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Impact behaviour of 3-layered metal-polymer-metal sandwich panels

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ABSTRACT

Ductile 3-layered sandwich panels made of metal cover sheets and a polyolefin core were produced with different layer thicknesses of core and cover sheets in laboratory scale. Because of their lightweight potential, they are interesting for the use in automotive, nautical and even aviation applications. Their impact behaviour is changing, depending on their material and geometrical conditions (quality of the metal and polymer, thickness of the different layers). Therefore, impact tests were performed to investigate this effect, using a steel-polyolefin combination with varying thicknesses of the layers and measuring the post-impact deflections. The results show that all the considered factors influence the panels' crashworthiness.

With the aim of studying the mechanical behaviour of damaged specimens, post-impact tensile tests were performed. Tests were monitored by thermography, a valid technique able to identify the presence of a damaged region in the panels before reaching the yielding stress.

A discussion on the obtained experimental results proposes some parameters to identify and quantify the impact damage: the specific deflection and related area, the strain to failure and the damage stress from thermography.

1. Introduction

Sandwich composites are a particular class of composite materials combining two or more mono-material layers with different physical and mechanical properties. They generally present outer stiffer skins made of steel or aluminium alloys sheets with an inner core of a homogeneous or structured polymer layer, or fibre reinforced plastics. Sandwich composites have recently found wide applications in many industrial fields such as the automotive one but also in aviation and marine areas, aiming to manufacture lightweight but stiff and performing structures [1,2].

These composites have, in fact, many interesting features. First of all, they can be easily manufactured and they are characterised by a high specific strength, a good sound-deadening and damping, as well as impact resistance and good formability. Besides, their characteristics can be improved and tailored to the specific needs, by varying combination and thickness of layers.

An example of application of such sandwich panels is the automotive hood consisting of two aluminium or steel skins combined with a polypropylene (PP) core (Hylite®) or two steel layers with a polyamide (PA) core [2–5]. Focusing on steel metal sheets as reinforcement layers, some studies were proposed on panels made of high-grade austenitic stainless steel (316L) cover sheets and a core of a polyolefin (PP/PE), which is a polypropylene (PP) and polyethylene (PE) blend [6–8], or even with titanium cover sheets for biomedical or aviation applications [9]. A number of combinations in thickness and steel material were investigated to understand the influence of these material and geometrical changes on the forming limits of these hybrids compared to the metallic mono-materials [9].

It is important to know the mechanical properties of these sandwich composites for their final application. For instance, formability is one of the main information required when designing the shape of automotive components [10], but it is also a property affecting their behaviour when subjected to impacts [11].

Focusing on the application of sandwich panels in the automotive field, important issues are low velocity impacts of small objects, i.e. stones. This kind of event is, in fact, very frequent and it is important to evaluate its effect on the residual mechanical behaviour of the damaged panel and on the integrity and reliability of the structure where it is placed.

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Nomenclature

E	elastic modulus
PE	polyethylene
PP	polypropylene
PU	polyurea
SDD	specific damage deflection, normalised with respect to impact energy
SDE	specific damage extension, normalised with respect to impact energy
YS	yielding stress
UTS	ultimate tensile strength
ε_f	elongation to failure
σ_D	damage stress identified by thermography

Scientific literature presents studies on the effect of impacts not only on metal sheets, but also on combining different coupled layers. For instance, metal sheets can be combined with fibre-reinforced layers (*i.e.* fibre-metal laminates [12–14], or with plastic layers to improve impact behaviour. Focusing on these sandwich panels, recent studies showed that polymers can increase the overall impact resistance of steel, when the polymer layer is applied on the opposite side to the impact and providing that sufficient adhesion is offered between the layers [15–17]. These studies considered experimental impact tests and numerical simulations on panels made of two layers, steel and polyurea (PU). It is stated the importance of the 1 mm thick PU layer that captures and dissipates part of the shock. In addition, if the plate does not fail during the initial shock loading, PU can increase the effective shear modulus of the bilayer plate and thus delay the onset of the necking instability. Because of these considerations, polymeric coatings of metal sheets retard the occurrence of fracture.

This behaviour is evidenced also increasing the thickness of the polymeric layer up to 12 mm, both with high [18] and low-velocity impacts [19]. In the second case, PU coated aluminium plates show a considerable reduction in out-of-plane deformation when compared to the uncoated plates, thus suggesting the possibility of using such a covering layer as an efficient energy absorbing and damping material against low velocity impact damage.

The study by [20] performed numerical analyses to check also the influence of impact on multi-layered steel plates (metal-polyurea-metal sheet). They highlighted that the cohesive strength plays an important role during impact for energy dissipation, especially during the final stage of panel perforation and petalling fracture.

In the present work, attention is focused on a three-layered symmetrical metal-polymer-metal sandwich panel shown in Fig. 1. With the aim of understanding the mechanical response of this material after low-velocity impacts, experimental impact tests are carried out varying the thickness of both metal and PP/PE layers. The attention is then focused on the post-impact residual strength of the damaged panels experimentally determined by applying tensile unidirectional load.

To get more information on the behaviour of the impacted panels, the infrared thermography is applied to monitor variations in surface temperature of the specimens. Infrared thermography is a non-contact and non-destructive experimental technique, based on the concept of surface temperature scanning during the application of a mechanical or thermal load to a structural component. In the literature different methods have been developed by means of thermography, initially applied to homogeneous materials [21], and recently applied also to composite structures [22,23]. The attention is focused on the correlation between the thermal response of the material under mechanical loads, either static or dynamic, and the detection of the damage initiation. In particular, this technique can detect the damage initiation at very early stage, in correspondence of the stress at the end of thermoelastic trend, during tensile test. This stress is called damage initiation stress, σ_D [22].

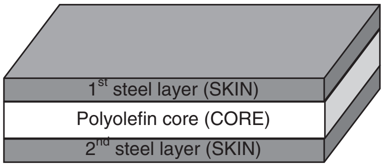

Fig. 1. Scheme of the sandwich panels.

2. Material and experimental setup

This paragraph describes materials and methods used for the experimental tests.

2.1. Sandwich panels

The sandwich panels were produced in a two-stage roll bonding process. In the first stage, after a pre-treatment of the surfaces of the metal sheets of deep drawing qualities and of the PP/PE foils, an epoxy resin (Köratec 201) with a thickness of approximately 10 μm was applied on the metal surface and cured at around 260 °C. Then, the polyolefin foil was pre-heated up to 120 °C and roll bonded to the metal cover sheet. In the second step, this “half sandwich” was roll bonded to the final sandwich panel with the pre-treated second cover sheet under appropriate conditions. More information about the pre-treatment conditions and the process is in [6].

Four types of sandwich panel with different layer thicknesses were produced as listed in Table 1. Also, two deep drawing steel grades TS245 and TH620 (EN 10027-1 standard) were used for manufacturing the panels. They both were produced by rolling, the TH620 was kept in the work hardened version and the TS245 finally recrystallization annealed. TS245 is used for panels A, C, D with higher thicknesses; TH620 is used for panel B having the thinnest metal sheet. The mechanical properties of these steels, yield strength YS, ultimate strength UTS, elongation to rupture ε_f and Young’s modulus E, are given in Table 2.

The bonding behaviour of the sandwich panels was investigated in the past by T-peel test; inner defects could be analysed by Lock-in thermography as introduced in [24].

Table 1
Sandwich panels identification.

Panel #	Steel grade	Skin thickness [mm]	Core thickness [mm]	Total thickness [mm]
A	TS245	0.49	0.6	1.58
B	TH620	0.135	0.6	0.87
C	TS245	0.24	0.6	1.08
D	TS245	0.24	0.3	0.78