

A Comparative Study on Falling Weight Impact Properties of Jute/Epoxy and Hemp/Epoxy Laminates.

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ABSTRACT: One of the principal reasons for limited use of plant fibre composites is their sensitivity to impact loading and the difficulty in characterising and assessing the criticality of impact damage. In this study, a comparison between two composite architectures has been carried out, namely a hemp/epoxy random mat and a jute/epoxy plain weave laminate, both with $45\pm 2\%$ vol. of reinforcement fibres. Work carried out concentrated on comparing and discussing the falling weight impact performance of the two laminates with different fibre architecture, by studying their impact hysteresis cycles and investigating their respective modes of damage. This was done in view of a possible application of a hybrid of the two laminates for impact resistance purposes. The results allowed quantifying the superiority of hemp/epoxy on jute/epoxy laminates under falling impact loading: however, the latter laminates appear to show more consistent impact properties and a more predictable mode of damage, which was attributed to an improved a better fibre-matrix impregnation.

Keywords: Falling weight impact, hysteresis cycles, hemp fibre mat, jute hessian

1.0 INTRODUCTION

In recent years, the possible application of plant fibre composites for structural purposes has received a great deal of attention in literature. The interest of their application lies mainly in the fact that these materials are perceived as a step towards a real environmentally friendly material, since plant fibres are bio-degradable and carbon-dioxide neutral. This has been confirmed by LCA-based studies, especially focused on automotive applications, and possibly suggesting the use of biodegradable polymers (e.g., starch or fatty-acid based) as matrices [1-2]. However, the natural availability of a number of plant fibres throughout the world may represent more an unexpected complication than a real opportunity, if a real plant fibre selection is not achieved, based on rational considerations. In practice, the quality of plant fibre reinforcement for composites is affected by a large number of factors. These would include e.g., biological factors (fibre maturity, fibre differences) treatment (physical, chemical, etc.), fibre extraction (mechanical, enzymatic). The transition to a selection more based on materials vs. properties considerations e.g., in Ashby diagrams, which exist already in the more general field of natural materials [3], would require a large number of comparative studies to be performed.

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In practice, the application of plant fibre composites is still limited to non-structural components e.g., panels, ceilings, partition boards and interior car components. One of the principal reasons for this limitation is the sensitivity of plant fibre composites to impact and the difficulty in assessing the criticality of impact damage. In recent years, some comparative studies between laminates reinforced with different species of plant fibres have been published, but hardly any of these works is focused on impact damage caused by falling weight [4-5]. Plant fibre composites hardly offer any appearance of impact damage, even quite close to penetration, an evidence that generates some concern on their possible semi-structural application [6]. In particular, the analysis of data obtained from falling weight impact (IFW) tests on natural fibre composites is able to provide useful information on impact damage patterns. This is especially desirable since, due to the inherent presence of defects and the larger dimensional variability of plant fibres, defects leading to disruptions in the laminate geometry are more frequent than e.g., in glass fibre reinforced composites [7]. In this respect, one of the principal factors which appear to be detrimental for impact performance of composites manufactured using plant fibre mats is the presence of 3-D fibres in these mats [8]. On the other side, real 2-D mats are not easily obtained, so that the introduction of woven fibre laminates may be a competing route for composite manufacturing using plant fibres [9]. The rationale for this study is the comparison, based on 2-D impact properties of the final material, between two types of plant fibre composites, which have been proposed so far for impact-bearing purposes, although with investigations limited to unidirectional impact testing e.g., Charpy tests [10-11]. Falling weight impact tests and the analysis of impact hysteresis curves in these materials may suggest whether their damage tolerance can be considered acceptable for semi-structural purposes.

2.0 MATERIALS AND METHODS

In this study, a comparison between two composite geometries has been carried out, namely a hemp/epoxy random mat and a jute/epoxy hessian plain weave (single warp-single weft) laminate, with roughly the same amount of reinforcement. Both jute and hemp fibres have been decorticated, then bleached with sodium chlorite (NaClO_2) in optimised conditions.

With this aim, the static (tensile, flexural) and two-dimensional impact properties of a jute/epoxy plain weave laminate with 8 plies disposed at 0/0/45/45/45/45/0/0 (fibre content 46% vol.), and a hemp/epoxy mat (fibre content 43% vol.), have been measured. Impact hysteresis curves and fragmentation mode after falling weight impact have also been discussed, to suggest indications on the respective performance of the two composites.

Both composites were manufactured in a closed matching mould of dimensions 200x250 mm. Manufacturing was carried out by hand lay/up at room temperature, applying a slight pressure, in the order of 0.02 MPa. The materials were then extracted and samples removed for tensile, flexural and impact tests, as prescribed by the Italian standards UNI EN 61 ed UNI EN 63, to reduce as much as possible the discarded material. For each of the two composites, a minimum of ten samples have been tested in each loading mode (tensile, flexural, and IFW).

Using a CEAST Fractovis falling weight impact (IFW) tower, the samples have been impacted from a height of 0.5 m by a 11.4 kg mass, so to obtain a 56 Joules impact energy, using a 19.8 mm diameter impactor. Tensile and flexural tests have been carried out using an MTS universal testing machine in displacement control mode, applying a cross-head speed of 1.5 mm/min.

3.0 RESULTS AND DISCUSSION

Tensile and flexural tests results on the laminates are reported in Figures 1(a) and 1(b) respectively. These indicate the slightly higher tensile properties of the hemp/epoxy mat, which shows in contrast a lower flexural strength. The tensile mode of failure suggests that the plain weave jute/epoxy laminate breaks by tearing off of fibres perpendicularly to the direction of loading, due to the strength of the fibre-matrix bonding (Figure 2). This is not unpredicted for these types of laminates: it has been observed already by Santulli and Cantwell, and is suggestive of the inherent brittleness of the weave failure [12]. In contrast, hemp/epoxy laminates typically show both during tension (Figure 2) and during bending (Figure 3) a failure mode oriented in two different directions or even in multiple directions (Figure 4), both resulting in large delamination surfaces and therefore in considerable delay in damage progression. It can be suggested that this mode of failure is due to the random orientation of fibres, which is far removed from a uniform distribution, as indicated by the optical microscopy measurements at the surface of a hemp/epoxy mat, summarised in Figure 5. This is likely to contribute to the higher variability of flexural performance for this composite with respect to jute/epoxy laminates, as reported in Figure 1(b).

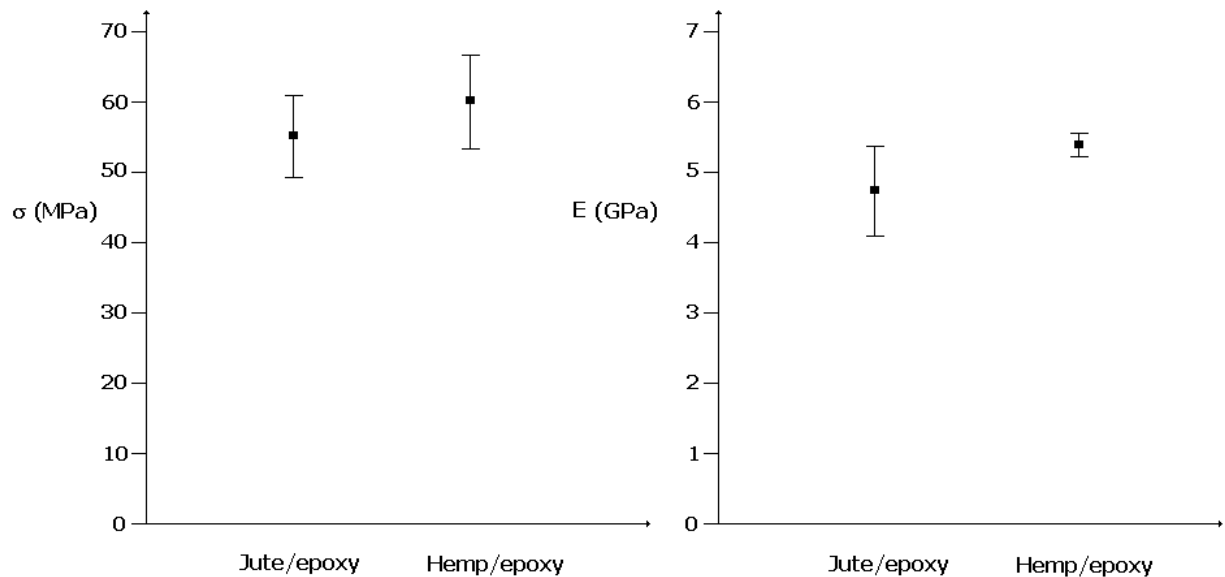


Figure 1(a): Tensile strength and modulus for both composites (average value and standard deviation)

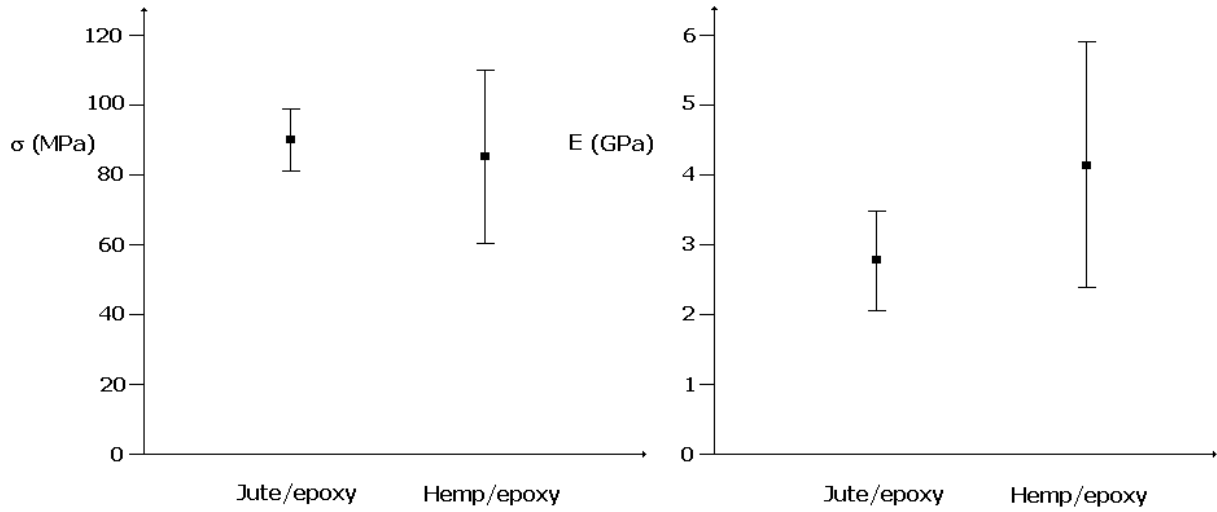


Figure 1(b): Flexural strength and modulus for both composites (average value and standard deviation)

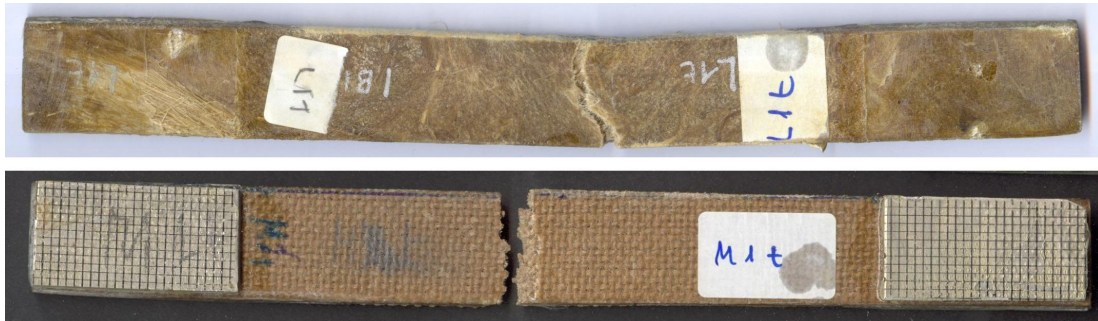


Figure 2: Tensile mode of failure for a hemp mat (top) and a jute plain weave (bottom)



Figure 3: Fractured surfaces of flexural samples of hemp/epoxy laminate (showing delamination in two directions, highlighted in (a) and (b); the extent of delamination is highlighted in (c) and (d).



Figure 4: Fractured surfaces of flexural sample of hemp/epoxy laminate (showing wider delamination area, reported as the black edges rectangle in figure)

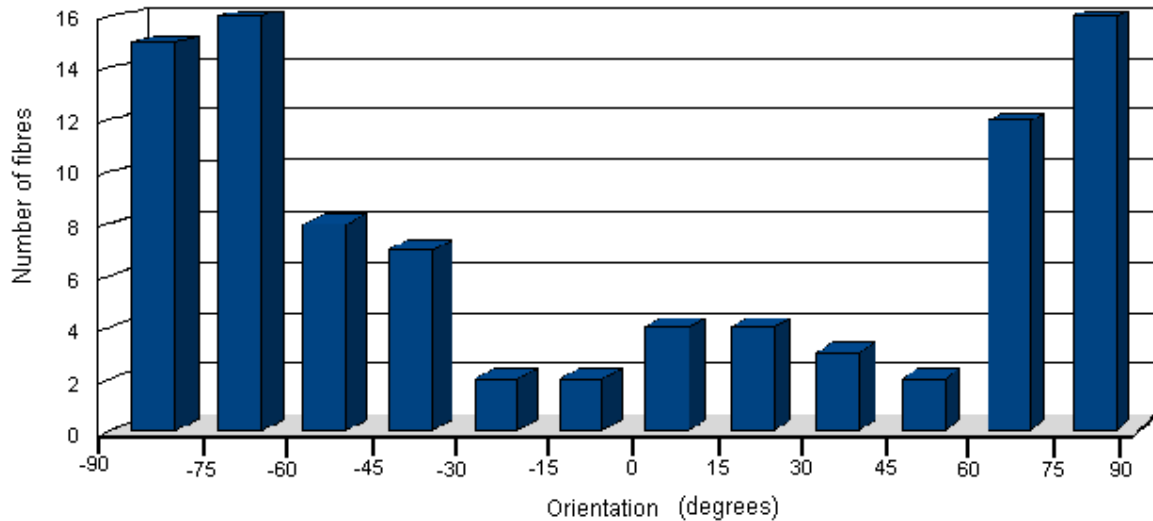


Figure 5: An example of fibres distribution according to orientation on the surface of a hemp-epoxy mat (0° being their orientation according to the X-axis)

The above variability is still present when looking at impact penetration data: despite this fact, the performance of hemp/epoxy laminates is still considerably superior (by around 30% on an average) when considering the maximum load during falling weight impact tests, as reported in Figure 6. The comparison of typical hysteresis cycles (Figure 6) clarifies that the hemp/epoxy laminate, because of its higher impact resistance, undergoes a higher rebound, up to negative values of displacement.

A more detailed study on parameters calculated from impact hysteresis cycles is then performed, on the lines of what initially proposed in [13]. It needs to be noted that in the case of penetration impact, the decrease of force after peak load is reached is related to further damage development due to the impactor passing through the specimen. Further complication arise, when considering the distribution of the impact hysteresis energy between the elastic, the plastic and the damping phase (typical ones are depicted in Figure 7). As discussed already for flax/epoxy laminates, a higher portion of damping (or rebound) energy would indicate a more efficient damage dissipation [14]. In this case, the results shown in Figure 8 would possibly indicate that the mode of failure is different: the inherent brittleness of jute/epoxy laminates results in the majority of energy being absorbed before reaching the peak load, therefore as elastic energy. In contrast, the higher damping energy of hemp/epoxy mats suggests also an improved impact damage tolerance of this composite. On an average, the linear stiffness is approximately 40% higher for the hemp mat than for the jute laminate. However, since the values are much more scattered for the former than for the latter (for both linear stiffness and even more for penetration energies), the real difference between the two is considerably lower. In the case of jute laminates, as shown from fibre orientation can be considered exactly $0/90$ with constant warp and weft size, as appearing in Figures 9a and 9b. This weave geometry yields a lower void content and a more effective fibre impregnation: both these characteristics, albeit necessary to have more consistent mechanical properties in the composite, may reduce impact properties, as verified by de Carvalho *et al.* in [15].

In hemp/epoxy mats, damping energy during the latter phase of impact penetration can be ascribed to the hindrance, owed to the presence of fibres with different orientation, as can again be observed in Figures 9(a) and 9(b). In this way, the penetration is more

"disturbed" by the presence of fractured fibres, than it is in the jute/epoxy laminate. This may confirm that the variability in properties is mainly due to the post-peak load (plastic + damping) behaviour during impact. In turn, this is determined by how the fibres orient themselves in reaction to the impact loading event. In particular, the material can show delamination progressing in two directions or even at random in multiple directions. Both these possibilities result in an improved damage tolerance across the composite, whose extent cannot, however, be predicted and is unlikely to be useful to material design. This is because the uneven distribution of randomly oriented hemp fibres in the matrix can lead to resin-rich areas and therefore concentration of stresses in the composite [16].

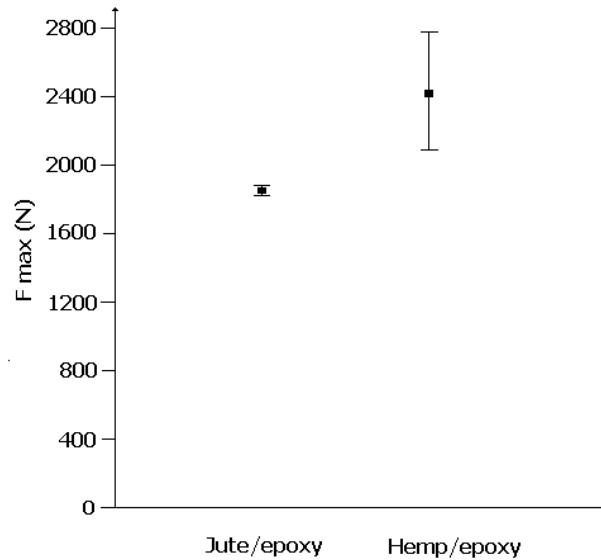


Figure 6: Maximum load during falling weight impact test

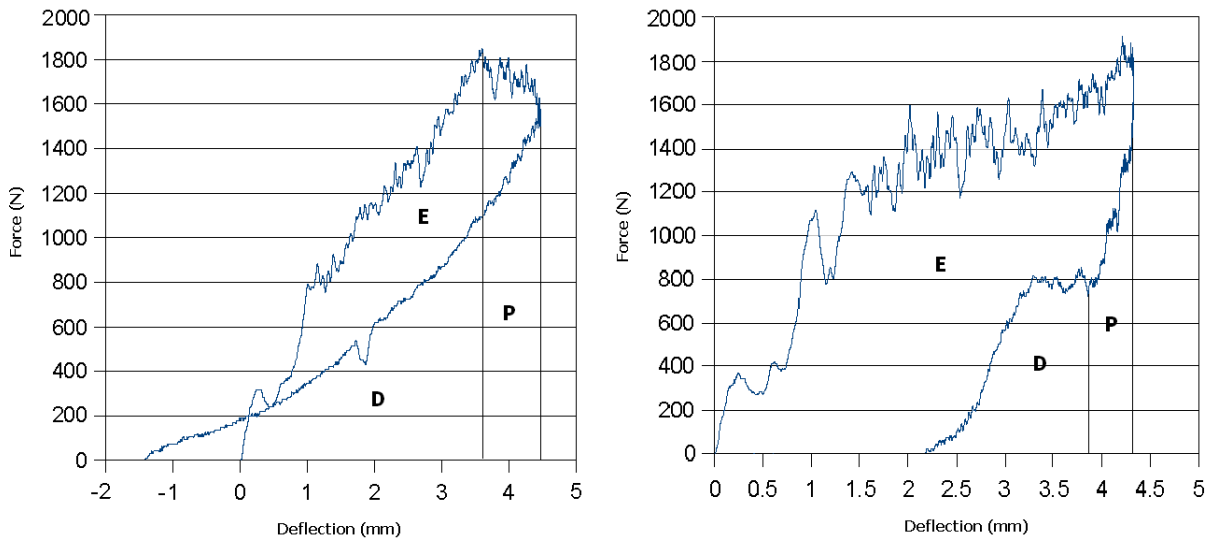


Figure 7: Typical impact hysteresis curves at 56 J for hemp/epoxy (left) and jute/epoxy composites (right)

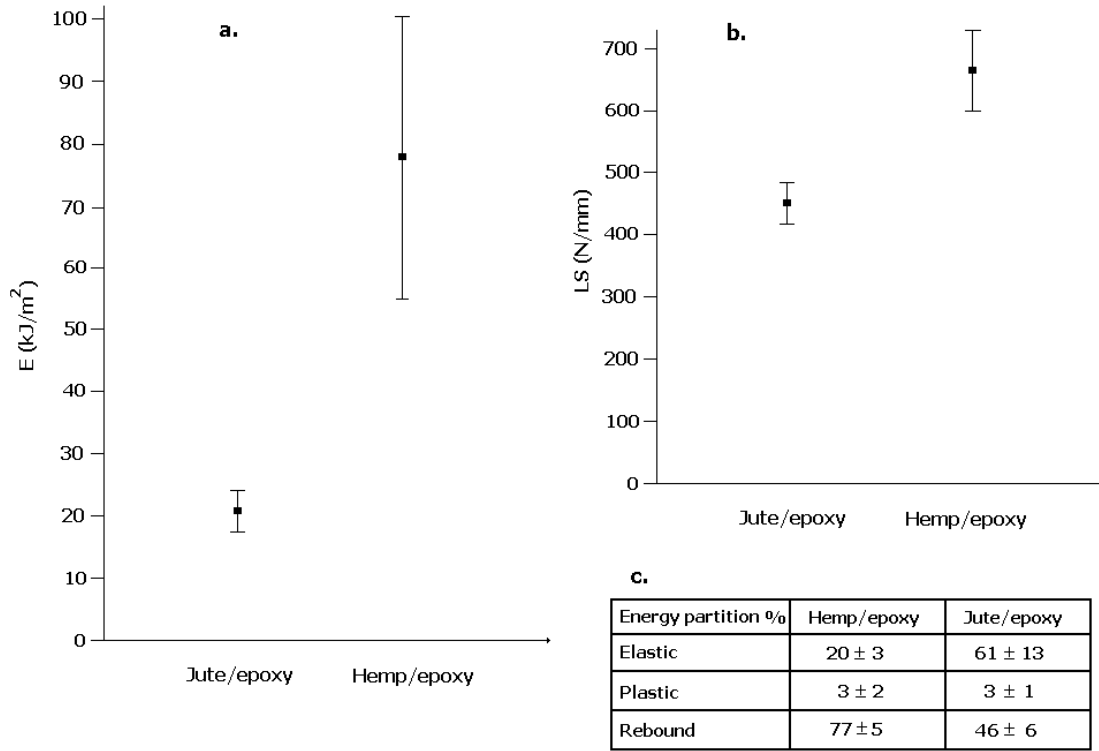


Figure 8: Hysteresis cycles analysis: (a) measured penetration energy (b) values of linear stiffness (c) energy partition.

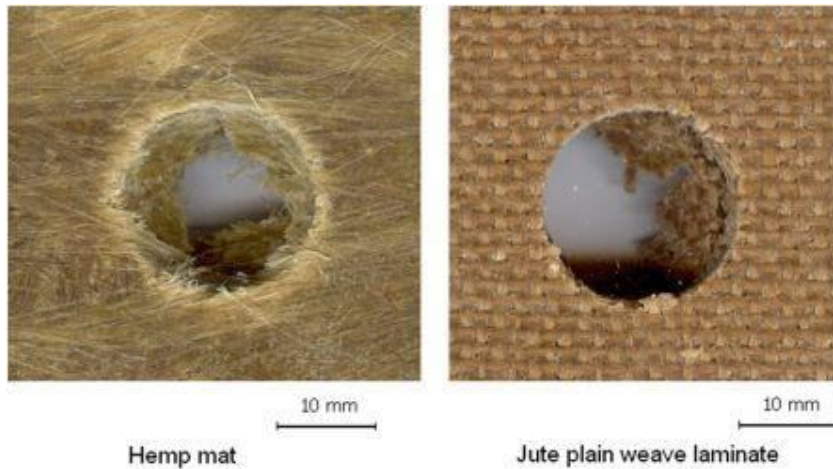


Figure 9(a): Impacted surfaces of the samples

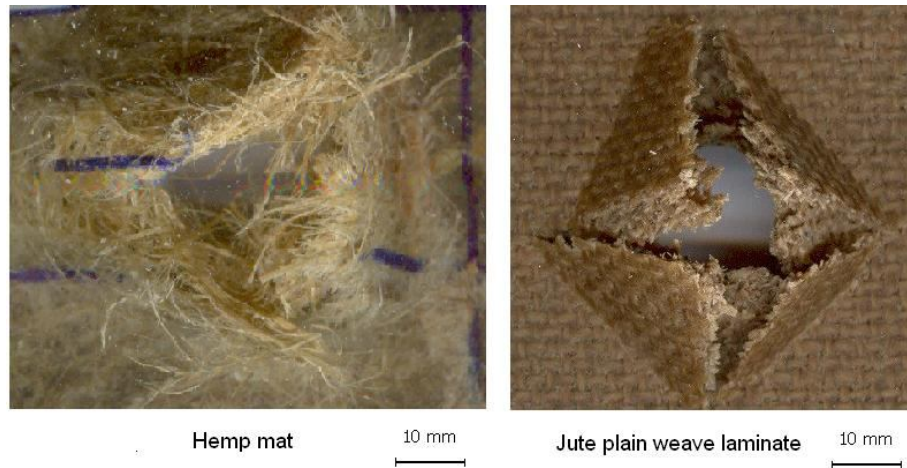


Figure 9(b): Back surfaces of the impacted samples

4.0 CONCLUSIONS

In general, the hemp/epoxy mat behaves in a better way than the jute/epoxy laminate with the same fibre content under falling weight impact. This can be attributed to the possibility of expanding the delaminated area in the composite during impact, as an effect of the random orientation of fibres, which results in damage propagation along two, or more, different directions. In addition, the jute/epoxy plain weave laminate is fractured mainly by tearing off of the fibres following a matrix crack, so it is more sensitive to the presence of defects, in spite of the fact that it is better impregnated and has more uniform properties. However, the difficulty to obtain a uniform distribution of hemp fibres in mats according to their orientation leads to a large scattering in properties, which considerably reduces the advantage of using a hemp mat as a more impact-bearing composite.

It is suggested therefore that manufacturing a hybrid laminate, using jute/epoxy plain woven and hemp/epoxy random mat, most preferably the latter (inherently stronger) as skins and the former as core, would be able to reduce the scattering in impact resistance values and lead to a better predictability of its impact behaviour, useful for materials design.

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