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Thermographic stepwise assessment of impact damage in sandwich panels

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ABSTRACT

Metal-polymer-metal sandwiches can find promising applications in the automotive field thanks to their lightweight and formability. The paper focuses on the effect of low velocity impacts on the residual mechanical behavior. Experimental stepwise tests are run on undamaged and impacted specimens with different combinations of thickness and grade for the outer steel skins and the inner polymeric core. Surface temperature evolution is thermally monitored during the tests with the aim to characterize the induced damage and to identify a parameter able to quantify the residual strength of the panel. Several approaches have been considered. The analysis of the thermal amplitude trend with the lock-in thermography evidences a variation in the thermal behavior of the specimens, defining a corresponding damage stress σ_D. We found a 20% σ_D difference between undamaged and damaged specimens. Moreover, impacted specimens experience a temperature and stress concentration at the impact area dependent on the indentation.

Based on these results, we evidence the possibility to relate impact indentation with the damage stress estimated by thermography and with the stress concentration factor induced by the impact. Therefore, thermography is a useful and valid tool for post-impact damage detection, monitoring and quantification of these multilayer sandwich materials.

1. Introduction

The present work focuses on sandwich panels with a metal-polymer-metal (MPM) structure. These panels are designed for weight-reduction when compared to a full structure and have many interesting characteristics for the mechanical designer such as good formability [1] [2], good damping properties with low polymer thicknesses, grades and thicknesses customizable to special requirements, possibility of asymmetric structures, high bending and buckling stiffness, possibility to be welded as well as adhesively joined, and attractive costs [3].

These hybrid panels are thought for automotive applications (i.e. side and roof panels of cars, vans and coaches) thanks to their lightweight and formability. In this field, the use of these panels is recently becoming more and more popular. For instance, Litecor® is a sandwich developed within the project InCar® Plus by ThyssenKrupp [4] and it is applied to commercial cars and trucks for internal and external panels. Through this material, they claim a weight reduction of these structures up to 40%.

Low velocity impacts, as the case of stones or small objects against vehicle panels, are very frequent for these applications caused for instance by hailstorms or ballast, and they can typically generate well visible damaged regions with plastic strains. It is often not easy to evaluate the effect of these damages on the residual mechanical behavior of the panels and to identify threshold damages before panel removal.

The parameter that could be more easily measured is the extension of the impacted zone and in particular the dome depth. However, in order to quantify the damage induced by these impacts, it is important to relate the dome depth to the effective residual strength of the panel. With this aim, in a previous work [5] we tried to quantify the damage by means of thermographic measurements. Impacted MPM sandwich panels were subjected to static tensile tests and monitored by a thermal camera. The effect of the impact was evaluated by defining a stress of damage initiation σ_D on undamaged and impacted (i.e. at the dome) samples. It was found that the damage stress at the dome region was up to 11% smaller than the one of undamaged specimens, with some variability depending on the steel grade used for the skins.

In the present paper we propose different thermographic approaches to quantify the effective damage of an impacted panel with respect to the depth of the dome that is a parameter easily measurable.

In particular, we apply cyclic loads with variable stress amplitude (stepwise tests), thermally monitoring the surface temperature trend of the specimens with the aim to quantify the plastic-induced damage.

To obtain significant values, we follow different thermographic

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techniques. We identify two parameters that seem able to quantify the induced damage: 1) the damage stress evaluated from the mean and amplitude temperature trend and 2) the stress concentration factor thermally evaluated. These parameters summarize the comparison of the thermal response between undamaged and impacted regions. In the literature, these approaches were extensively applied to homogeneous materials; as far as the authors know, they have not been applied to sandwich materials yet.

2. The sandwich panels

Object of this work are MPM panels, made of two metal skins and an inner polymeric core. Epoxy resin (Köratec 201) is used to bond the two metal sheets with the polymeric core. The manufacturing process of these MPM panels is based on a surface pre-treatment to activate this epoxy resin, followed by the roll bonding process between two steel cover sheets and the core made of a polyolefin foil, i.e. a blend of polypropylene and polyethylene (PP/PE) [6].

Different configurations with variable thickness are considered. These thickness variations of the metal sheets and the polymeric core are taken into account to evaluate the possibility to design a lightweight and customizable structure, able however to sustain loads and keep adequate stiffness.

Table 1 shows the types of sandwich panels tested in the present work. All these MPM panels present an inner core in polyolefin with variable thickness. Different steel grades of deep drawing qualities are selected in accordance with EN10027-1 standard with variable thickness. The identification of the panels in Table 1 reflects the thickness of the layers and the steel grade.

Table 2 reports the mechanical properties of the sandwich constituents and of the panels obtained from tensile static tests according to ISO 6892-1:2016. Values are averaged based on four tests. The values without tolerance range were calculated using the rule of mixtures. The applicability of this rule for calculating the mechanical properties of the panels was stated in [7] and [8].

Table 2
Mechanical properties from static tests.

Steel grade – Thickness (mm)	E (GPa)	YS (MPa)	UTS (MPa)
a. Sandwich constituents			
0.49 TS 245	180 ± 10	212 ± 7	319 ± 8
0.24 TS 245	170 ± 10	193 ± 5	281 ± 20
0.49 TH 470	194 ± 5	467 ± 21	514 ± 0.45
PP – PE	1.98 ± 0.2	28 ± 2	28 ± 2
b. Sandwich panels. Values without standard deviations are estimated by the rule of mixtures			
0.135/0.6/0.135 TH620	64 ± 2	193 ± 2	199 ± 2
0.135/1.2/0.135 TH620	35	114	114
0.49/0.6/0.49 TH470	99 ± 1	324 ± 6	326 ± 5
0.49/1.2/0.49 TH470	88	160	161
0.24/0.3/0.24 TS245	104 ± 5	138 ± 1	209 ± 1
0.24/0.6/0.24 TS245	70 ± 5	102 ± 1	158 ± 0.9
0.24/1.2/0.24 TS245	49	74	100
0.49/0.6/0.49 TS245	109 ± 15	135 ± 8	209 ± 9
0.49/1.2/0.49 TS245	82	110	158

3. Experimental setup, equipment and techniques

3.1. Impact tests

Impact tests are performed by a drop weigh tower, clamping the panels at the ground with a rigid frame. The guiding mechanism is a vertical pipe in polycarbonate. Some holes are drilled to avoid air compression. The impact free area is 60 × 60 mm^2 (see Fig. 1a).

The impacting mass has a semi-spherical tip with diameter 25.4 mm; this tip was subjected to surface hardening, ensuring that during the test any damage occurs at the panel, and not in correspondence of the impactor tip. Above the tip, a load cell (Kistler 9331B) connected with a signal amplifier (Kistler 5011B) is placed, to record the impact time. The total impacting mass is 1.47 kg (see Fig. 1b).

The impact energy is evaluated from the impactor velocity. With this aim, two lasers (M7L/20 by Microlelectronics) are placed laterally on a support, very near to the panel, as shown in Fig. 1b.

Load cell and laser signals are collected by an acquisition card (NI9239 and NI cDAQ 9171 by National Instruments). Finally, impact data are handled by NI Signal Express 2015 software with an acquisition frequency set to 50 kHz and the impact velocity v_{impact} evaluated as:

$$\boldsymbol{v}_{impact} = \frac{s_{laser}}{t_1 - t_2} + \left(t_3 - \frac{(t_1 + t_2)}{2}\right)\cdot g \tag{1}$$

where: s_{laser} is the vertical distance between the two lasers (20 mm), t_1 and t_2 are the times of impactor detection by the lasers, t_3 is the impact time recorded by the load cell and g is the gravity constant (see Fig. 1b). The resulting impact energy is 9.0 ± 0.4 J with an impact velocity equal to 3.51 ± 0.08 m/s.

Three over four 0.135/1.2/0.135 TH620 panels, thus with the thinnest steel layers, experienced a crack at the skin opposite to the impact. These panels are therefore discarded.

3.2. Measurement of impact indentation

After the impacts, two techniques are experimentally used to measure the indentation.

At first, the impact depth, i.e. the dome, is measured by photogrammetry (DIC), which is an optical technique evaluating the deformation of a grid pre-printed on the panel surface. Measuring the out-of-plane displacements on both panel sides by means of photogrammetry, the thickness reduction at the dome is also evaluated and resulted between 8% and 16% of the total initial thickness, depending on the thickness of the steel layer (see Fig. 2a).

The indentation measures are also repeated by a profilometer (Zeiss Prismo 5 VAST MPS HTGCMM, accuracy: 3 μm) as out-of-plane displacements along a straight line centered at the dome, only on the

Table 1
The sandwich panels.

Panel identification	Steel grade	Steel thickness [mm]	Polymer type	Polymer thickness [mm]
0.135/0.6/0.135 TH620	TH620	0.27	PP-PE	0.6
0.135/1.2/0.135 TH620	TH620	0.27	PP-PE	1.2
0.49/0.6/0.49 TH470	TH470	0.98	PP-PE	0.6
0.49/1.2/0.49 TH470	TH470	0.98	PP-PE	1.2
0.24/0.3/0.24 TS245	TS245	0.48	PP-PE	0.3
0.24/0.6/0.24 TS245	TS245	0.48	PP-PE	0.6
0.24/1.2/0.24 TS245	TS245	0.48	PP-PE	1.2
0.49/0.6/0.49 TS245	TS245	0.98	PP-PE	0.6
0.49/1.2/0.49 TS245	TS245	0.98	PP-PE	1.2