hardware, wheels and rivets because of its high strength, excellent fatigue resistance and its good strength to weight ratio. PEEK PEEK is a semicrystalline thermoplastic with excellent mechanical and chemical resistance properties that are retained to high temperatures. It is widely used in the transport sector, both alone and combined with other materials. PEEK is an ideal replacement for stainless steel, other types of metal tubing, and even glass, for weight reduction, comparable strength/mass, chemical resistance, hardness, and low extractable. Other applications of this material may be found in aerospace, medical and chemical industrials [4]. The PEEK used in this study test has been ceded by the company LATI [5]. In particular we have used the Larpeek 50, wich mechanical properties are reported for this PEEK type are reported in [6].

3. Low velocity impact behaviour at different temperature

3.1 Experimental setup

The tests were carried out with the machine CEAST 9300 drop tower impact system (Figure 1). This experimental configuration allows a perpendicular impact on the sheets within the range of impact velocities 0.5 m/s $\leq V_0 \leq$ 20 m/s and with temperatures from 15 ºC to 100 ºC. These temperatures were reached by the climate chamber provided the equipment.

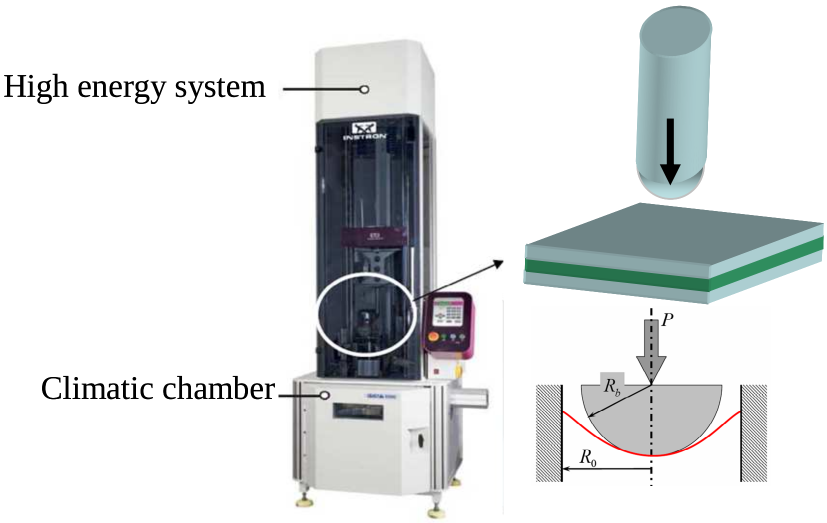

Figure 1. CEAST 9300 drop tower and scheme of impact configuration

The impact velocity V_0 is fixed by the user by choosing the height from which the striker is dropped [7]. The tested square like specimens possess a size of A_t = 130x130mm^2 and a thickness of h=1 mm for aluminum sheets and h=3 mm for PEEK sheets. They were clamped by toggle clamps and screws all around the active surface of A_t = 100x100mm^2. Toggle clamps and screws were symmetrically fixed in order to avoid any disturbance during the test.

The steel striker used has a hemispherical shape. Its larger diameter is φ_p = 20 mm and its mass is M_p = 0.177 kg. The striker was attached to the instrumented bar of the drop weight tower, whose mass is M_{bar} = 1.182 kg. The bar at the same time is attached to a metal frame, whose mass is M_f = 4.3 kg. Additional mass was added to the setup in order to increase the effective mass to M_{total}= 10.159kg.

3.2. Numerical Model

The numerical model was developed using the explicit finite element code Abaqus/Explicit [8]. This numerical model consisted of various solids: the sandwich plate composed by three ones and the impactor. For the sandwich plate two kinds of elements were used in order to get a good damage-dependent evolution of the zone. The four-node linear tetrahedron element (C3D4), which allows greater freedom of damage propagation, was implemented in the impact region of each plate defined as an area of 40 mm diameter (twice the diameter of the striker). Moreover, the area corresponds to the transition zone of radial symmetry was meshed with eight-node brick hexahedral elements with one integration point (C3D8R). The sandwich plate was constrained by all its lateral faces and the rigid body was constrained not to move in the X and Y directions. As in this impact analysis the main aim is comparing the response of the temperature effect over the sandwich configuration tested, the material constitutive law which both materials are defined with, should include temperature dependency for both material deformation and failure. The Johnson-Cook plasticity model [9,10] was employed to model the flow stress behavior of the different materials studied in the numerical simulations. Parameter used in the model are showed in Table 1. In case of the PEEK material, the transition temperature was considered for thermoplastic polymer according to the work of Louche et al. [3]. It is important to consider a thermal softening caused by a great location of plastic deformation by the expression:

$$\Delta T(\bar{\varepsilon}_p, \dot{\bar{\varepsilon}}_p, T) = \frac{\beta}{\rho \cdot C_p} \int \bar{\sigma}(\bar{\varepsilon}_p, \dot{\bar{\varepsilon}}_p, T)\, d\varepsilon_p \tag{1}$$

where β is the percentage of plastic work transformed to heat (Quinney Taylor coefficient), C_p is the heat capacity and ρ is the density. The temperature sensitivy parameter of the Johnson-Cook (JC) plasticity model used for thermoplastic PEEK polymer was identified during compressive test at imposed temperatures between transition temperature and melting temperature (Figure 2, [6]). In addition to a J-C plasticity model, it was developed a J-C progressive damage model [9,10] which specifies a damage initiation criterion as well as damage evolution. The general expression for the equivalent plastic strain defined by this model is given by:

$$\bar{\varepsilon}_p = D_1 + D_2 \cdot \exp(-D_3 \cdot \eta) \cdot [1 + D_4 \cdot \ln(\frac{\dot{\bar{\varepsilon}}_p}{\dot{\bar{\varepsilon}}_0})][1 + D_5 \cdot T_H] \tag{6}$$

where η is the stress triaxiality and D_i are constants (Table 2) calibrated according experimental data reported in [11]. The damage criterion of for Polyether-ether-ketone (PEEK) has been defined as constant failure strain equal to 0.25 according experimental data of tensile test reported in [6]. As the initial temperature increases the value of force peak decreases, due to the effect of thermal softening of polymer core (Figure 3, left). A qualitative agreement for experimental and numerical data was obtained by the model for force-displacement curves (Figure 3, right).

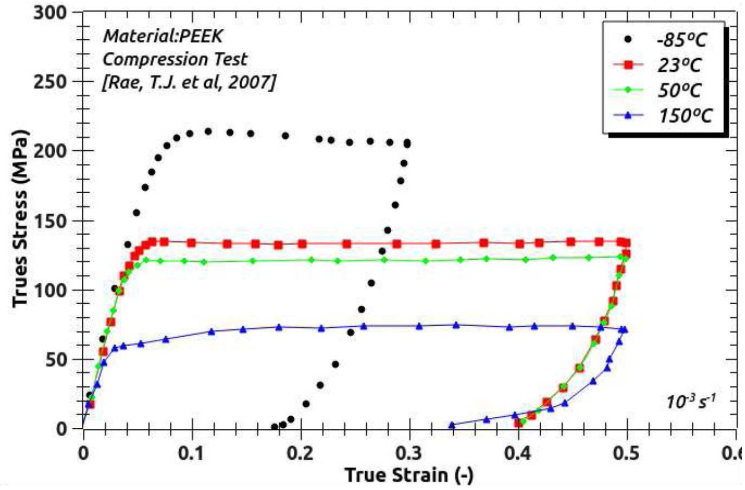

Figure 2. Compression behavior of PEEK material [6]

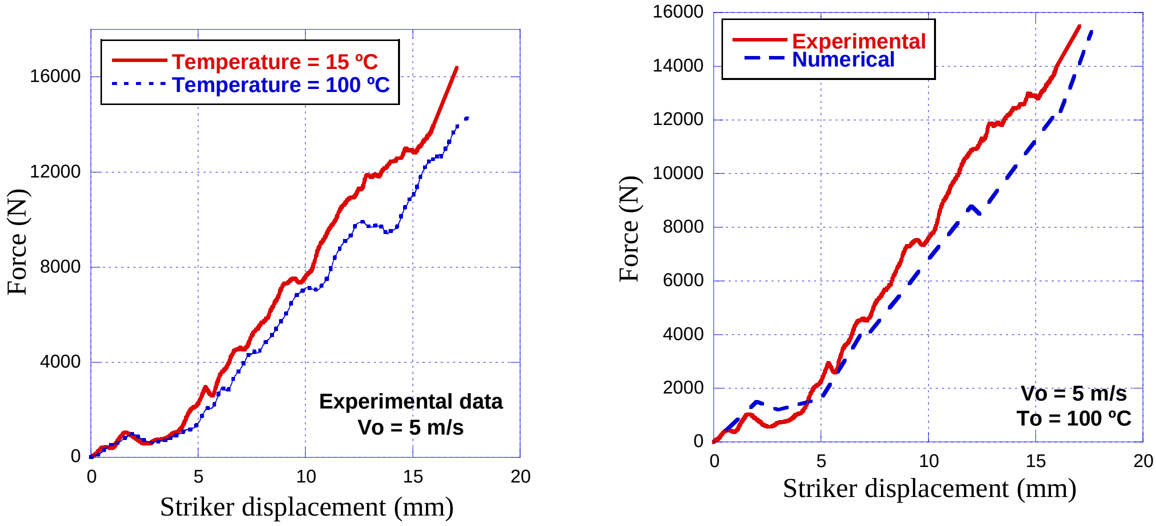

Figure 3. Experimental data of force-displacement of striker for different temperatures (left). Experimental and numerical data of force-displacement of striker (right).

Material	ρ [kg/m^3]	E [GPa]	ν	A [MPa]	B [MPa]	n	C	m	T_{melt} [K]	$\dot{\bar{\varepsilon}}_0$ [s^{-1}]
2024Aluminum	2780	109.8	0.31	352	440	0.42	0.014	1.7	775	0.000333
PEEK	1300	3.5	0.4	120	20	0.36	0.04	0.88	300	0.015

Table 1. Constants used to define the thermoviscoplastic behaviour of Jhonson-Cook model [11, 6].

Material	D1	D2	D3	D4	D5
2024Aluminum	0.112	0.123	1.5	0.007	0.0

Table 2. Constants used to define the J-C damage criterion [11].

5. Conclusions

The experimental and numerical analysis of low impact velocity at different temperature for peek sandwich material support the following conclusions. For modeling low-velocity impact deformation behavior of PEEk material has been necessary to consider a thermal softening caused by a great location of plastic deformation. It was included a dependence of the temperature and strain rate on work transformed to heat. The temperature sensitivy parameter of the Johnson-Cook (JC) plasticity model used for thermoplastic PEEK polymer was identified during compressive test at imposed temperatures between transition temperature and melting temperature. A qualitative agreement and an under-estimation of about 20% of the maximum impact load were obtained by the model. However, for modelling PEEK, it could be interesting to use (or implemented) other types of models, such as damage models or Drucker-Prager model well adapted to pressure sensitivy.

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References

[1] W. Hufenbach, J. Jaschinski, T. Weber, D. Weck. Numerical and experimental investigation on Hylite sandwich sheets as an alternative sheet metal. *Archives of Mechanical Engineering,* 3:68-80, 2008

[2] A. Carrado, J. Faerber, S. Niemeyer, G. Ziegmann, H. Palkowski. Metal/polymer/metal hybrid systems: Towards potential formability applications. *Composite Structures,* 93: 715-721, 2011.

[3] H. Louche, F. Piette-Coudol, R. Arrieux, J. Issartel. An experimental and modeling study of the thermomechanical behaviour of an ABS polymer structural component during an impact test. *International Journal of Impact Engineering,* 36: 847-861, 2009.

[4] D. Williams, A. McNamara, R.Turner. Potential of polyetheretherketone (PEEK) and carbon-fibre-reinforced PEEK in medical applications. *Journal Materials Science Letters* 6(2):188-190, 1987.

[5] LATI. Lati Polyether-ether-ketone materials properties data table. Technical Report <http://www.lati.com>; 2014.

[6] P. Rae, E. Brown, E. Orler. The mechanical properties of poly(ether-ether-ketone) with emphasis on the large compressive strain response. *Polymer,* 48: 598-615, 2007.

[7] J. Rodríguez-Martínez, A. Rusinek, A. Arias. Thermo-viscoplastic behaviour of 2024-T3 aluminium sheets subjected to low velocity perforation at different temperatures. *Thin-Walled Structures,* 49: 819-832, 2011.

[8] H. Hibbitt, B. Karlsson, P. Sorensen. Abaqus user's manual. *Abaqus Explicit 6.12,*2012.

[9] Johnson GR, Cook W. Fracture characteristics of three metals subjected to various strains, strain rates, temperature and pressures. *Engineering Fracture Mechanics* 21(1):31-48, 1985.

[10] A. Arias, J.A. Rodríguez-Martínez, A. Rusinek. Numerical simulations of impact behaviour of thin steel plates subjected to cylindrical, conical and hemispherical non-deformable projectiles. *Eng. Fracture Mechanics,* 75 (6): 1635-1656, 2008.

[11] T. Wierzbicki, Y. Bao, Y. Lee, Y. Bai, Calibration and evaluation of seven fracture models. *International Journal Mechanical Sciences*, 47: 719–743, 2005.