INVESTIGATION OF THE IMPACT PROPERTIES OF GLASS FIBRE/HMPP FIBRE HYBRID COMPOSITE MATERIALS FOR CIVIL INFRASTRUCTURE CONSTRUCTIONS

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1 Introduction

Threats to civil infrastructure from explosions and earthquakes are becoming an increasingly frequent global reality. Preventative measures are required in order to protect structural members and reduce the likelihood of catastrophic failure of load bearing members such as beams, pillars and columns, avoid human casualties. Consequently, there is now a need to consider these threats when designing new buildings and consider retrofitting venerable buildings with blast resistant materials. For this reason, numerous researchers are developing high-energy absorbing, lightweight and strong materials for civil infrastructure retrofitting and new constructions.

Advanced fibre composites which were primarily developed for defense and aerospace industries have made inroads into fast growing and high volume civil infrastructure industry nearly a decade ago There are traditional para-aramid synthetic fibres such as Kevlar which are significantly expensive for the use of civil infrastructure construction. The recent development of less expensive, high modulus synthetic fibre has opened a new path for the development of cheaper, high performance, impact resistant composites which are affordable for civil infrastructure development. The focus of this project is the study of lower cost, high-energy absorbent continuous fiber laminates, and in particular, high modulus polypropylene (HMPP) fibers. Innegra™ S is the commercial name used by Innegrity for its HMPP fiber. The combination of low density/weight, high toughness and rapid manufacturability make this material a cost effective solution for impact resistant fiber composite applications where carbon or aramid fibers are traditionally used [1]

2 Theoritical background of Impact energy absorption in composites

The response of a laminated composite to an impact object depends on the impact parameters of the impactor and the material properties of the composite materials such as stacking sequence, inter-laminar shear strength, tensile and ¯ flexural properties of the composites. When an object impacted on the laminates, the impact energy was absorbed by the composite and damage such as delamination, fibre breakage, and matrix crack occurs. The delamination is the dominant energy absorption process under low-energy impact situation whereas the large deformation dominates the energy absorption under high-energy impact for ductile fibre composites [2-6].

When an impactor strikes a surface of composite component, the impact energy released by the impactor is transferred in to two quantities. One is the elastic energy, which stored elastically in the specimen and transferred back to the impactor. The other part is the absorbed energy that is the sum of absorbed energy in the component by its damage initiation and propagation, and the energy absorbed by the impact system in vibration, heat and inelastic behavior of the impactor or supports. As such the total energy by the impactor is equal to the energy absorbed by the component and the energy released back to the impactor.

Due to brittle nature of most composite material when a certain stress level is exceeded due to an impact a permanent local damage will results in affected area [2,3,4].

The compression stress $\boldsymbol{\sigma_C}$.after an impact of mass $\boldsymbol{m}$ at velocity $\boldsymbol{V}$ can be calculated as [2, 3];

$$\boldsymbol{\sigma_C}.= \boldsymbol{V}(\boldsymbol{E_{cr}\rho})^{0.5}$$

where $\boldsymbol{E_{cr}}$ is the transverse compression module and the $\boldsymbol{\rho}$ is the density.

$$\text{Impact energy} = ½\, mV^2$$

Since the indentation due to an impact closely follows Hertz contact law the contact force ***P*** due to an impact can be related as [2,3]:

$$P = k\alpha^{3/2}$$

Where ***k*** is the contact stiffness and ***α*** is the indentation. Following the analysis, the energy absorbed during the indentation ***U*** can be expressed as [2];

$$U = \frac{2}{5} k\alpha_{\max}^{\frac{3}{2}}$$

3. Experimentation and Preliminary Results

3.1 Experimentation

The specimens were made from HMPP material, Colan ANG150 and ANG410. The Glass fabrics, Colan MU410 and AR106 WC were used together with ANG for hybrid materials. Rectangular flat samples 150 mm long in 6 different lay-up configurations were prepared (Table 1, 2 and 3). The materials for hybrid samples were uni-axial and woven cloth. These layers were placed in the middle and offset from the middle layer to evaluate its contribution in impact energy absorption. KINETIX R246TX epoxy resin with KINETIX H160 Hardener sourced from ATL Composites Australia was used to manufacture specimens. All the material samples were cured in an oven at 80 C for 6 hrs.

The drop weight impact tests were performed on INSTRON 8200 and the mechanical tests were done on a 100 kN MTS servo-hydraulic testing machine. Testing was performed in accordance with ASTM D6110 and D3039.

3.2 Preliminary Results

Post-processed preliminary results are shown in Tables 4, 5 and 6. The Fig 1shows the percentage of energy absorbed by each specimen type during the impact. Figures 2 -6 shows the recorded energy absorption and the force exerted on the specimen. Figures 7 to 10 shows the impact damage caused to some selected specimen.

4. Discussion of Results Conclusion

Table 4 and 5 depict mechanical properties and impact energy absorption of tested HMPP and HMPP/Glass Hybrid materials respectively. Also Fig 1 shows percentage of energy absorption per thickness of material for each layup. It is clearly shown that the materials HMPP_410_GO, Gl/HMPP_410_2 and Gl/HMPP_150_2 have shown significantly improved mechanical and impact energy absorption properties. This can be attributed to the location of the glass fibre layer. The specimens with middle glass fibre layer significantly improved the impact resistance but specimens with offset glass fibre layers substantially improved contact forces, as shown in Table 6 However, the majority of hybrid materials tested have shown improved mechanical and impact energy absorption properties. The figure 1, depicts the percentage of energy absorption by each specimen. It is clear that the specimens with offset fibre layers have shown substantial improvements in impact energy absorption. However, the specimens of plain weave HMPP material have also shown the comparable energy absorption properties, but their mechanical properties are significantly low.

Further as depicted in Figures 2 and 3, the addition of uni-axial fibre layer has not improved the resistant force. However the deflection was significantly less than HMPP410 samples. Figures 3 to 6 also show the significant improvement of stiffness while maintaining the improved energy absorption properties by addition of glass layers. However, addition of woven cloth has not improved the energy absorption of the hybrid materials. Figures 7 to 9 shows the failure modes of HMPP samples and a hybrid sample. The HMPP samples show more delamination due to low velocity impact and the hybrid sample evidently depicts the combination of brittle matrix/fibre crack and the delamination at the failure stage.

5. Conclusion

Hybrid composite materials of Glass/HMPP with Epoxy resins have been experimentally investigated for their mechanical and impact energy absorption properties. It has been found that hybrid specimens have shown significant improvement in mechanical and impact energy absorption properties. More testing regimes are warranted for the investigation of the effects of the layup configuration and the volume fraction of HMPP for energy absorption and impact properties of the hybrid laminates. It is clear that the laminates that have glass fibres at offset locations to the center have shown significant improvements in impact energy absorption capacity.

References

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Product	Fiber Type	Yarn	Weight g/m2
ANG150 (Colan)	HMPP	Plain Weave	150
ANG410 (Colan)	HMPP	4 shaft Satin weave	135
MU4500 (Colan)	E-Glass Uni	WARP	480
AR106 (Colan)	E-Glass Woven	Plain Weave	630

Table 1. Details of specimen materials

Panel Name	Material(s)	Lay-up
HMPP150	A	[0/0/45/45/0]s
HMPP410	AA	[0/0/45/45/0]s
Gl/HMPP_150_1	A(a) /U (g)	[0a/0a/0a/0g]s
Gl/HMPP_150_2	A (a)/U(g)	[0a/0a/0g/0a]s
Gl/HMPP_410_1	AA(a) /U (g)	[0a/0a/0a/0g]s
Gl/HMPP_410_2	AA(a) /U (g)	[0a/0a/0g/0a]s
Gl/HMPP_GO	AA (a)/WC (g)	[0a/0a/0g/0a]s
Gl/HMPP_GC	AA(a) /WC(g)	[0a/0a/0a/0g]s

Table 2. Material configurations

Panel Name	Average thickness (mm)
HMPP150	2.39
HMPP410	2.77
Gl/HMPP_150_1	3.56
Gl/HMPP_150_2	3.44
Gl/HMPP_410_1	2.86
Gl/HMPP_410_2	2.92
Gl/HMPP_GO	2.64
Gl/HMPP_GC	2.65

Table 3. Thickness of specimens

U- Uni-axial (MU410) WC- Glass WC (AR106) A-ANG150 AA-ANG 410

Panel Name	Elastic Modulus GPa	Poisson's Ratio	Strength MPa
HMPP150	1.6	0.388	98.5
HMPP410	2.7	0.326	84.5
Gl/HMPP_150_1	10.5	0.23	260.0
Gl/HMPP_150_2	10.3	0.255	236.3
Gl/HMPP_410_1	12.9	0.242	247.7
Gl/HMPP_410_2	12.2	0.267	291.0
Gl/HMPP_410_GO	9.1	0.189	136.2
Gl/HMPP_410_GC	8.8	0.164	144.0

Table 4. Mechanical properties of the materials

Panel Name	Total Energy/thick (J/mm)	Energy @Failure/thick (J/mm)
HMPP150*	3.55	3.33
HMPP410 **	1.51	1.40
Gl/HMPP_150_1***	2.42	2.26
Gl/HMPP_150_2 ***	4.52	4.36
Gl/HMPP_410_1***	3.88	3.88
Gl/HMPP_410_2***	6.74	6.49
Gl/HMPP_410_GO$^{\#}$	3.95	3.94
Gl/HMPP_410_GC$^{\#}$	3.0	2.92

Table 5. Impact energy of materials

Impact Energy - *20.9J **12.6J * 32.5J # 19J**

Panel Name	Average Max. Load (N)
HMPP150	159
HMPP410	430
Gl/HMPP_150_1	383
Gl/HMPP_150_2	657
Gl/HMPP_410_1	672
Gl/HMPP_410_2	732
Gl/HMPP_GO	478
Gl/HMPP_GC	281

Table 6. Thickness of specimens

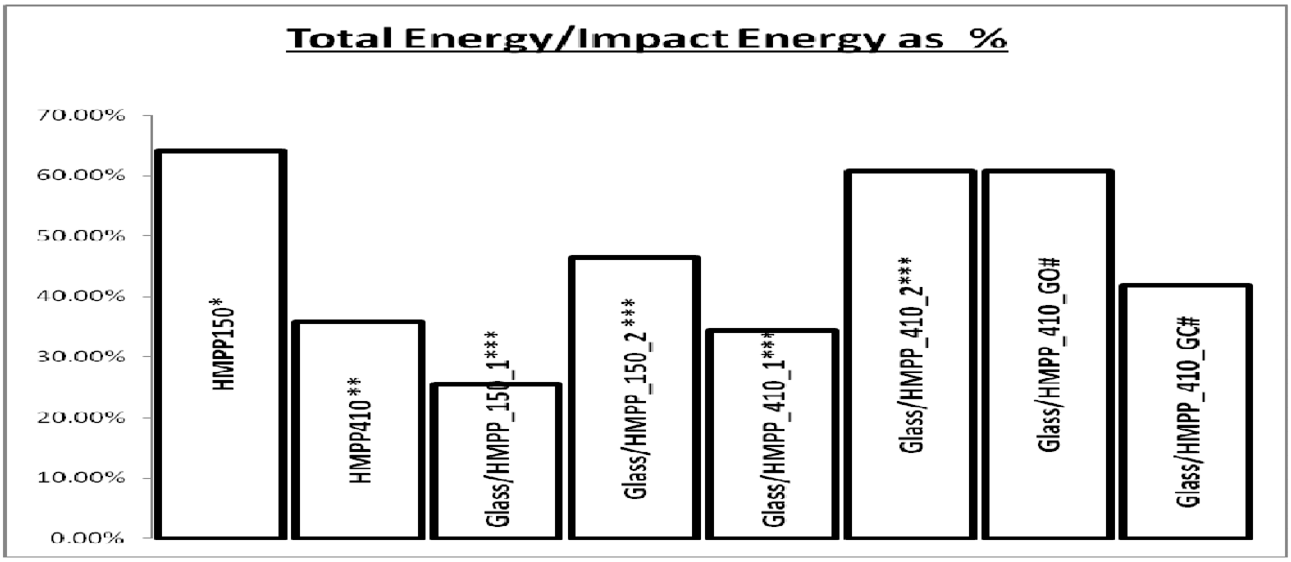

Figure 1 Percentage of total Energy to impact energy (Impact Energy - *20.9J **12.6J *** 32.5J # 19J)

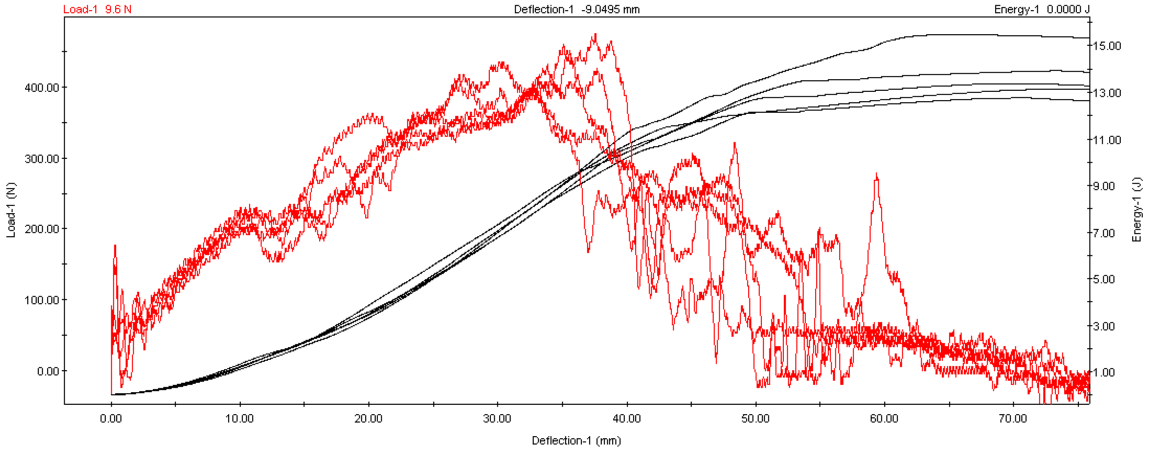

Figure 2. The contact force and the energy absorption of HMPP410 specimens with deflection.

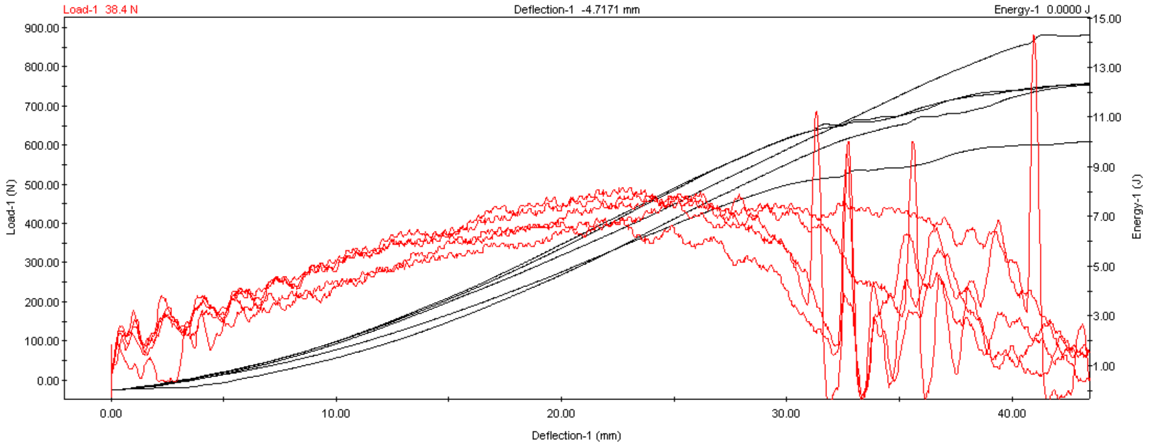

Figure 3. The contact force and the energy absorption of Gl/HMPP410-1 specimens with deflection.

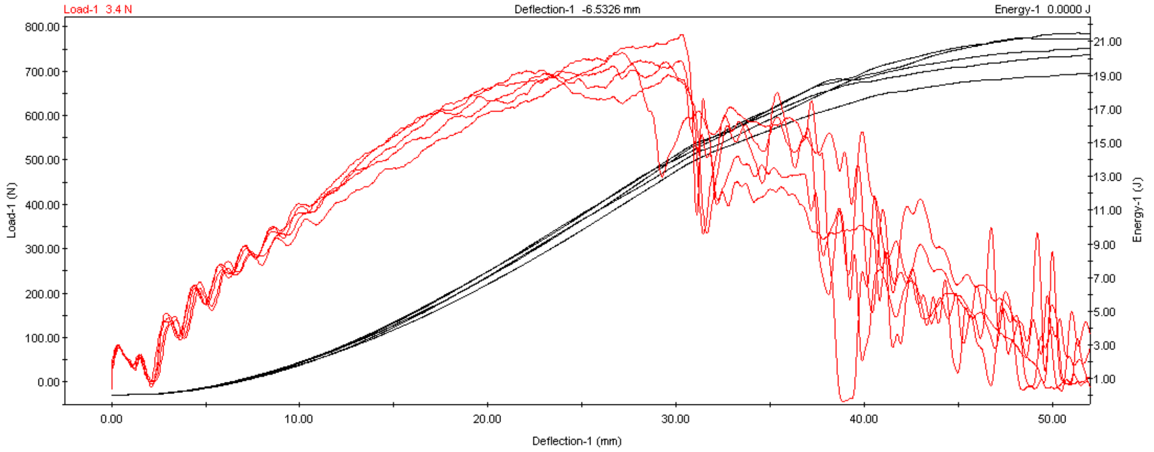

Figure 4. The contact force and the energy absorption of Gl/HMPP410-2 specimens with deflection.

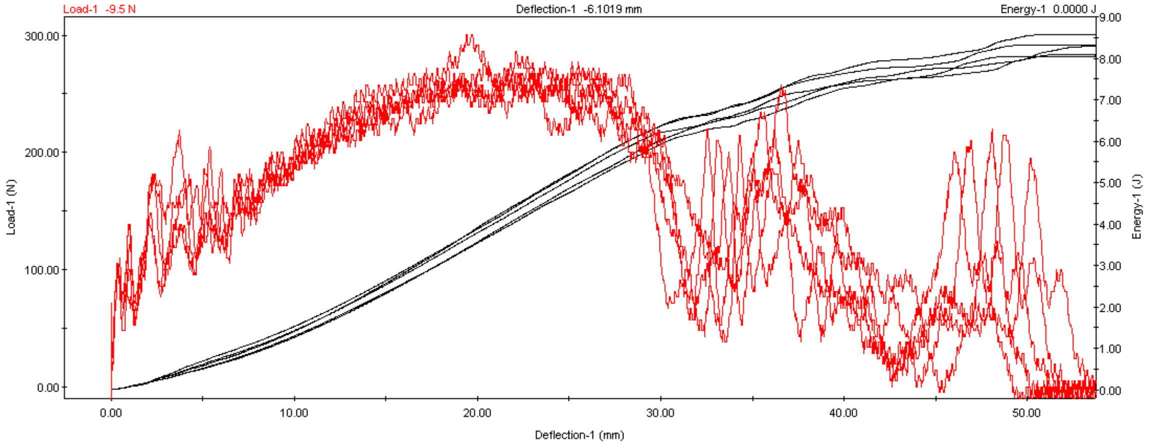

Figure 5. The contact force and the energy absorption of Gl/HMPP_GC specimens with deflection.

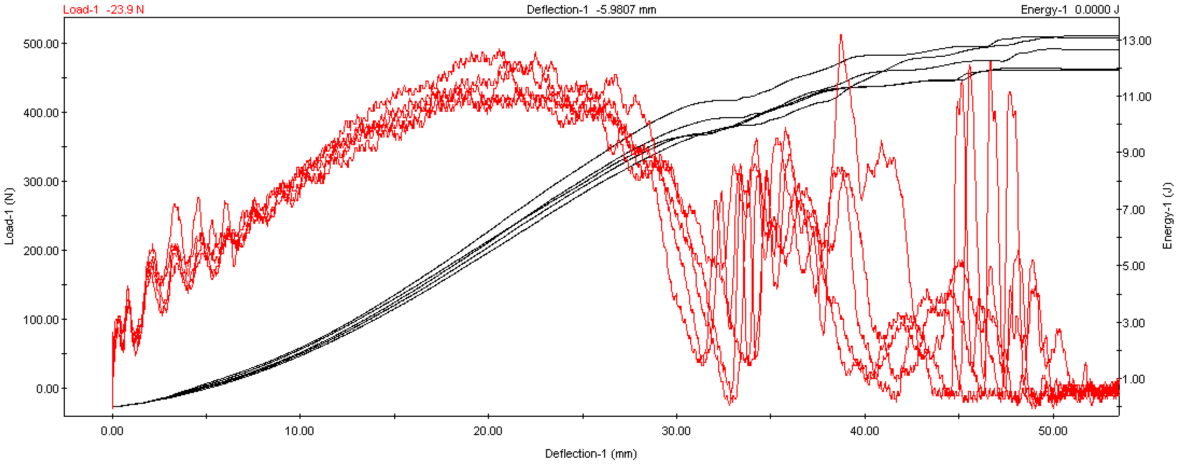

Figure 6. The contact force and the energy absorption of Gl/HMPP_GO specimens with deflection.

Figure 7. Impact damage of a HMPP 150 specimen.

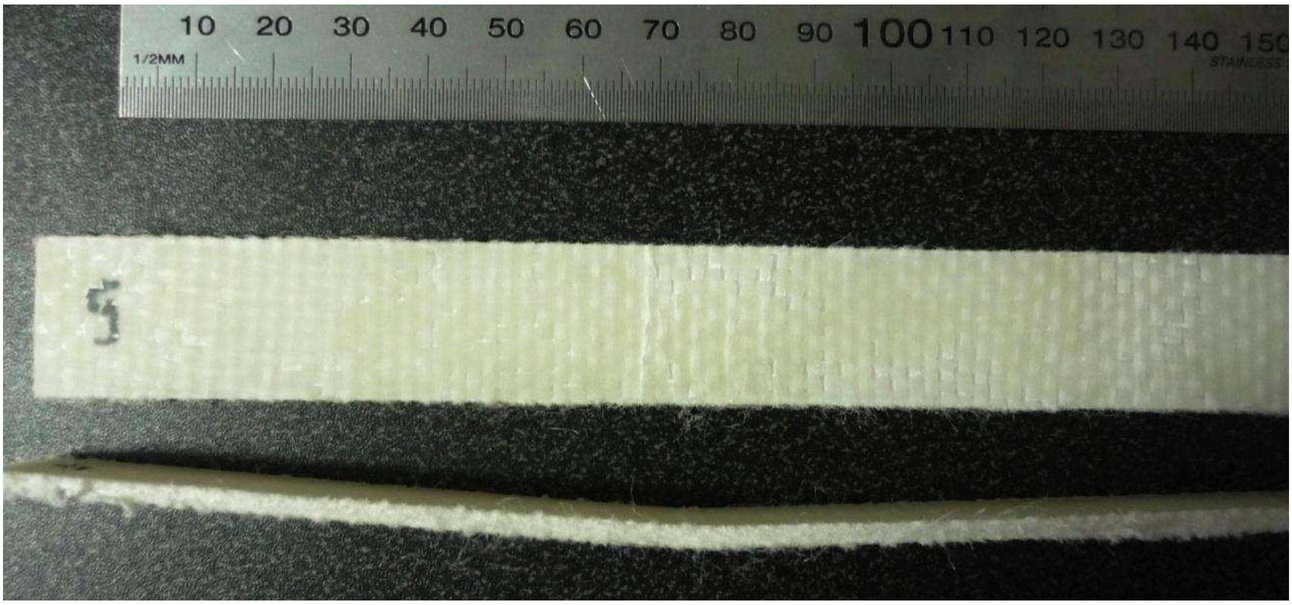

Figure 8. Impact damage of a HMPP 410 specimen.

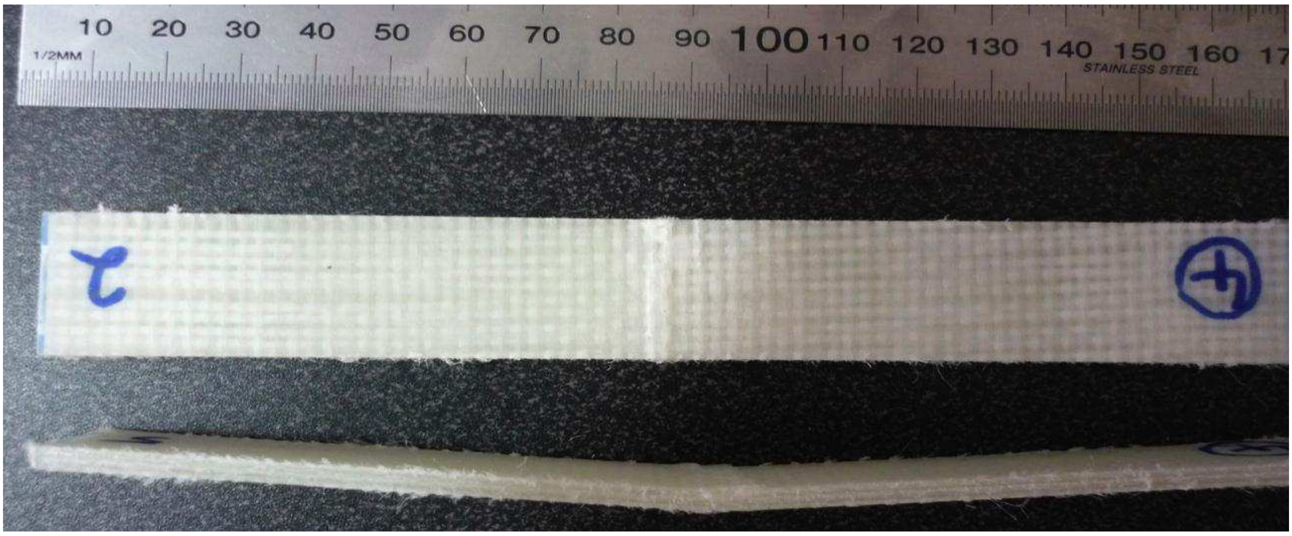

Figure 9. Impact damage of a Gl/HMPP 410-2 specimen.