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MEASUREMENT OF IMPACT-DAMAGED AREAS IN COMMINGLED E-GLASS/POLYPROPYLENE LAMINATES VIA THERMOGRAPHIC IMAGES ANALYSIS

by C. Santulli

University of Reading, School of Construction Management and Engineering
Whiteknights, Reading, RG6 6AY, United Kingdom

Abstract

In this paper, a method is proposed to measure the impact-damaged area in 3-D commingled E-glass polypropylene laminates impacted at three different energy levels, 15, 30 and 45 Joules. The method is based on analysis and thresholding of images obtained by transmission transient thermography on both faces of the samples using a 500 W infrared lamp. This allowed performing fast measurements of the impact-damaged area in these laminates. In addition, the method is non-destructive and requires only a limited post-analysis of data, which could be ideally automatised, especially on a large number of specimens.

1. Introduction

Commingled E-glass/polypropylene fibre laminates (®Twintex) are increasingly used for automotive applications for their outstanding impact resistance and their lower cost with respect to carbon fibre composites [1-2]. The presence of fibres oriented in the direction of thickness has always being regarded as detrimental for the impact resistance of polymeric composite materials. However, in the particular case of commingled laminates, a small percent of 3-D fibres can reduce the effect of damage at crossovers and possibly improve the resistance of these laminates to delamination. A drawback of the introduction of 3-D fibres is however that they present more complex impact damage patterns and influence of defects can be larger than in 2-D commingled laminates (figure 1). This adds to the importance of correctly characterising impact damage, including a reliable measurement of impact-damaged areas. Transient IR thermography has already shown some potential in characterising the impact-damaged areas on glass fibre composites [3-4].
In the particular case of commingled laminates, the application of transmission transient thermography allowed to characterise falling weight impact damage in these laminates, up to a thickness in the order of 3.5 mm [5]. In addition, the modes of damage revealed by thermographic images were related to the moulding parameters (pressure, compression time) of the different laminates tested, leading to considerations on the influence of the manufacturing process on impact performance [6]. This work proceeds from the previous ones, trying to refine the measurement of impact-damaged areas using image analysis techniques, in the specific case of commingled laminates with insertion of a limited amount of through-thickness fibres.

2. Materials and methods

Commingled E-glass/polypropylene laminate plates (100x100 mm) with 1-2%

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through-thickness fibres (60%wt. glass fibre content) have been impacted at energies of 15, 30 and 45 Joules on a Rosand IFW5 impact tower using a 12.7 mm. diameter impactor. Five plates have been impacted per each impact energy. After impact, the damaged area was observed using an Agéma Thermovision 900 SW thermographic camera, thermo-electrically cooled, with a spectral response 2-5.4 micron and a sensitivity 0.1ºC. The camera was fitted with a 25 mm lens, so that images of the specimens could be focused at a minimum distance of 480 mm. Thermographic images were averaged over a period of 30 seconds immediately following a 3-second heating phase obtained with a 500 W infrared lamp, by averaging each pixel on a sequence of 10 images, each one acquired every 3 seconds. Heating yielded on the laminate surface a maximum temperature of 45°C. After 30 seconds, the maximum temperature difference across the sample surface decreased to less than approximately 3.2°C, and therefore at that moment the signal/noise ratio was deemed no longer sufficient for impact damage characterisation. The adoption of transmission transient thermography for studying impact damage in these laminates has been suggested by the fact that this method allowed a better control over temperature in the initial part of the transient.
The impacted face and backface thermographic images at impact energies between 15 and 45 Joules have been analysed to obtain a reliable measurement of impact-damaged area on the surfaces and possibly across the thickness of the samples. Since previous studies have shown that commingled 3-D laminates typically present a quasi-elliptical impact damage area with some preferential directions of propagation, usually along the x-axis, a rectangular area of 40x32 mm (100x80 pixels) with centre corresponding to the centre of the impacted area was selected for analysis.

The method selected for image analysis, carried out using ©Corel Photo-paint software, involved using thresholding techniques by comparing the grey level histograms of the region of the samples including the impact area with the histograms of the remaining part of the laminate image (figure 2). A possible improvement of the method would include transforming the images on the greyscale and then subtracting pixel-by-pixel images taken at each impact energy, so to measure difference between impacted areas at the minimum energy (15 Joules) and at higher energies. This would possibly reduce the effect of the edges on the identification of the most suitable thresholding level for the images.

3. Results

The impact-damaged areas measurements obtained with the two methods (in mm²) are reported in table 1. It is noteworthy that for the lowest impact energy the backface damage appears to be comparable with the impacted face damage. This is not the case for higher impact energies, which present comparatively much larger damaged areas, increasing with an exponential law (exponent probably around 1.5) with impact energy. This confirms that 3-D commingled composites can occasionally show backface damage for impact energies well below penetration energy, as appearing by typical IR thermography images shown in figure 3 [7]. This was explained by the energy dissipated by the breakage of fibre bundles, which are able to absorb damage evenly throughout the thickness. At larger impact energies, the effect of the surface and sub-surface damage is higher, so that damage tends to sharply decrease across the thickness, as it is shown by interpolation of typical damage extent at different depth inside the specimen (figure 4).
The method applied, although simple, proved suitable for a first evaluation of impact damage in these composites, the real difficulty being to correctly threshold the images histogram. In most cases, the histogram presents a clear separation

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between the grey levels of the damaged area and the bulk of the specimen. It has to be noted, quite obviously, that images taken in the first few seconds of cooling transient appear to allow easier and more reliable measurements. However, disposing of a larger number of images on the same sample during the same transient equally allows refining the measurement.
Further IR thermography observations would need to concern the possible characterisation of impact-damaged areas, discerning growing levels of damage, possibly with the use of a microfocus lens on specific regions of the damaged region.

4. Conclusions

The analysis shows that this method leads to measurement of the apparent impact-damaged area. This would be possible also from optical microscopy generated images, but IR thermography presents the obvious advantage of not needing to section the samples under observation. It is also important to consider that this is a particularly difficult case for the usually non-uniform "whitish" colour of the samples and their low conductivity, so that the results appear promising for further applications.

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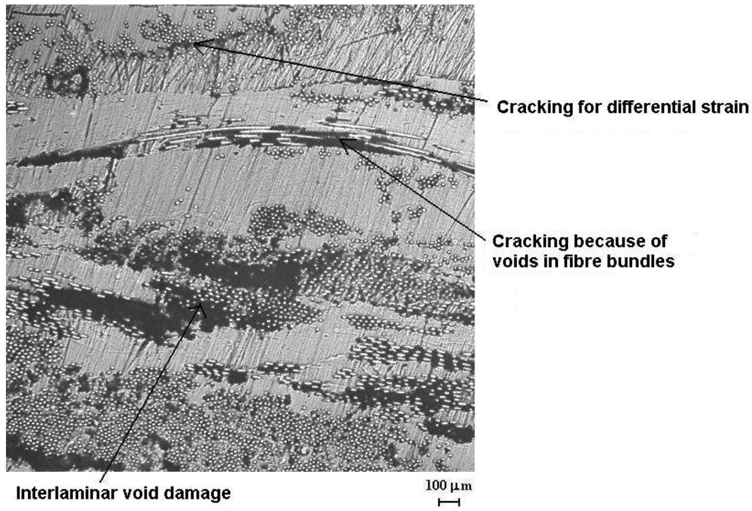

Figure 1 *Different types of defects triggering impact damage in 3-D commingled laminates*

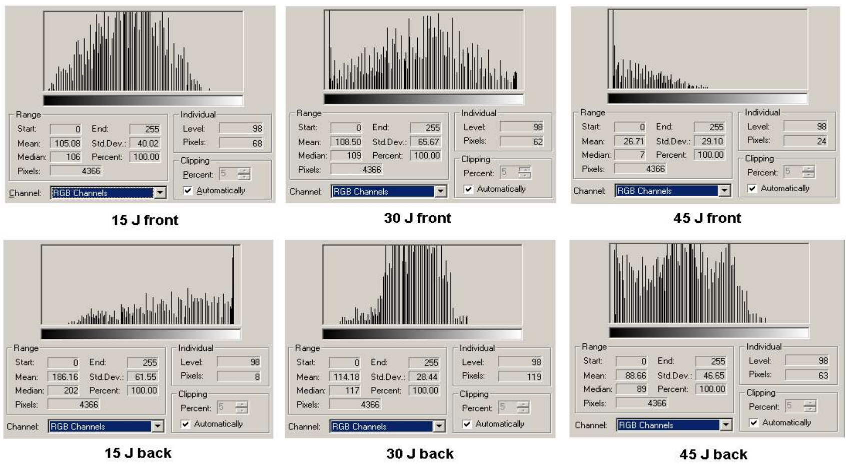

Figure 2 *Grey level histograms for thermographic images (area 40x32 mm) of impacted 3-D commingled laminates*

Table 1 *Impact-damaged areas (in mm²) as measured from IR thermography images*
(average and standard deviation over five samples) measured by image thresholidng

Surface	**15 Joules**	**30 Joules**	**45 Joules**
Impacted	81 ± 18	275 ± 105	773 ± 87
Backface	108 ± 20	29 ± 12	235 ± 65

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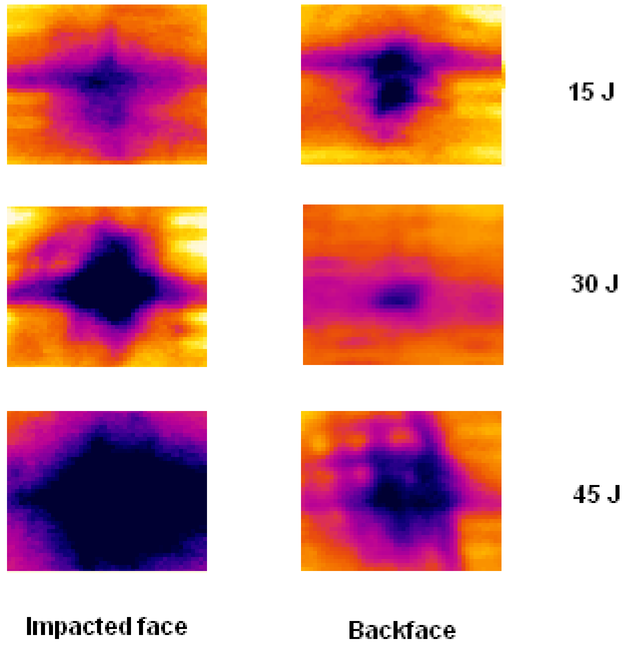

Figure 3 *Typical IR thermography images of impacted areas in 3-D commingled laminates (40x32 mm area) (all of these images were acquired after 15 seconds transient)*

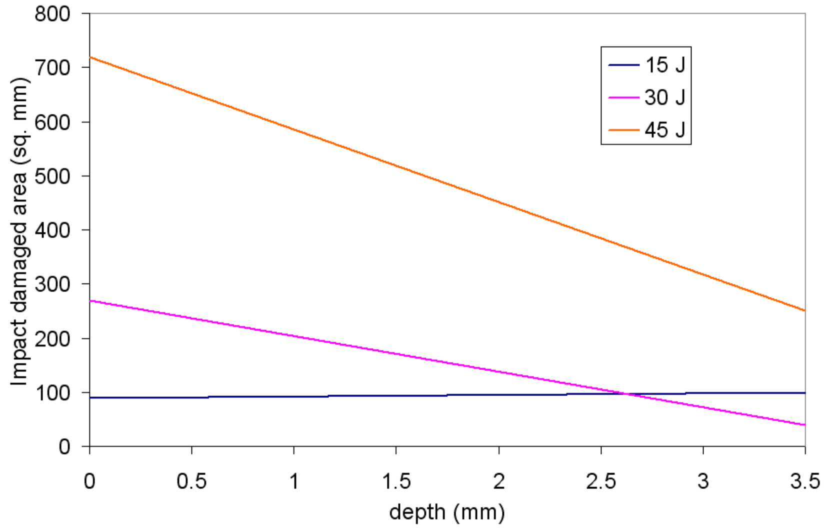

Figure 4 *Linear interpolation of a typical evolution of impact-damaged area inside a sample of 3-D commingled laminate*