Tomasz Lendze [1], Rafał Wojtyra [2], Laurent Guillaumat [3], Christine Biateau [4], Krystyna Imielińska [5*]
[1]- Michelin Polska, Olsztyn, Poland
[2]- Ocean Engineering and Ship Technology, Gdańsk, Poland
[3]- Ecole Nationale Superieure des Arts et Metiers, Laboratoire de Materiaux Endommagement Fiabilite et Ingenierie des Procedes, Bordeaux, France
[4]- Universite Bordeaux 1, Laboratoire de Mecanique Physique, Bordeaux, France
[5]- Gdańsk University of Technology, Department of Materials Science and Engineering, Gdańsk, Poland

LOW VELOCITY IMPACT DAMAGE IN GLASS/POLYESTER COMPOSITE SANDWICH PANELS

ABSTRACT

Impact resistance of glass/polyester facesheets/PVC foam core sandwich structures was primarily assessed in terms of skin-/core bonding efficiency using two types of adhesives and bonding with uncured resin. Also, the air-coupled ultrasonic C-scan technique was estimated as a means of characterizing impact damage size in sandwich structures. The following observations were made. The impact damage size estimated by visual inspection was much more extensive in all samples, which is due to the C-scan images showing only the overlapping delaminations area directly under the impact site, whereas the visual inspection of the laminate surface and macroscopic observations of the sample section show the extent of the largest, single delamination. The least extensive damage size was found in the two-phase high-density adhesive samples showing also the highest tendency for core cracking. In contrast, the “pinkglue” adhesive, which is low-density due to the presence of the microspheres provides greater local flexibility which prevented core craking.

Key words: *Sandwich structures, durability, impact behaviour, scanning electron microscopy (SEM), glass fibre composites.*

INTRODUCTION

Sandwich structures provide an efficient method to increase bending rigidity without a significant increase in structural weight. Due to their high superior bending stiffness, low weight, excellent thermal insulation, acoustic damping, ease of machining, corrosion-resistance and stability composite sandwich structures are widely used in the aerospace, marine, aeronautics, automotive and recreational industries. However, they are also characterized by mechanical behavior that is strongly dependent on incidental damage induced in these materials by foreign object impacts. These impacts carry energy, which can be dissipated through several mechanisms, such as fiber-breaking, fiber-matrix debonding and delamination in the facesheets, while the cores disperse energy by crushing and shear deformation.

* corresponding author

Damage tolerance of sandwich structures is substantially more complex than conventional laminated structures and accordingly, requires much experimental effort in order to understand the mechanisms involved so as to develop more efficient structures and to reduce the extent and frequency of in-service repair [1]. Numerous experimental studies were conducted on impact behaviour of sandwich structures [2-7]. The significance of fabrication techniques on the impact resistance of sandwich panels has been pointed out in Ref. 8. The one-step process of bonding an uncured laminate skin to the core was compacted to bonding the skins using adhesives. With foam cores, when one step process is used to cure the facings to the core, localized cell wall collapse and cell coalescence occurs, before the matrix material hardens which leads to nonuniform thickness and weaker cores near the skin/core bondline. The problem is caused by the high pressure required to cure the facings. According to Abrate [2] better sandwich structures are obtained by prefabricating the skins and then bonding them to the core since less pressure will be required then. In advanced engineering using the prefabricated laminate bonding is a common practice.

The damage tolerance of a sandwich composite is largely influenced by the energy absorption capabilities of the face, the core and efficiency of skin/core adhesive bond [3]. At present the shipbuilding industry is dominated by the glass fibre/polyester resin laminates used both as massive hulls and as skins in sandwich structures. The most common core material is polyvinyl chloride (PVC). Although available for decades, it is still unequalled with respect to impact strength. Combined with its high peel strength linear PVC foams are today still the ideal solution for dynamically loaded structures such as slamming areas in the bottom part of boat hulls since a damage tolerant foam core is capable of diverting the shock wave in the panel direction, absorbing the energy thanks to its cellular structure [2].

The most frequent practice in shipbuilding is to bond the core to the “wet” laminate before curing. Alternatively, the polymer adhesive can be used to bond the skin to the core. In the present study the question is raised about he adhesion efficiency of the three types of glass/polyester facesheets-PVC foam core joints in terms of their impact resistance.

MATERIALS AND EXPERIMENTS

Materials used in this work were 26 mm thick glass fibre/polyester sandwich panels with closed cell PVC foam core Divinycel H80 (DIAB) (20 mm thick, density 80 g/m^2) and different adhesives binding the glass fibre/polyester facesheets to the core (table 1). The matrix resin was pre-accelerated polyester resin Palatal U541TV-03 (Sarzyna, Poland) cured with Metox 50. The fibres were in the form of alternate plies of chopped strand mats (150g/m^2) and plain weave E-glass fabric (450g/m^2) supplied by Krosno, Poland. 5-ply laminates were formed (1,1 meters by 1,5 meter) using the traditional wet (hand) lay-up technique. Fibre volume fraction of laminates was about 40 % with average thickness of 2,5 mm. The sandwich panels were made similar to those fabricated in marine industries, using two methods: 1/ the fully cured laminate sheets were coupled with the core using two different adhesives (Scott Bader Crestomer 118-6PA, 1196-2PA) 2/ the core was bonded to the “wet”, uncured laminate. Finally, samples 150 x 80 were cut and post-cured at 60 °C.

***Table 1.** Designations of the materials*

Sample name	Description
"whiteglue"	Crestomer 118-6PA, multiple purpose adhesive
"pinkglue"	Crestomer 1196-2PA Low density high bond strength adhesive
"wet"	no adhesive, core bonded to the laminate before curing

The low velocity impact response of the sandwich plates was studied using impact drop tower completely designed in Universite Bordeaux 1, (LAMEFiP), instrumented with a load cell, a laser extensometer (used as velocity indicator) and a second laser to calculate the deflection of the specimens placed just underneath them. The specimens were supported on two parallel 35 mm diameter hemi-spherical steel cylinders positioned on movable supports with a 120 mm span, (Fig. 1). The projectile had a 25 mm diameter hemispherical tip. The impact force history obtained during the test was measured using piezo-electric load cell located above the impactor tip. The signals from the load cell were sent to an amplifier and recorded by computer in text file. A total of 1500 data points were collected during each impact event. Changing mass and drop height varied impact energy. To observe various types of damages 5 energy levels were employed 19,7-51,6J. The information about maximum impact force, and deflection was compared for three types of core/face bonding techniques [9].

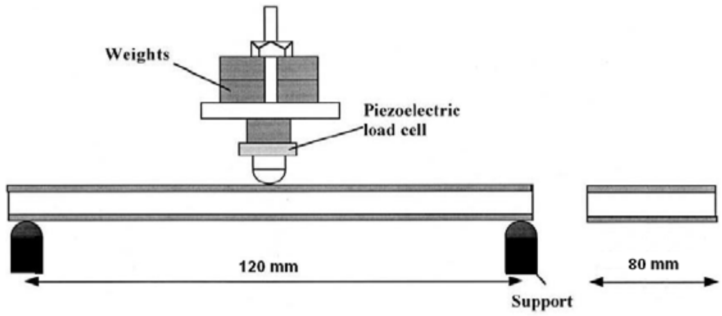

Fig. 1. Schematic diagram of impact conditions.

Visual inspection [10] and air-coupled ultrasonic C-scan technique were used to assess the level of damage inflicted in the materials after the impact event. The ultrasonic C-scan technique developed at Laboratoire de Mecanique Physique Universite Bordeaux 1 has been described in Ref. [11, 12].

In order to study the morphology of the face /core joints sandwich structures that were subjected to impact (19,7J) were cut near the impact site, next they were ground and polished using alumina powder. The sections were examined using SEM microscope (Philips). The quality of the bond was assessed prior and after impact.

RESULTS AND DISCUSSION

Impact tests.

Typical load (deflection)-time characteristics showing the response of the 3 different sandwich samples under the impact of 39,3J are shown in Figs. 2a,b. It has been observed that at low impact energy (up to 39,9J) all samples respond in a similar way, in terms of peak load except when core cracking occurred, which was often the case for "whiteglue" specimens even at lowest impact energy. At high (51,6J -Fig. 2c) impact energy, major differences in force-time plots can be indicative of serious damage occurring either in the core (core crack) or at core/face interface. Lower values of deflection observed for "pinkglue" samples may result from the specific morphology of the "pinkglue" adhesive, which is of low density with many air bubbles. Compared to "whiteglue" sample a lower density adhesive interlayer can provide greater local flexibility without loosing stiffness of whole structure. It is implied that during impact load this layer compresses more, providing a slight increase of indentation and decrease of in-plane displacement. Therefore entire panel bends less and the relative energy consumption is also smaller.

The load (deflection) histories show multiple oscillations before peak load for all samples at all energy levels which may result from vibrations of the support and initiation of damage in the material. The latter can be distinguished using high speed photography. This has been reported in Ref. 9.

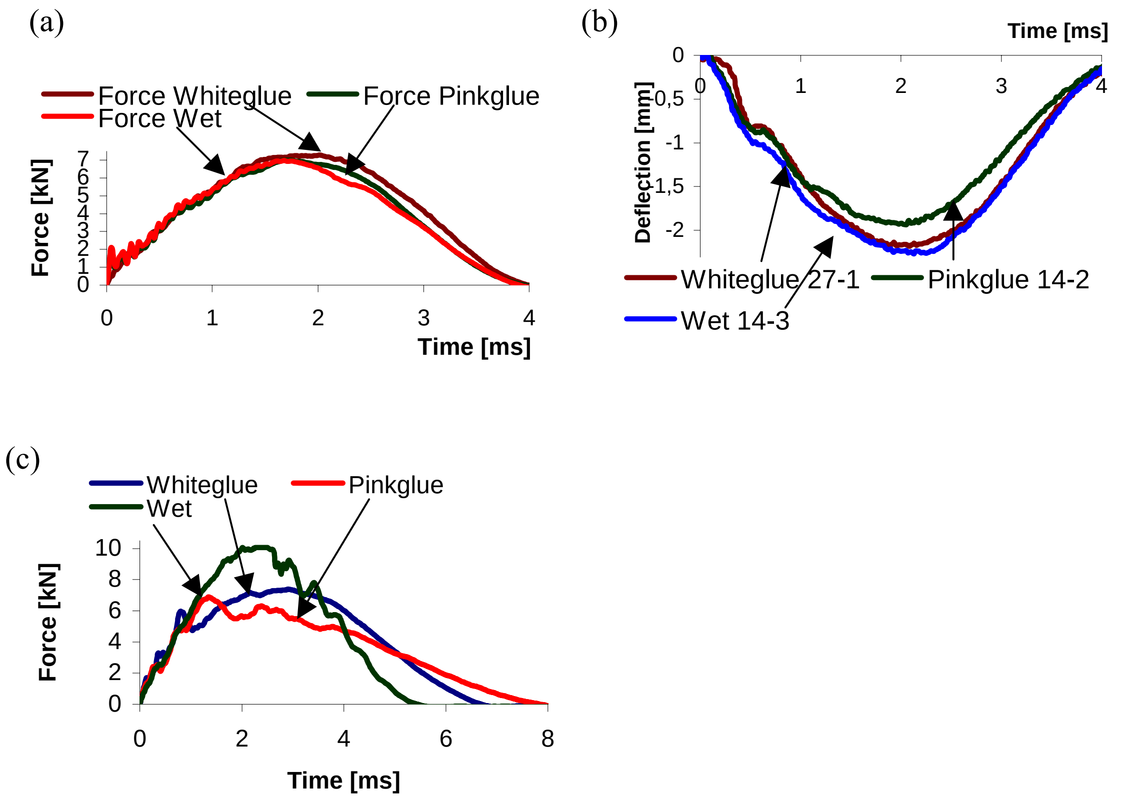

Fig. 2. Load (a), deflection (b)-time characteristics showing the response of the 3 different sandwich samples under impact 39,3J, (c) load-time plot for 51,6J (core crack in "pinkglue" and "whiteglue" samples.

Characterisation of impact damage.

Low-energy impacts can incur damage, which is hard to detect by visual inspection. However, at certain energy level, when delaminations are formed in the laminate skins the impact damage area is visible and can be estimated using quantitative image analysis. Fig. 3 shows the top skins of the samples after impact 19,7J. The least extensive damage area is observed for "whiteglue" sample (Fig. 3a).

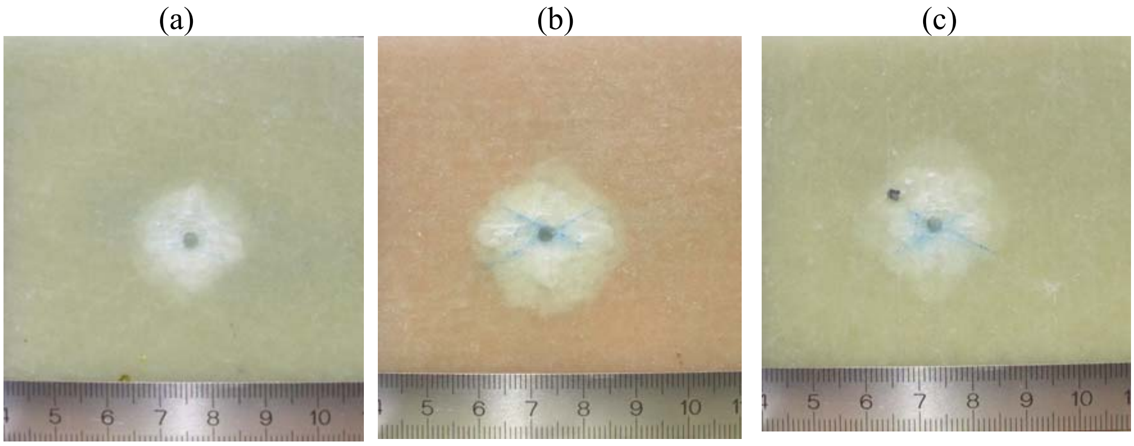

Fig. 3. Illustration of damage observed visually on the surface of the samples subjected to impact 19,7J: (a) whiteglue", (b) "pinkglue", (c) "wet" sample.

However at higher impact energies many samples, particularly " whiteglue" samples contained core cracks and extensive face/core debondings, which can be seen both on the surface and cross-section of the laminate (Fig. 4).

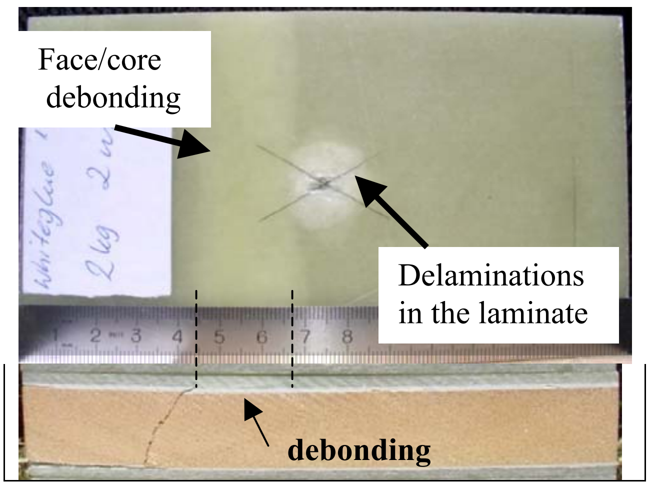

Fig. 4. Core-crack damage observed on the surface and cross-section of the laminate.

Detecting damage in sandwich panels is not an easy task especially in the case of core cracking when the laminate does not transmit light (e.g. carbon fibre). It was found that, core crack was followed by facesheet debonding, accordingly damage area consists of delamination in the facesheet and additional debonding at the upper face/core interface (Fig. 4). In glass-fibre laminates the debonding area can be easily noticeable by visual inspection of unpainted and transparent or semi-translucent small size specimen, (rectangular area indicated with an arrow in Fig. 4) nevertheless finding such damage on the painted glass-fibre or opaque laminate surface such as carbon fibre laminate appears to be difficult in real structure conditions. Accordingly, ultrasonic C-scan technique is used in the inspection of the real structures.

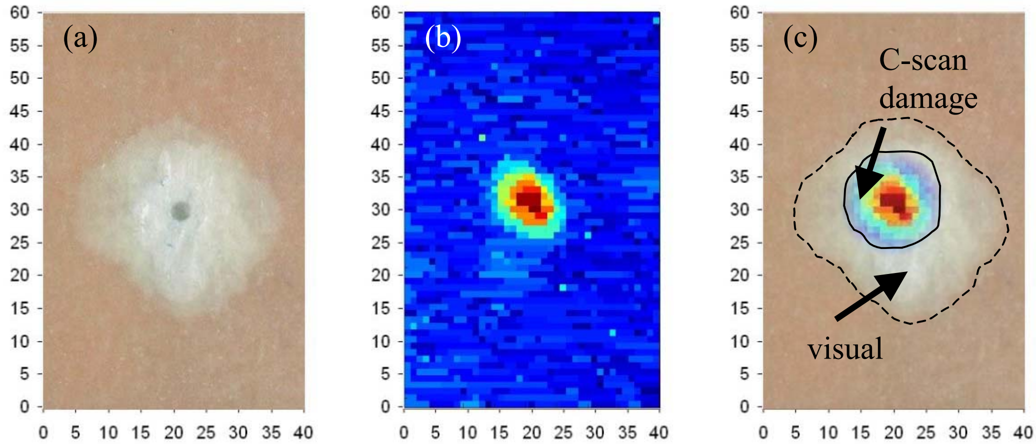

Fig. 5. Comparison of visual (a) and C-scan areas of damage (b) in "pinkglue" specimen subjected to impact 19,7J. Comparison (c).

In the present work the air-coupled C-scan images were obtained in order to study the possibility of using this new technique (Fig. 5) for sandwich structures. Normally, in order to make the C-scans of the structure water environment was used between the transducer and the examined object. The specially designed piezoelectric transducers allow performing the tests in air. For simple laminates this technique was proved useful and gave reliable results [11,12]. However, as seen in Fig. 5 the area which is demonstrated in the C-scan shows only overlapping damage in each layer of the top face of the sandwich sample, leaving single delaminations and interface debondings undetected. Accordingly, the size of impact damage obtained from C-scan examination is always less compared to visual inspection.

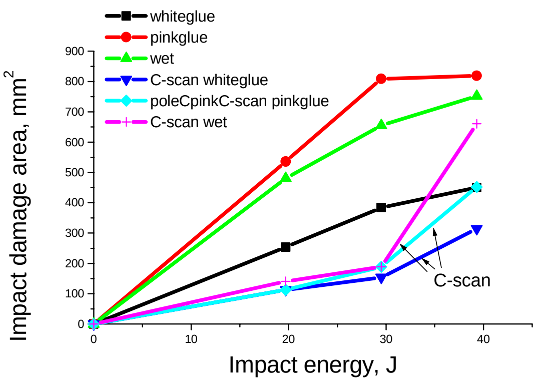

Fig. 6. Impact damage area as a function of impact energy for three types of sandwich structures: visual inspection and C-scan results.

Microscopic examination

Impact behaviour of the samples was analysed in terms of their microstructure. The quality of adhesive bonding was examined. Figs. 8,9 show the core /adhesive interface in the three sample types studied in this work prior to impact and post impact.

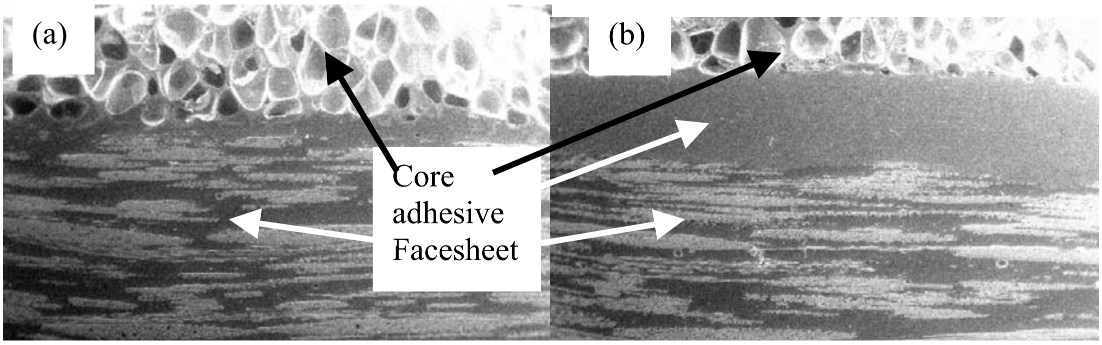

Fig. 7. Macroscopic view of the sandwich structure “wet”(a), “whiteglue” (b) sample.

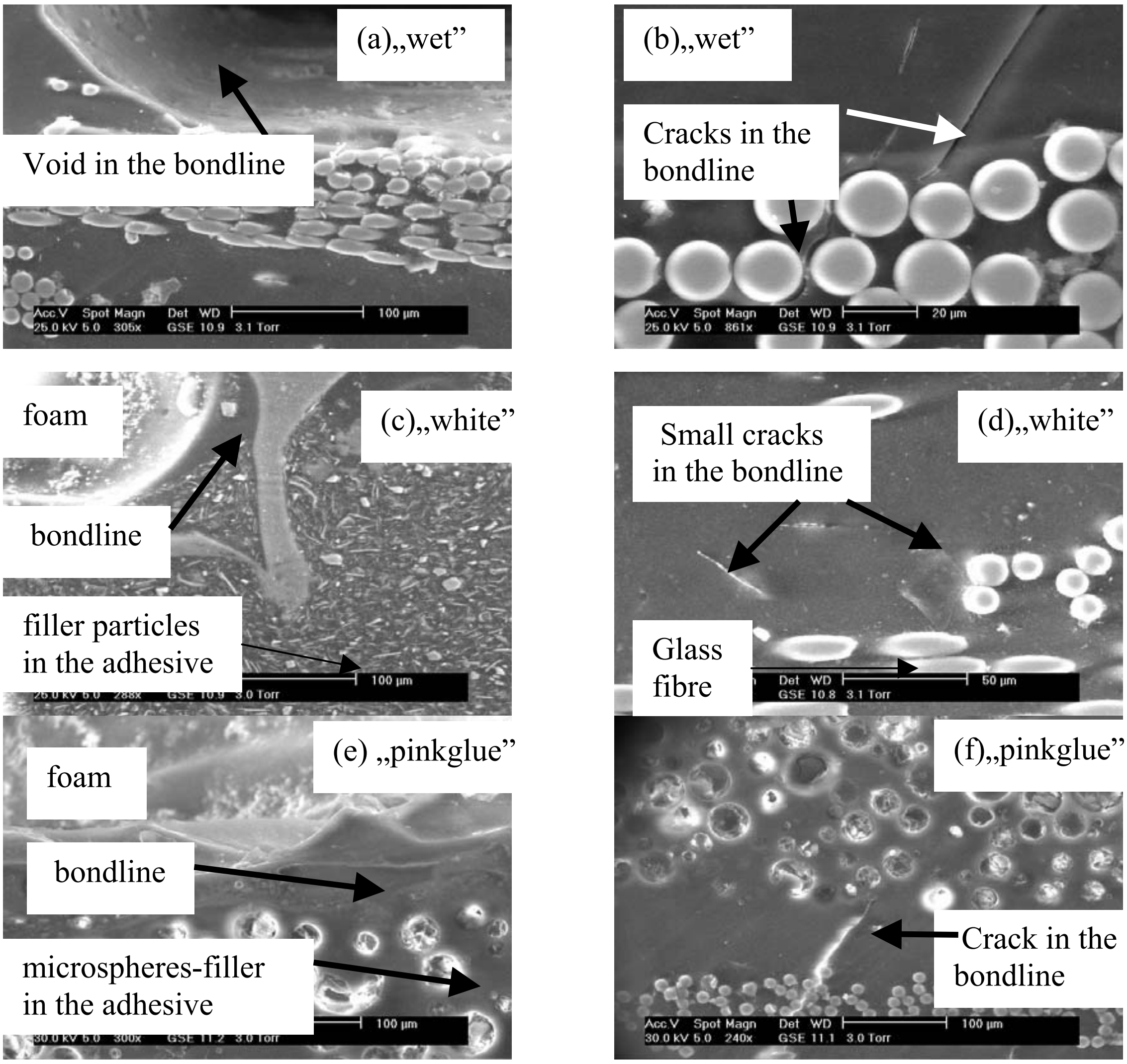

Fig. 8. Face/core interfacial area prior to impact (a,c,e), and after impact 19,7J (b,d,f), “wet”, (a,b), “whiteglue”, (c,d), “pinkglue” (e,f).

Good adhesion along the interfacial line was observed in macroscopic examination in all sample types before impact (Fig. 7). However, studies at high magnification showed that in “wet” samples big voids were present in the interfacial region (Fig. 8a) which could be the source of crack initiation uder impact. No traces of cracks can be observed in the adhesive layer in “whiteglue” sample at higher magnification (Fig. 8c). Similarly, perfect bonding was obtained in “pinkglue” sample (Fig. 8e). However, samples subjected to impact experienced severe damage both in the face and in the bondline. Transverse cracks developed in the “wet” laminate in the resin rich region between the core and the face (Fig. 8b). In “whiteglue” sample small cracks were observed in the resin at the laminate/adhesive interface (Fig. 8d). Finally, in the “pinkglue” sample extensive crack propagated across the adhesive layer and the resin in the interfacial region (Fig. 8f).

The differences observed in the interfacial region of the samples affect impact damage size. The smallest damage area observed in the “whiteglue” samples result from high adhesion efficiency and good mechanical resistance of the white adhesive which prevents formation of cracks under impact. The morphology of the adhesive is two phase (Fig. 8c), with rigid particles arresting the crack propagation. By contrast, “pinkglue” sample with the porous structure of low density adhesive is less resistant to impact crack propagation (Fig. 8f). Extensive cracks were also observed in the interfacial region of “wet” samples (Fig. 8 b).

CONCLUSIONS

In the present work the impact resistance of sandwich structures was assessed in terms of skin-core bonding efficiency using two types of adhesives and bonding with “wet” resin. Also, the air-coupled ultrasonic C-scan technique was estimated as a means of characterizing impact damage size in sandwich structures. The following observations were made.

- In all sample types top skin of the sandwich structure suffered some damage (delamination, etc.) due to impact. The least extensive damage size was found in the “whiteglue” samples. However, these samples suffered from skin/core debondings and core cracking at all impact energies. In contrast, the “pinkglue” adhesive, which is low-density due to the presence of the microspheres provides greater local flexibility leading to slight increase of indentation and decrease of in-plane displacement. This prevents to some extent the core cracking.
- In terms of impact damage size in each case the size of C-scan damage area was significantly smaller than in visual inspection of the sample sections which is due to the C-scan images showing only the overlapping delaminations area directly under the impact site, whereas the visual inspection of the laminate surface shows the extent of the largest, single delamination. The combination of these two results gives information about both intensity as well as maximum extension of damage.
- The preliminary assessment of three methods of bonding of the PVC foam core to glass/polyester laminate shows that each method has its qualities and weaknesses accordingly, it’s not possible to distinguish one which is best in terms of impact behaviour. “Wet” laminates bonding is simple and cheap, “whiteglue” provides the least extensive delamination size and pinkglue resists core cracking.
- The air-coupled C-scan testing with respect to sandwich structures is still a very recent technique and further tests need to be performed, in order to ensure the reliability of the results.

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