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Low Velocity Impact Behaviour of Sandwich Composite Structures with E-Glass/Epoxy Facesheets and PVC Foam

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Abstract

This study presents the impact behaviour of marine sandwich composite beam structures that manufactured by vacuum-assisted resin infusion process (VARIM). The sandwich composite consists of different thicknesses of upper and lower E-glass fibre-reinforced polymer as facesheets and PVC foam as core material. Low velocity impact tests have been conducted to understand the impact response of the sandwich composite by using a drop-weight impact machine with a hemispherical impactor. Square samples with 100 mm X 100 mm side dimensions were subjected to impact machine at five energy levels of 20J, 40J, 60J, 80J and 100J. The impact loadings have been applied to thicker facesheet of the sandwich composite to obtain impact parameters experimentally. Damage type on thicker facesheets and internal parts of PVC foam have been characterized through the contact force - time, contact force - displacement and contact force - energy curves after the tests. Impact failures that occurred on the upper facesheets, core and lower facesheets of the specimens were observed.

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Keywords: Sandwich Composite Material, Low Velocity Impact Testing, Impact Energy

1. Introduction

Low velocity impact tests were widely used in order to understand the dynamic deformation of composites by many researchers (Abramovich et al, 2010; Klepka et al, 2012). Low velocity impact tests are preferred to observe dynamic deformation and failure modes of materials (Espinosa, 2000). Atas and Sevim (2010) examined the impact behaviour of sandwich composite panels with PVC and Balsa cores under different impact energies. The load-deflection curves and energy profile diagrams were obtained to understand impact response and fracture modes. Delaminations between glass-epoxy layers and face/core debonding were examined.

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Soliman et al. (2012) studied the low velocity impact behaviour of carbon woven fabric composites that reinforced with multi-walled carbon nanotubes (MWCNT) under 15J, 24J, 30J, 60J and 120J of energy levels. Load-displacement responses for composite plates under different energy levels were obtained. Dhakal et al. (2007) worked with different impactor geometries on their impact damage observations. They studied hemp fibre reinforced unsaturated polyester composites under low velocity impact loading. Instrumented falling weight impact setup was used with different velocity levels of 2.52 m/s, 2.71 m/s, 2.89 m/s and 2.97 m/s. Failure mechanism of composites and matrix cracking were obtained by scanning electron microscope (SEM). It was seen that as the impact velocity increased, the damage to back face of the laminate increased. Wang et al. (2013) worked on the low-velocity impact behaviour of foam-core sandwich panels experimentally and numerically. Hemispherical steel impactors with various diameters were used for different energy levels. The displacement and the velocity were obtained by using digital image correlation technique. The parameter for impact behaviour of the sandwich panels were studied. 3D finite element modelling was simulated to observe impact response of the damaged model. The good agreement between experimental and numerical data was obtained.

Compression-after-impact response of composites was investigated by many researchers. Yan et al. (2010) studied the failure mechanism of woven fibre reinforced composites by examining the compression failure of composites that were previously tested by low-velocity impact testing. The paper contributed a numerical investigation of the compression-after-impact response of E-glass fibre-reinforced vinyl ester composite materials. The damages in the fibres and matrix were modelled numerically in order to understand the sub-laminate buckling and damage upon compression loading. It was seen that the crack propagation was along the thickness direction in shear mode to cause eventual failure of the composite. Demircioglu et al. (2018) investigated the fracture behaviour of eco-friendly wood skinned sandwich composites under low-velocity impact experimentally. Different core configurations with various thicknesses with E-glass and rubber cork layers were used. The impact behaviour of the specimens was examined in terms of energy absorption capacity, maximum contact force and penetration depth. Balikoglu et al. (2018) manufactured sandwich composites which consist of E-Glass fabrics and bisphenol-A epoxy ester resin with PVC foam by using vacuum assisted resin transfer molding (VARTM) method with pinewood and ashwood layers. Low-velocity impact experiments with 30J and 60J energy levels were completed to investigate the damage state in the foam core and facesheets. Column compression tests of impacted and virgin specimens were compared.

The main aim of this paper is to investigate the impact behaviour of sandwich composites subjected to low velocity impact experimentally. The sandwich composite material used for the experiments was manufactured with E-glass epoxy facesheets and PVC foam core by using vacuum-assisted resin infusion molding process (VARIM). Its material properties for each failure mode and fracture behaviour were investigated previously (Toygar et al., 2019). Moreover, to understand the size and core density effects on the fracture mechanism of the material, several experimental and numerical analysis were completed (Balaban and Tee, 2019). In this study, the thicker facesheet was chosen as upper facesheet and was exposed to impact testing with 20J, 40J, 60J, 80J and 100J energy levels. The material properties of the sandwich composite are shown in Table 1. Due to the test results, contact force-time, contact force-displacement and contact force-energy curves were drawn for each energy impact level in order to obtain the low velocity behaviour of the sandwich composites.

Table 1: Physical and mechanical properties of the sandwich composite materials (Toygar et al., 2019).

Poisson ratio (ν)		**Modulus of Elasticity (GPa)**			**Shear Modulus (GPa)**
ν_{12}	ν_{13}	E_{11}	E_{22}	E_{33}	G_{12}
0.15	0.15	18	18	10	7.44

2. Experimental Testing

In this study, all sandwich composite specimens that had been impacted, were manufactured using vacuum assisted resin infusion molding process (VARIM) in the Composite Research Laboratory of Dokuz Eylül University in Izmir. E-glass fabrics having density of 800 g/m^2 were used as reinforcing material and epoxy resin (Hexion MGS L160 with a density of 1.13 g/cm^3) and hardener (Hexion MGS H160 with a density of 0.96 g/cm^3) for a resin-hardener ratio of a 100:25 by weight were selected as matrix material.

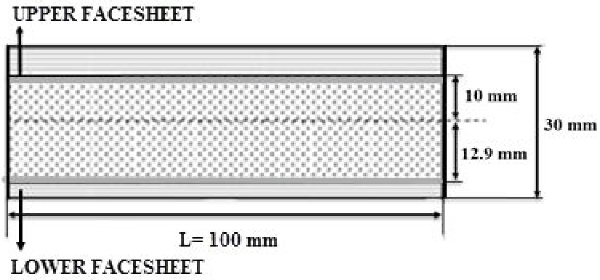


Figure 1: Dimension of each test specimen.

In the test procedure, the Fractovis Plus impact testing machine was used to conduct low velocity impact tests. The impactor that was used to strike the specimens, was a hemispherical indenter with a 12.7 mm diameter and attached to maximum loading capacity of 22.4 kN piezoelectric force transducer. The total falling mass of the impactor was 5 kg (including impactor and crosshead mass). The detailed low velocity impact test cabin is shown in Figure 2.

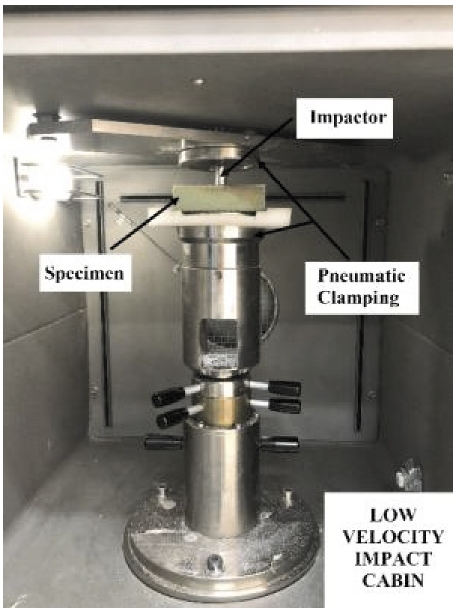


Figure 2: Demonstration of low velocity impact test cabin.

The impact energies for this study were selected as 20J, 40J, 60J, 80J and 100J to investigate the impact energy effect on the low velocity impact behavior of sandwich composites. Impact characteristics such as contact force-time, contact force-deflection and contact force-energy, maximum contact force curves were obtained for impact energy levels such as 20J, 40J, 60J, 80J and 100J.

3. Results and Discussions

Three specific results such as rebounding, penetration and perforation can be obtained after low velocity impact testing. As shown in contact force – time graphs (Figure 3), for each impact energy level, contact time increased by increasing the impact level, then it dropped sharply. It was seen that 80J energy level was initial of the penetration-perforation transition energy. According to the contact force-time curves, the curves have only one peak with small energy levels or rebounding cases during the experiments due to the damages of upper facesheets. On the other hand, with the experiments caused penetration (60J) and perforation (80J, 100J), the force-time curves have two peaks as both upper and lower facesheets were damaged by the impactor with 80J and 100J energy levels. In the experiment with 80J and 100J impact energy level, on the contact force-time graph, there is a second peak value which explains that the deformation characteristics of the foam core material. It is obvious that the stiffness of the lower facesheet during the experiments raised as well.

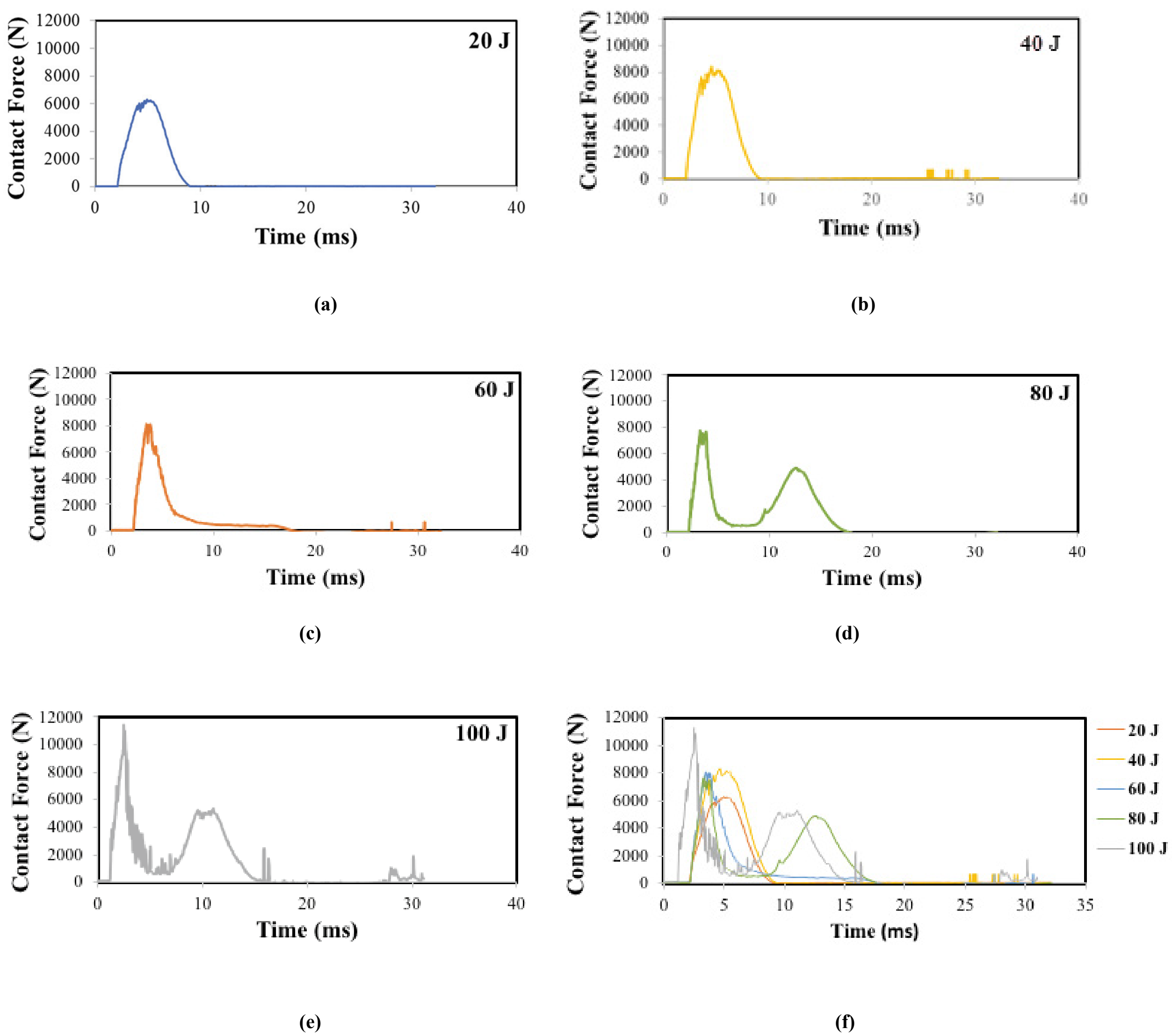


Figure 3: Contact force–time curves with energy levels of a) 20J, b) 40J, c) 60J, d) 80J, e) 100J, f) all energy levels

On the other hand, as shown in contact force–displacement curves (Figure 4), increasing the impact energy levels caused the bigger deflection values on the sandwich composites. Contact forces did not change significantly with the raise of impact energy level after 60J.

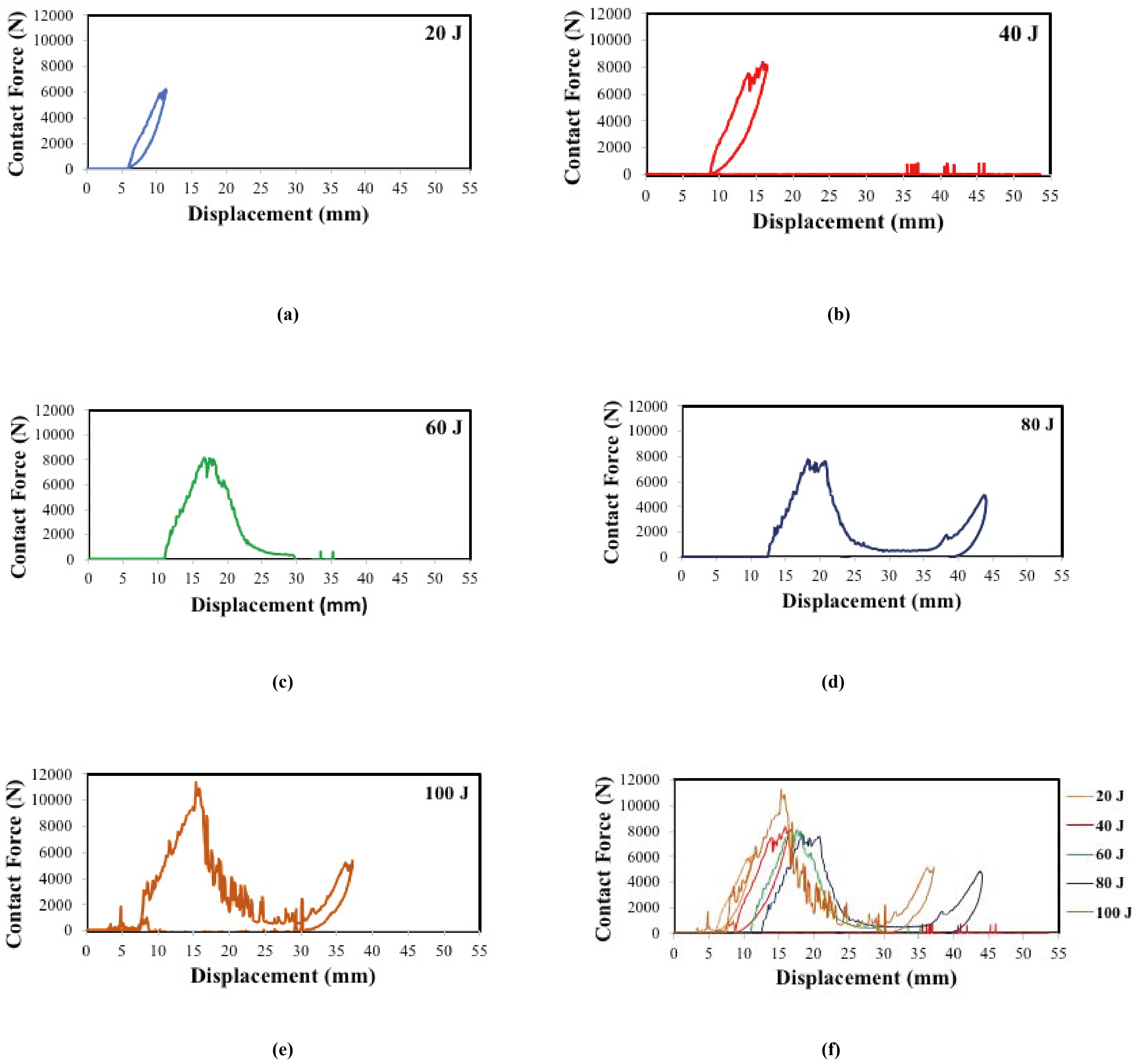


Figure 4: Contact force–displacement curves with energy levels of a) 20J, b) 40J, c) 60J, d) 80J, e) 100J, f) all energy levels.

The contact force–energy curves are given in Figure 5. It is clear that the contact force raises by increasing the impact energy. The contact force reached zero after having a peak area in the rebounding phase. Rebounding phase went to penetration and perforation with increasing the impact energy, respectively. The impact energy is defined as the total energy implemented to a sandwich composite material.

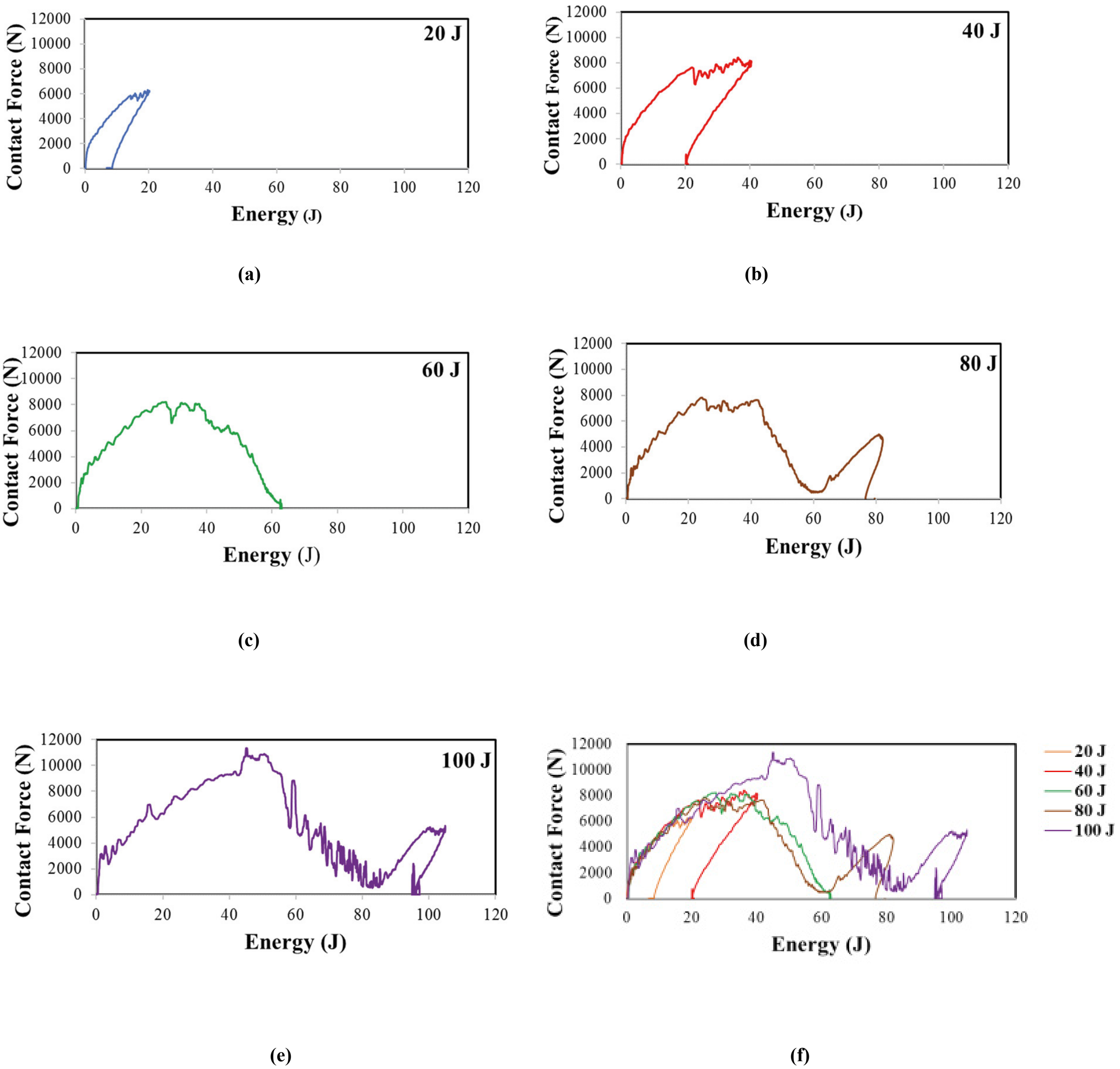
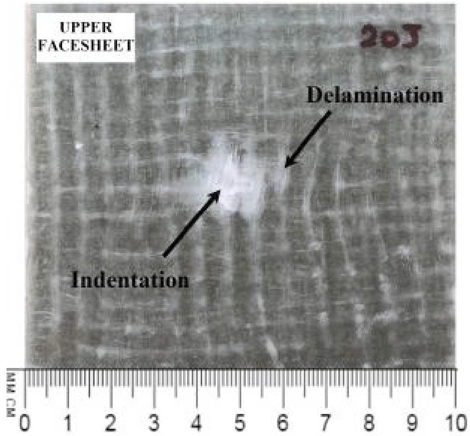
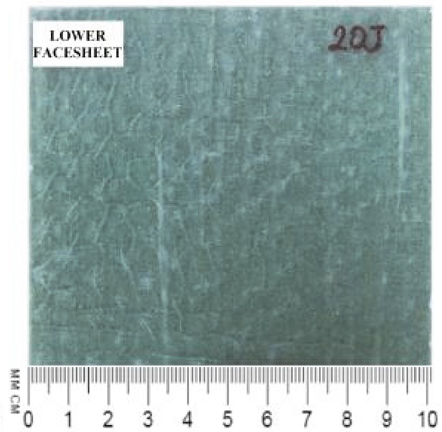


Figure 5: Contact force–energy curves with energy levels of a) 20J, b) 40J, c) 60J, d) 80J, e) 100J, f) all energy levels.

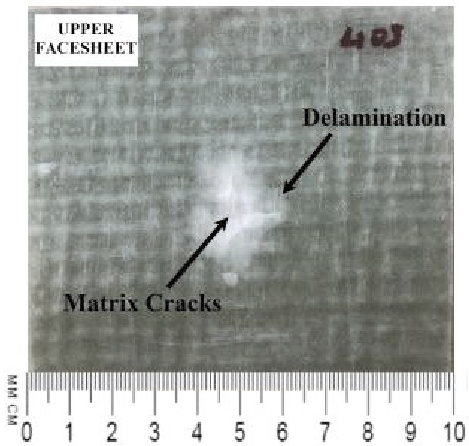
The damaged specimens are shown in Figure 6. Under the impact energy of 20J, there was no damage seen on the lower facesheet of the sandwich composites. Indentation failure could be seen on the upper facesheet and delaminations occurred on the upper interface of the upper facesheet only. As the impact energy increased to 40J, matrix cracks and delaminations also occurred at the lower interface of the upper facesheet. As shown in Figure 6b, there was no any damage on the lower facesheet with similar energy level of 40J. Under the impact energy of 60J, although there was no damage observed on the lower facesheet, indentation failure and fibre cracks could be seen on the upper facesheets and PVC foam only. In Figures 6g and 6h, fibre cracks and delamination were observed on both upper and lower facesheets under impact energy of 80J. As the impact energy increased to 100J, fibre cracks and delamination areas on the upper and lower facesheets increased by increasing impact energy (Figures 6i and 6j).


UPPER
FACESHEET
20J
Delamination
Indentation
MM CM
0 1 2 3 4 5 6 7 8 9 10

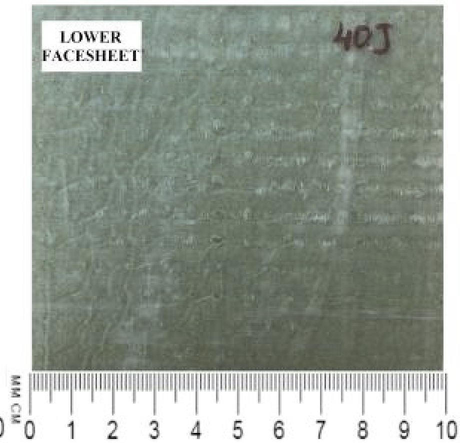
(a)


LOWER
FACESHEET
20J
MM CM
0 1 2 3 4 5 6 7 8 9 10

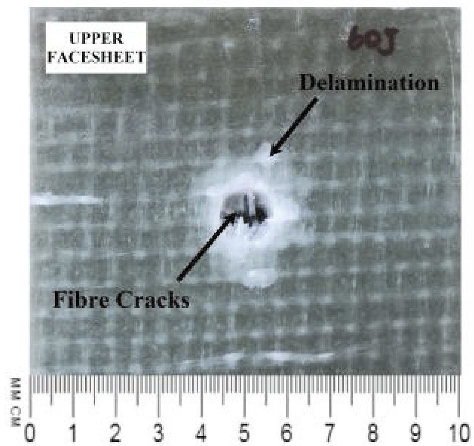
(b)


UPPER
FACESHEET
40J
Delamination
Matrix Cracks
MM CM
0 1 2 3 4 5 6 7 8 9 10

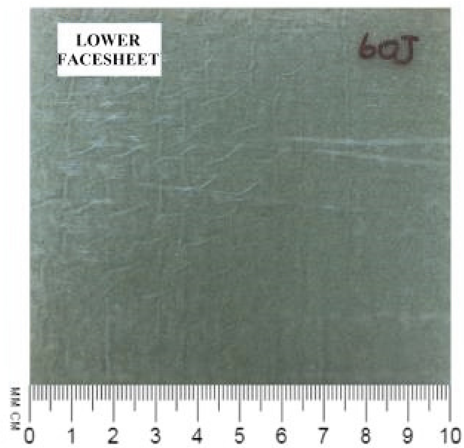
(c)


LOWER
FACESHEET
40J
MM CM
0 1 2 3 4 5 6 7 8 9 10

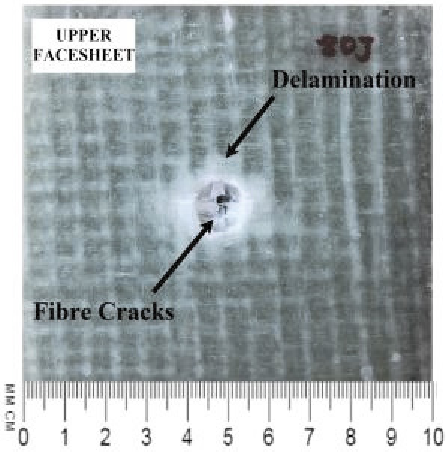
(d)


UPPER
FACESHEET
60J
Delamination
Fibre Cracks
MM CM
0 1 2 3 4 5 6 7 8 9 10

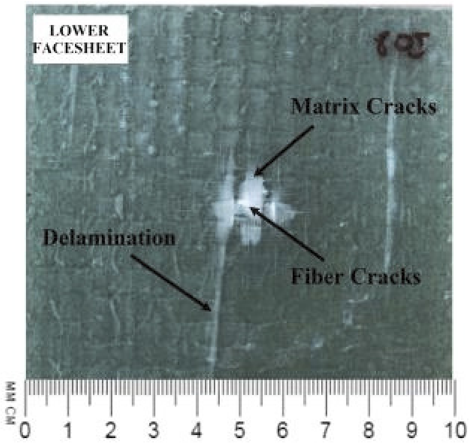
(e)


LOWER
FACESHEET
60J
MM CM
0 1 2 3 4 5 6 7 8 9 10

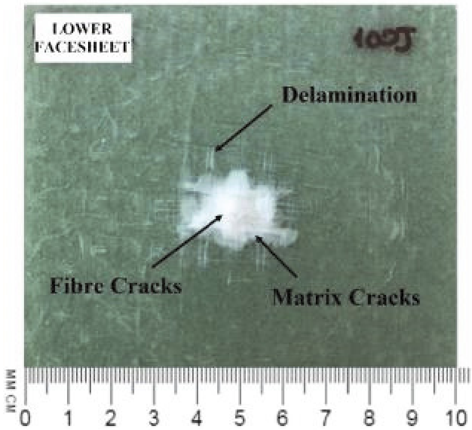
(f)



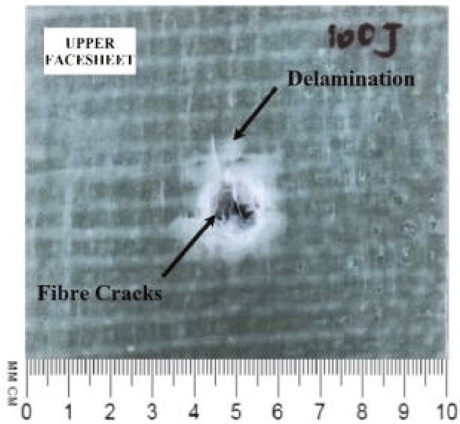
(g)



(h)



(i)



(j)

Figure 6: Damaged specimens after low velocity impact testing with energy levels of a) 20J - upper facesheet, b) 20J - lower facesheet c) 40J - upper facesheet, d) 40J - lower facesheet e) 60J - upper facesheet J, f) 60J - lower facesheet g) 80J- upper facesheet, h) 80J - lower facesheet i) 100J - upper facesheet j) 100J - lower facesheet

4. Conclusion

In this paper, the impact behaviour of sandwich composite material consisted of E-glass fibre-reinforced polymer facesheets and PVC foam core was investigated experimentally. Sandwich composites were fabricated by vacuum assisted resin infusion molding method (VARIM). Impact characteristics such as contact force-time, contact force-displacement, contact force-energy curves were drawn. According to different energy levels, the impactor caused damage in the upper facesheets only, in the lower facesheets or stopped in the core materials. The differences between the effects of different energy levels were observed. It was seen that the impact damage area increased with the increment of impact energy level. In the small energy configurations, the matrix and small fibre cracks occurred, whilst the damages could be seen clearly in the test configurations with higher energy levels.

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