

# Chapter 4

## Results and Discussion

### Compression After Impact Experiment

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#### 4.1 Introduction

Tests to determine Compression after Impact (CAI) strength of composite laminates are carried out. The specimens of composite laminates with two configurations are used for performing the CAI tests:

- $[0/40/-45/90/90/-45/45/0]_{2s}$ , Glassfiber Angleply Laminate (GAL)
- $[0]_{24}$ , Glass Fiber reinforced epoxy Laminate (GFL).

The specimens were first impacted with 12 J (approximately) with the help of the airgun setup described in Chapter 2. Then the impacted panels were subjected to compression test.

#### 4.2 Impact Test

The specimens were impacted in controlled conditions, with the help of an airgun setup described earlier. The striker bar used in these experiments was made of aluminium; length of striker used was 15.5 mm(approximately), shown in

Fig. 2.4; its diameter was 12.6 mm (approximately) and its mass varied between 4.7 gm and 5.0 gm.

The specimen was first clamped in between the rear mount plate and the front mount plate. The gas chamber was then filled with compressed air and released with the help of the solenoid valve. The striker was accelerated in the gun barrel and impacted the specimen. Velocity of the striker was measured with the help of a laser torch and oscilloscope as described in Chapter 2. Details of impact test (impactor mass, impact velocity and impact energy) on the specimens are given in Table 4.1 and Table 4.2. Each specimen was impacted with 12 J (approximately).

### 4.3 Compression Test

The impacted specimens were prepared for compression test as described in Chapter 2. They were then clamped along with buckling the guides between the jaws of the MTS to find their compressive strength. The strain gauges, attached on both sides of the specimen, were connected to virtual instrumentation. The specimen was then compressed under displacement controlled mode with the loading rate of 4 mm/min. The load was applied till the specimen failed completely, i.e. upto the moment the specimen was unable to bear any load. The data obtained was then plotted using GNUPLOT. The GFL specimen (F1) after compression failure is shown in Fig. 4.1(b) and its stress-strain plot is shown in Fig. 4.1 (a). The dimensions of the specimen were 100 mm  $\times$  150 mm and strain gauges were attached at the positions described in Fig. 2.13 In Fig. 4.1(b) only one strain gauge can be seen; other strain gauge is aligned with the first but at the reverse side of the specimen. Four end tabs, as shown in the Fig. 4.1(b), are of dimension 100 mm  $\times$  60 mm; they are attached to the specimen for its proper gripping in the jaws of MTS. The area enclosed by blue pen shows the damage area due to impact and the damage extending laterally being shown by area bounded between two green lines.

In the plot, shown in Fig. 4.1(a), the responses of both the strain gauges being same at the initial stage upto 42 MPa. Then the strain curves start deviating from each other showing that the specimen buckles in spite of using buckling guides. The deviation is due to the increase of buckling; the

magnitude of compressive stress of one side ( $\epsilon_1$ ) increases and decrease on the other side ( $\epsilon_2$ ). Infact, at high compressive stress of 66 MPa response of one of the strain gauge ( $\epsilon_2$ ) becomes tensile.

### 4.3.1 Criterion for Compressive Strength

In the plot, shown in Fig. 4.1(a), it is found that after a certain load, strain increases on one side and decreases on the other side due to buckling of the specimen. Some criterion should be chosen to evaluate the compressive strength of the specimens. To evaluate the compressive strength of the specimens a criterion is formulated in this study which is based on the fact that the difference between strains on two sides of a panel is equal to 20% of the average strain. Quantitavily, the criterion is:

$$\left[ \frac{\epsilon_2 - \epsilon_1}{\left( \frac{\epsilon_1 + \epsilon_2}{2} \right)} \right] = 0.2$$

The failure of specimen is taken at the point where it follows the above mentioned failure criterion and the compressive strength at that point is considered as the failure compressive strength.

### 4.3.2 Compressive Strength of GFL Panels

The failure of GFL specimens occurred in three distinct ways (Fig. 4.1 to 4.10). In the first type of failure the impacted damage area extended to both the side edges of the specimen. Specimens F1, F4, F5 and F7 failed through this kind of failure. In the second category of failure, the damage due to impact extended to only one side; Specimens F3, F6, F8, F9 and F10 lie in this category of failure. In the third category of failures, the failure during compression took place at a location which is slightly far away from the centre of the impact. Specimen F2 failed through this category.

According to the failure criterion, discussed in previous section, compressive strength of the specimen shown in Fig. 4.1 was 45.9 MPa. Compressive strength of other GFL specimens shown in Fig. 4.2 to Fig. 4.10 are given in Table 4.3. The average compressive strength of failure of GFL

specimens was 58.5 MPa.

### *4.3.3 Compressive Strength of GAL Panels*

The failure of GAL specimens occurred in two distinct ways. In first type of failure the damage area due to impact extended to both sides of the specimen, the specimens A1, A2, A3 and A4 lie in this category of failure. In second category of failure the damage due to impact extended to only one side; specimen A5 lie in this category of failure. These specimens can be seen in Fig. 4.11 to Fig. 4.15. The compressive strength of GAL specimens, after satisfying the failure criterion mentioned in previous section, is given in Table 4.4. The average compressive strength of failure of GAL specimens is 15.7 MPa.

### *4.3.4 Discussion*

From the results of both GFL and GAL specimens (given in tables 4.3 and 4.4), it is observed that in comparison to GAL specimen the GFL specimens possess much higher compression strength after impact. The average compressive strength of GFL specimen is 58.5 MPa which is 3.7 times higher than the compressive strength of GAL specimen. All panels of GFL and GAL were impacted with the impact energy close to 12 J and similar striker bar made of aluminium. The impact damage area in GFL and GAL panels is similar. However, the growth of damage area under compressive load shows that failure zone is wider in case of GAL. This suggests that delamination cracks in a laminate already nucleated by impact of a foreign body propagate more easily in angleply laminates. This matches with the finding of Kumar, P. and Rai, B. (1990) that replacement of the surface ply on each side of an angle plied Kavlur reinforced epoxy laminate with a balanced ply of fabric reduced the projected impact damage area. This might also explain that interlaminar cracks of GAL specimen reach the side edges of the specimen at much reduced load.

## 4.4 Closure

The compression after impact tests conducted on two type of specimens, glassfiber fabric laminate and glassfiber angleply laminate. It was found that compressive strength of glassfiber fabric laminate is 3.7 times the compressive strength of glassfiber angleply laminate as the average compressive strength of glassfiber fabric laminate specimens is 58.5 MPa and the average compressive strength of glassfiber angleply laminate specimen is 15.7 MPa. This means that the GFL specimens are better than the GAL specimens in CAI test.

**Table 4.1: Details of the Impact Test of GFL specimens**

Exp. No.	Striker Mass (gm)	Impact Velocity (m/s)	Impact Energy (J)
F1	4.7780	71.02	12.05
F2	4.8601	70.01	11.91
F3	4.8428	69.02	11.60
F4	4.8428	71.10	12.24
F5	4.8521	69.40	11.70
F6	4.8521	70.67	12.12
F7	4.8521	71.01	12.23
F8	4.8053	70.63	11.98
F9	4.8950	69.73	11.90
F10	4.8950	70.64	12.21

**Table 4.2: Details of the Impact Test of GAL specimens**

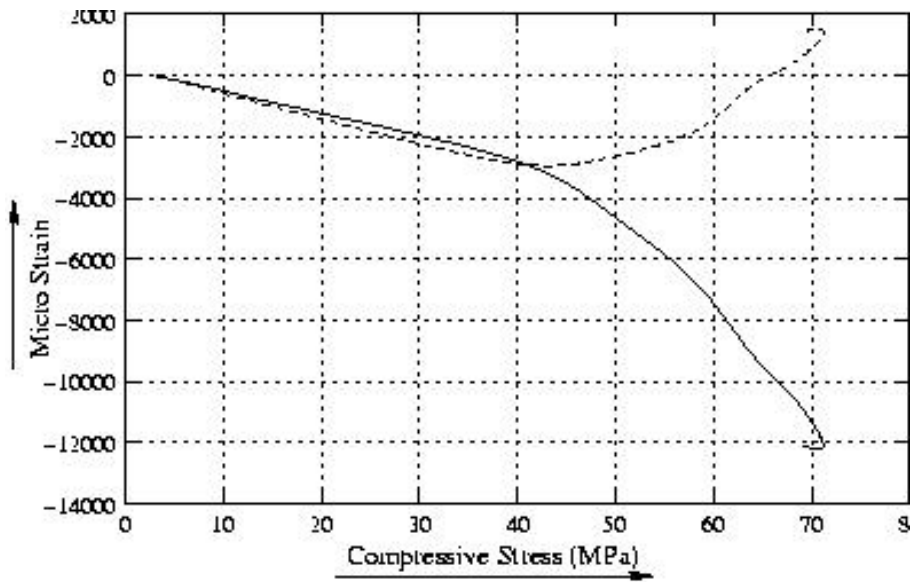
Exp. No.	Striker Mass (gm)	Impact Velocity (m/s)	Impact Energy (J)
A1	4.8950	70.01	12.11
A2	4.8950	69.73	11.90
A3	4.8601	70.00	11.91
A4	4.7780	71.02	12.06
A5	4.7846	70.36	11.84

**Table 4.3: Compressive Strength of GFL specimens at failure**

Exp. No.	Compressive Strength (MPa)	Average Compressive Strength (MPa)
F1	45.9	58.5 ± 19.1
F2	90.1	
F3	84.3	
F4	32.1	
F5	62.2	
F6	68.4	
F7	64.2	
F8	51.4	
F9	52.2	
F10	34.6	

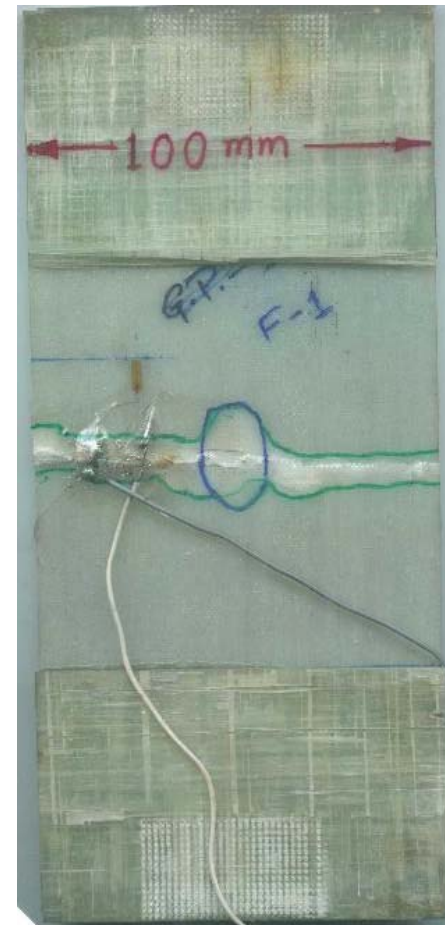
**Table 4.4: Compressive Strength of GAL specimens at failure**

Exp. No.	Compressive Strength (MPa)	Average Compressive Strength (MPa)
A1	14.2	15.7 ± 2.2
A2	15.3	
A3	17.3	
A4	13.2	
A5	18.6	

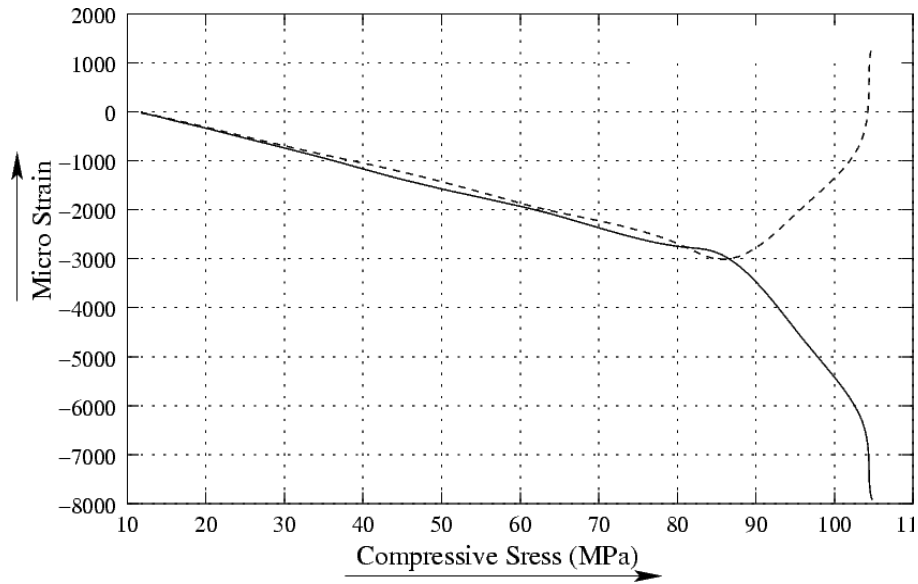


(a)

Fig. 4.1 GFL specimen (F1), with impact energy of 12.05 J;  
 (a) Stress vs. strain on front and rear strain gauges and  
 (b) Specimen after compression failure; damage area after impact is shown in blue and damage during compression is shown in green.

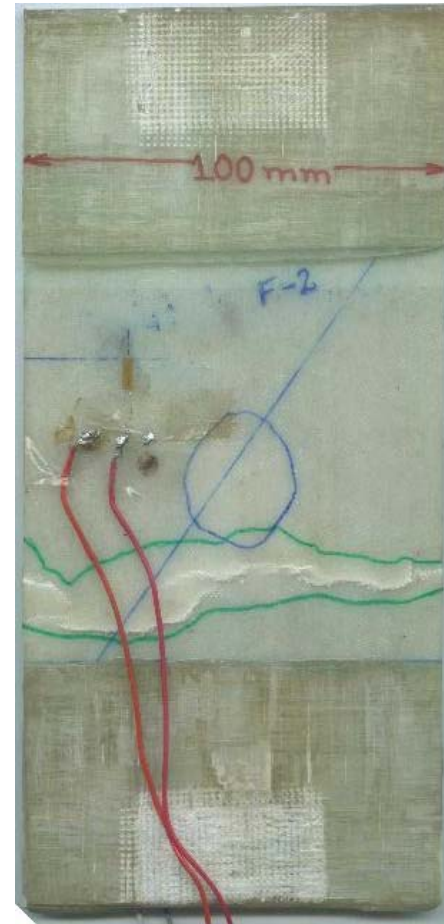


(b)

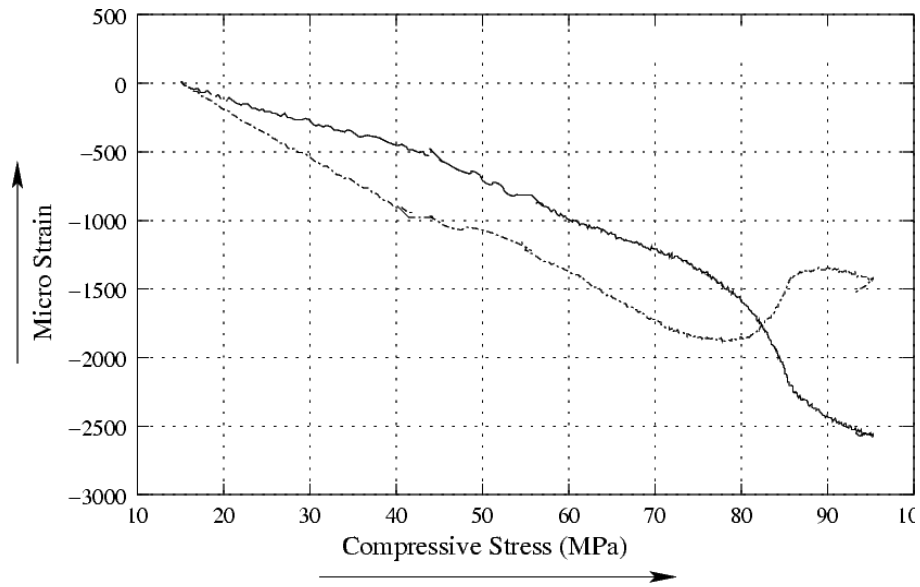


(a)

**Fig. 4.2 GFL specimen (F2), with impact energy of 11.91 J;**  
**(a) Stress vs. strain on front and rear strain gauges and**  
**(b) Specimen after compression failure; damage area**  
**after impact is shown in blue and damage during**  
**compression is shown in green.**

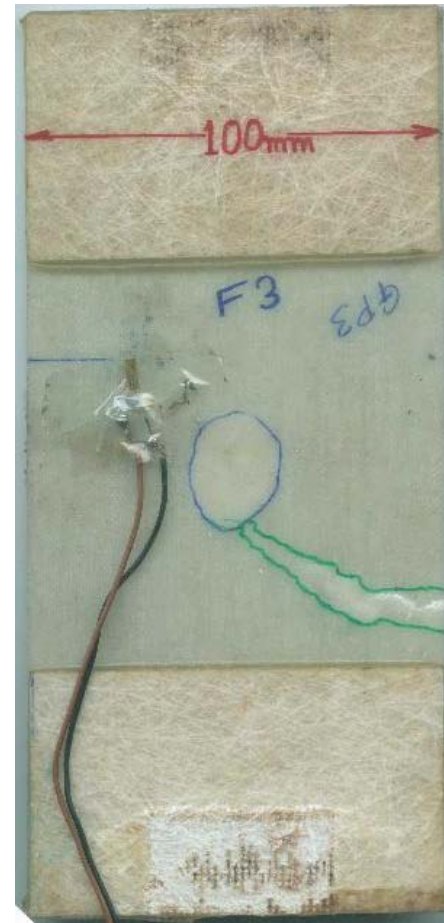


(b)

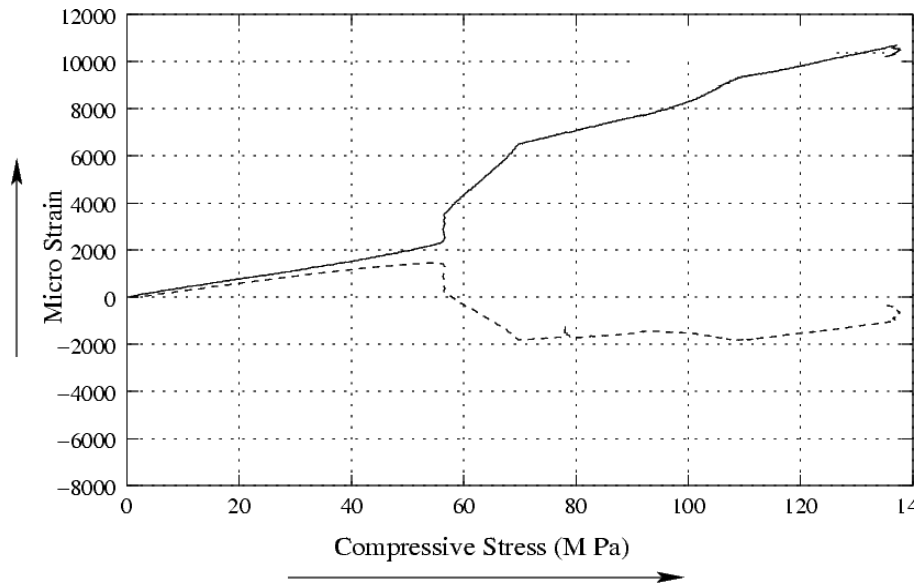


(a)

**Fig. 4.3 GFL specimen (F3), with impact energy of 11.60 J;**  
**(a) Stress vs. strain on front and rear strain gauges and**  
**(b) Specimen after compression failure; damage area**  
**after impact is shown in blue and damage during**  
**compression is shown in green.**

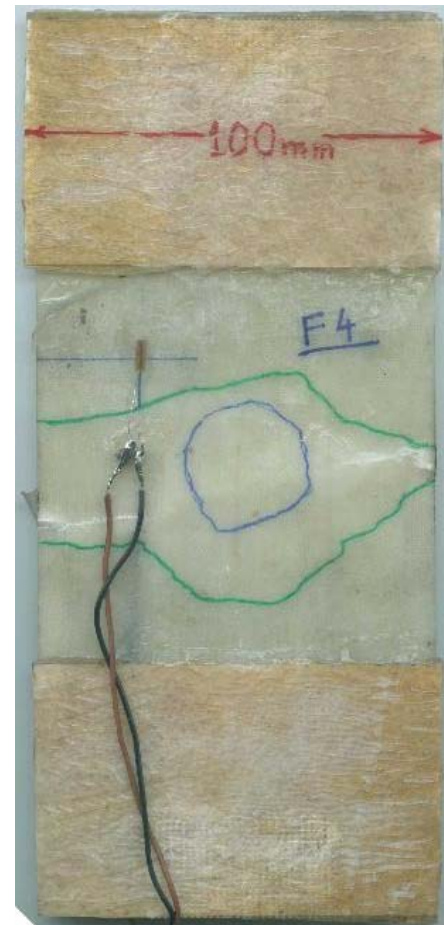


(b)

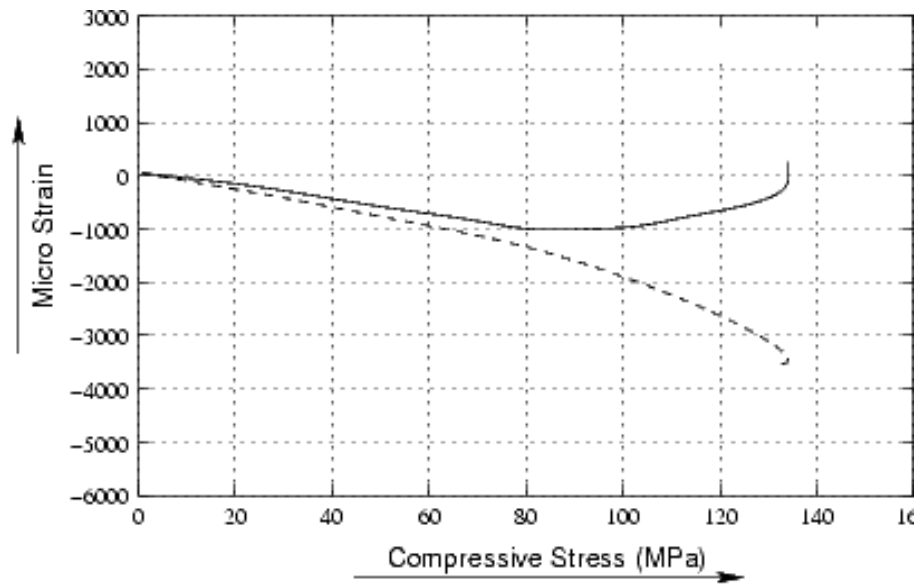


(a)

**Fig. 4.4 GFL specimen (F4), with impact energy of 12.24 J;  
 (a) Stress vs. strain on front and rear strain gauges and  
 (b) Specimen after compression failure; damage area  
 after impact is shown in blue and damage during  
 compression is shown in green.**

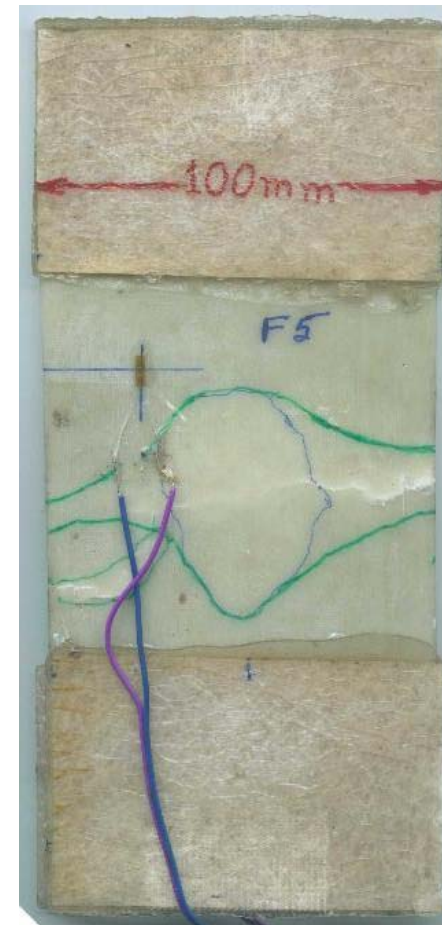


(b)

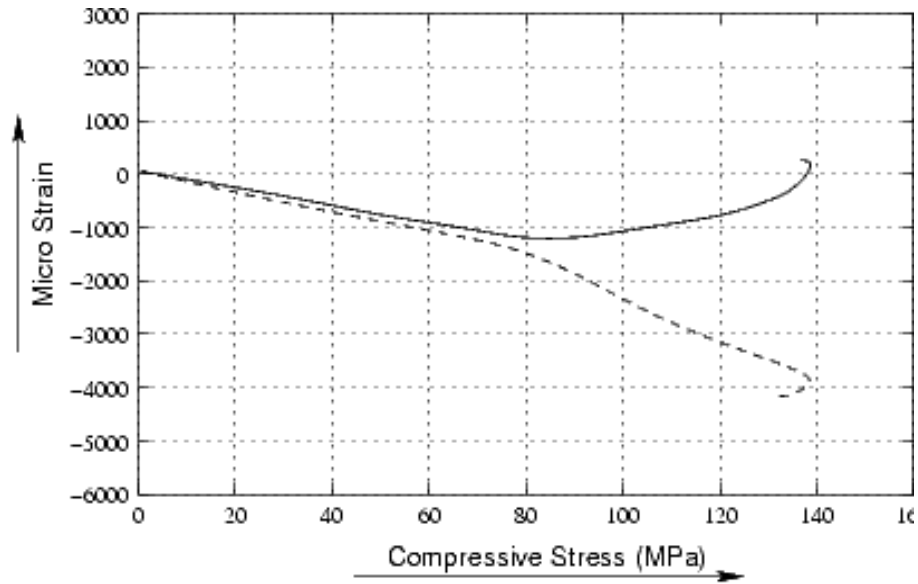


(a)

Fig. 4.5 GFL specimen (F5), with impact energy of 11.70 J;  
 (a) Stress vs. strain on front and rear strain gauges and  
 (b) Specimen after compression failure; damage area after impact is shown in blue and damage during compression is shown in green.

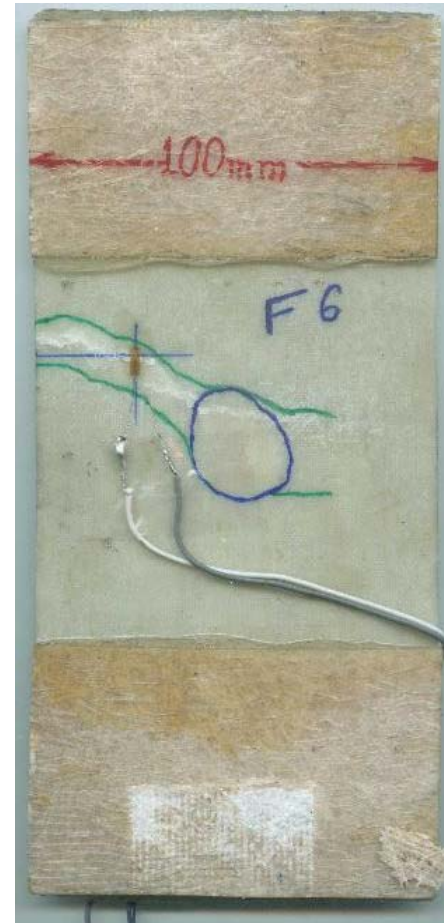


(b)

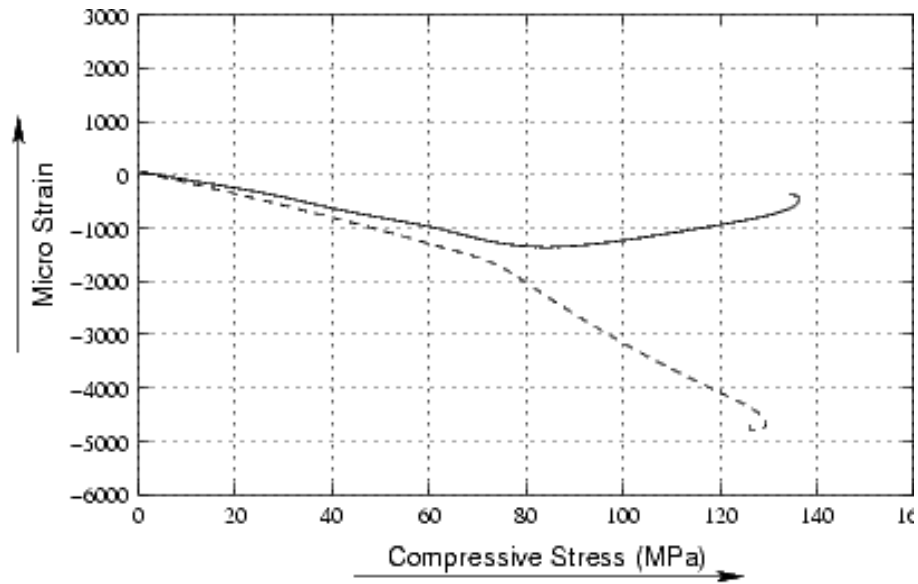


(a)

Fig. 4.6 GFL specimen (F6), with impact energy of 12.12 J;  
 (a) Stress vs. strain on front and rear strain gauges and  
 (b) Specimen after compression failure; damage area  
 after impact is shown in blue and damage during  
 compression is shown in green.

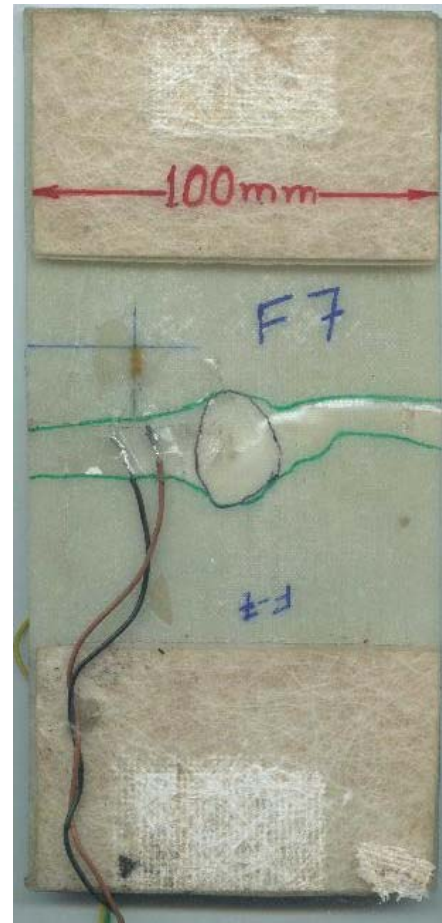


(b)

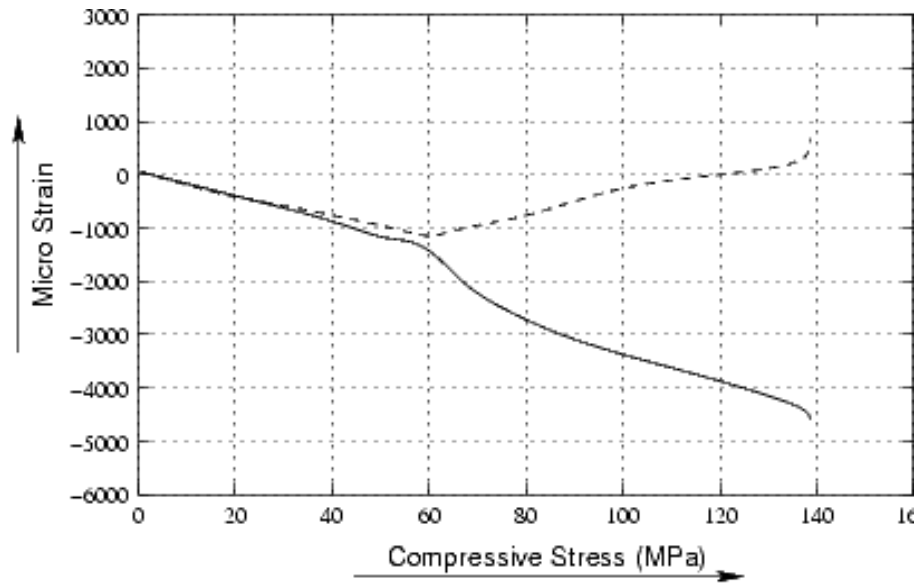


(a)

**Fig. 4.7 GFL specimen (F7), with impact energy of 12.23 J;  
 (a) Stress vs. strain on front and rear strain gauges and  
 (b) Specimen after compression failure; damage area  
 after impact is shown in blue and damage during  
 compression is shown in green.**

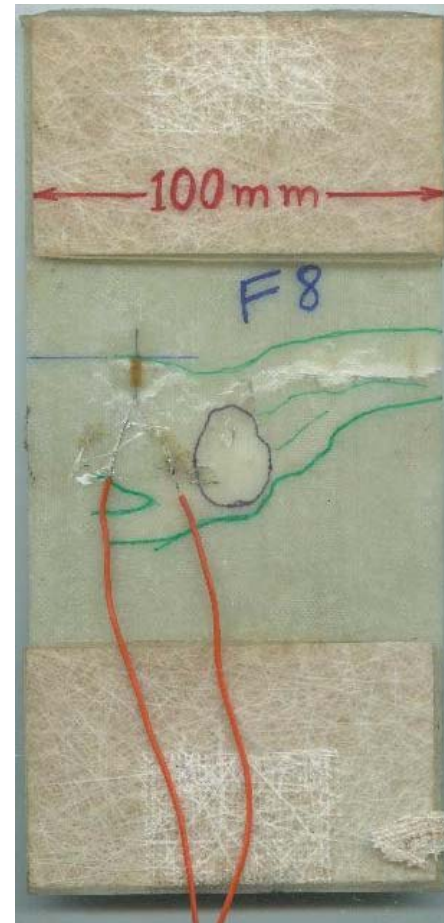


(b)

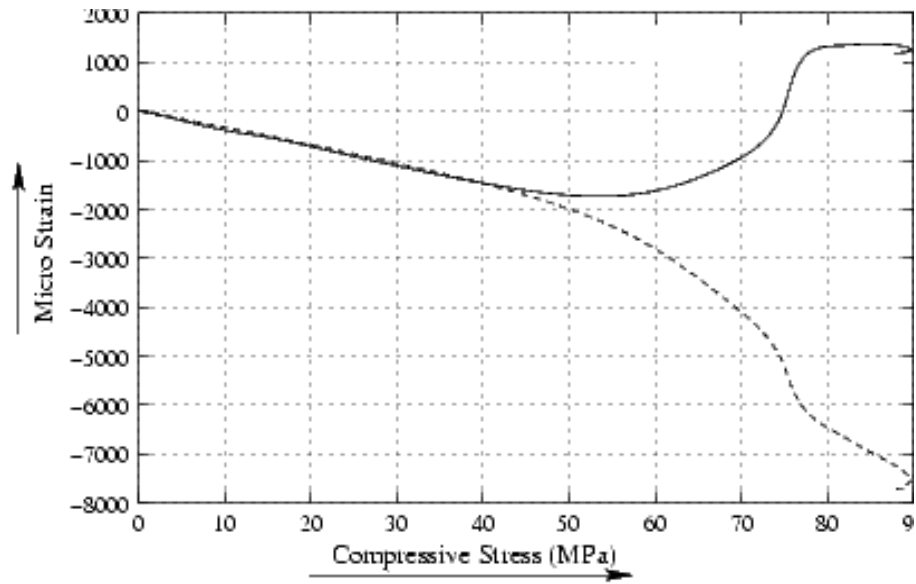


(a)

**Fig. 4.8 GFL specimen (F8), with impact energy of 11.98 J;**  
**(a) Stress vs. strain on front and rear strain gauges and**  
**(b) Specimen after compression failure; damage area**  
**after impact is shown in blue and damage during**  
**compression is shown in green.**

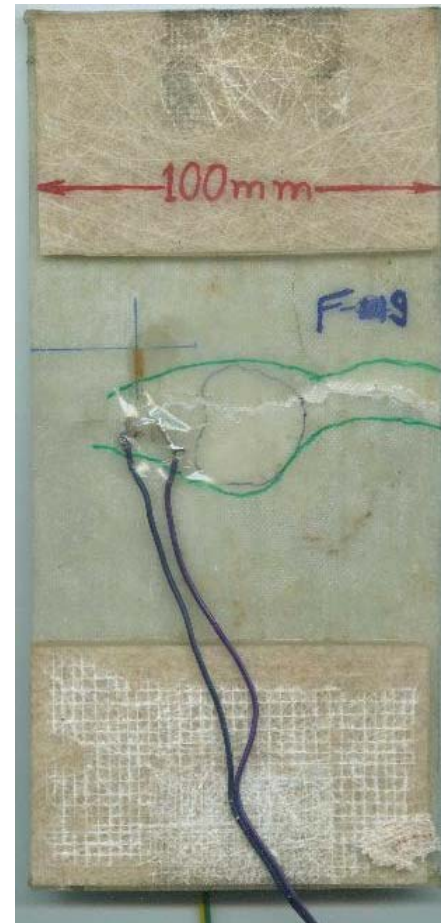


(b)

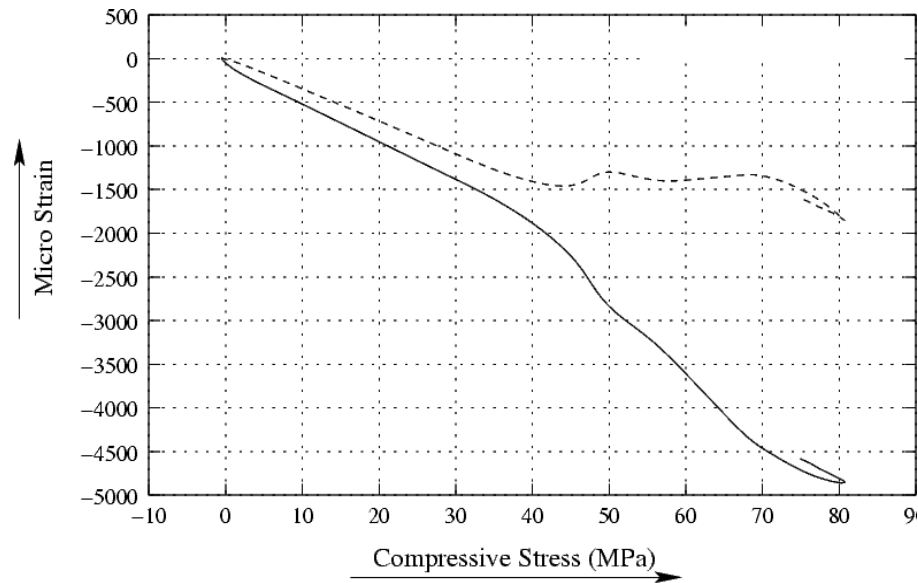


(a)

**Fig. 4.9 GFL specimen (F9), with impact energy of 11.90 J;**  
**(a) Stress vs. strain on front and rear strain gauges and**  
**(b) Specimen after compression failure; damage area**  
**after impact is shown in blue and damage during**  
**compression is shown in green.**

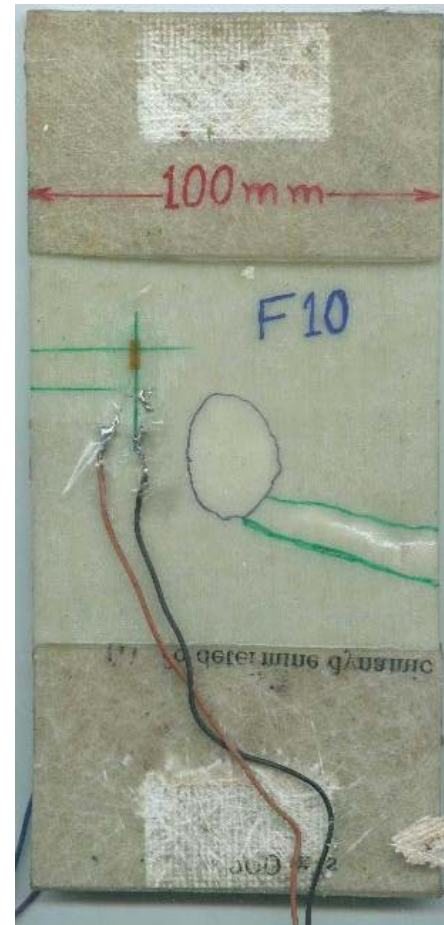


(b)

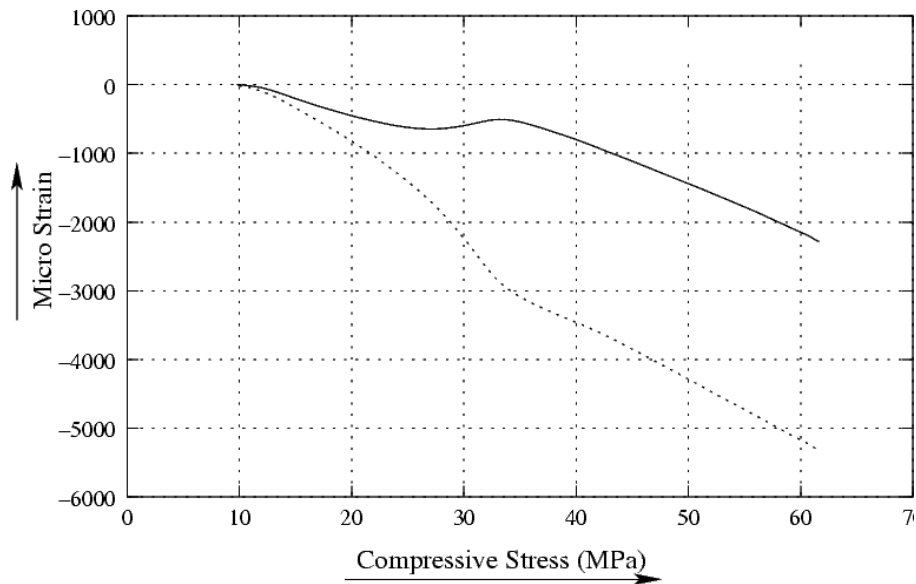


(a)

Fig. 4.10 GFL specimen (F10), with impact energy of 12.21 J;  
 (a) Stress vs. strain on front and rear strain gauges and  
 (b) Specimen after compression failure; damage area  
 after impact is shown in blue and damage during  
 compression is shown in green.

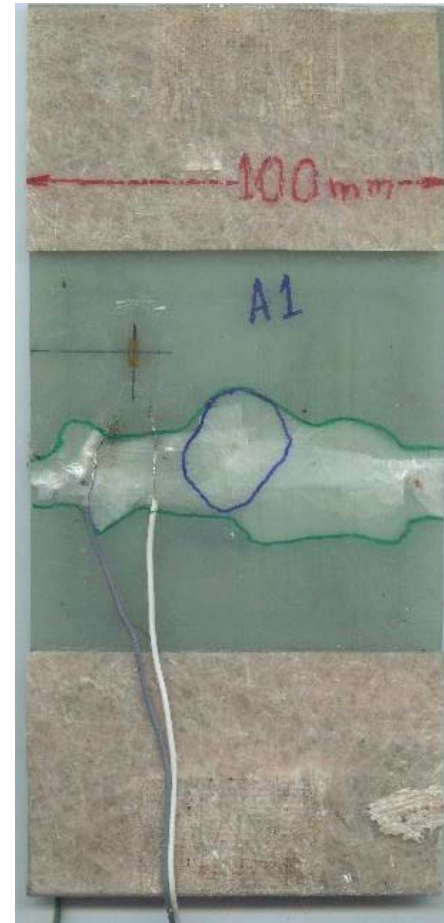


(b)

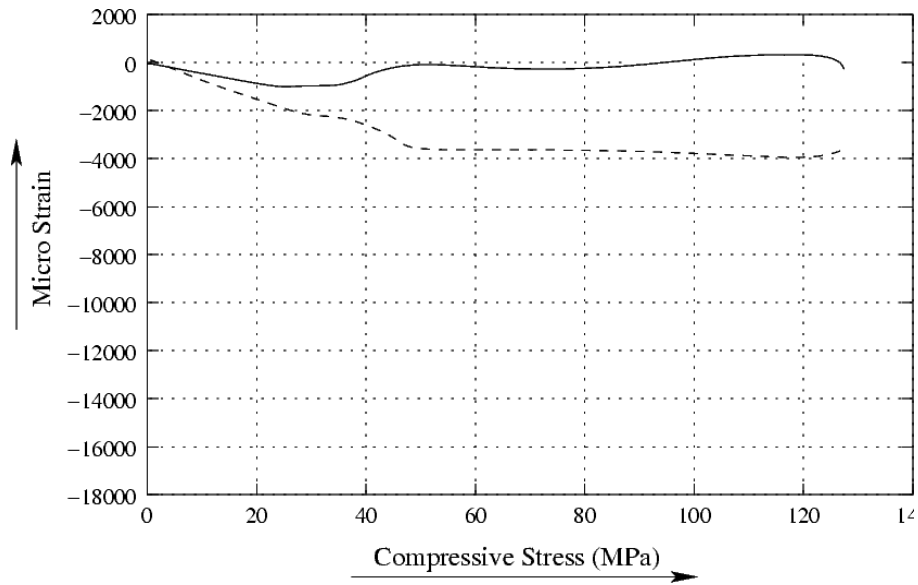


(a)

**Fig. 4.11 GAL specimen (A1), with impact energy of 12.11 J;**  
**(a) Stress vs. strain on front and rear strain gauges and**  
**(b) Specimen after compression failure; damage area**  
**after impact is shown in blue and damage during**  
**compression is shown in green.**

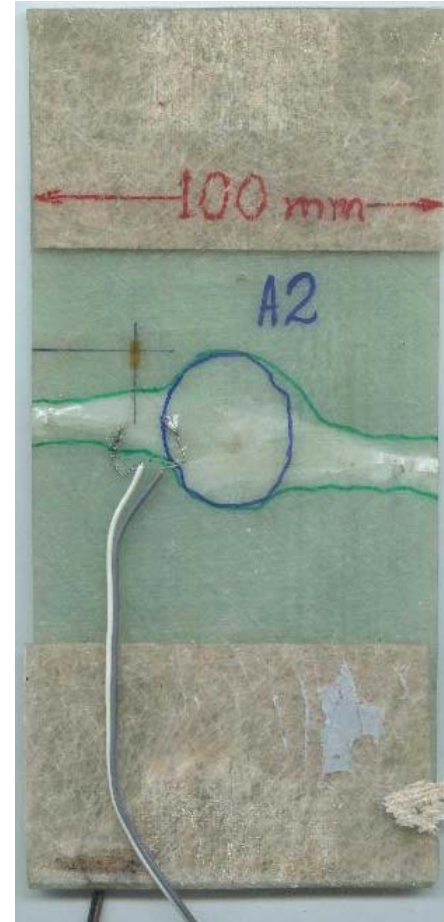


(b)

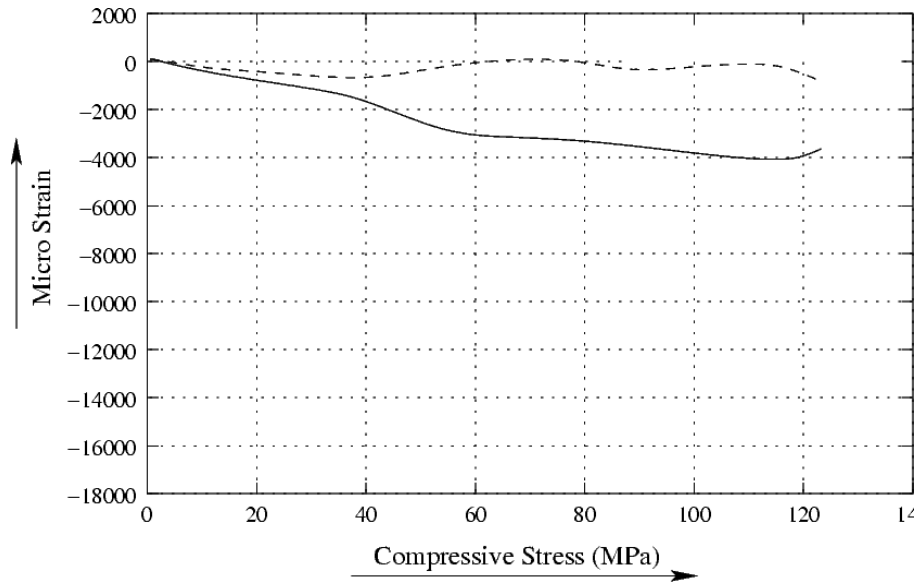


(a)

Fig. 4.12 GAL specimen (A2), with impact energy of 11.90 J;  
 (a) Stress vs. strain on front and rear strain gauges and  
 (b) Specimen after compression failure; damage area  
 after impact is shown in blue and damage during  
 compression is shown in green.

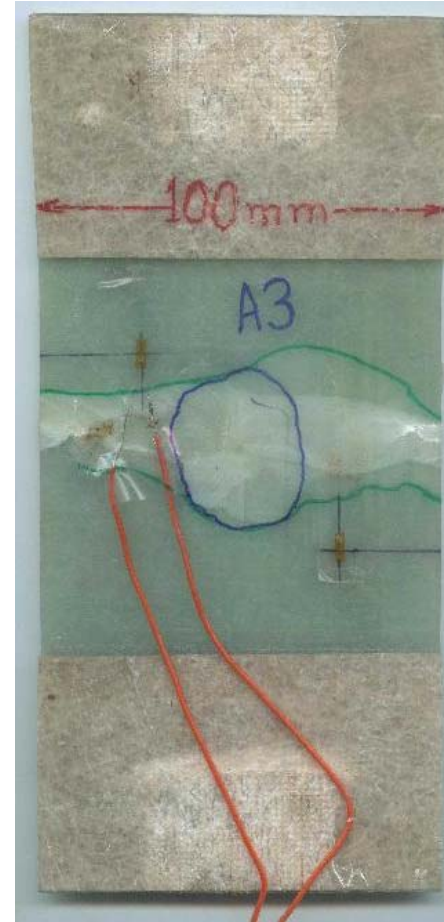


(b)

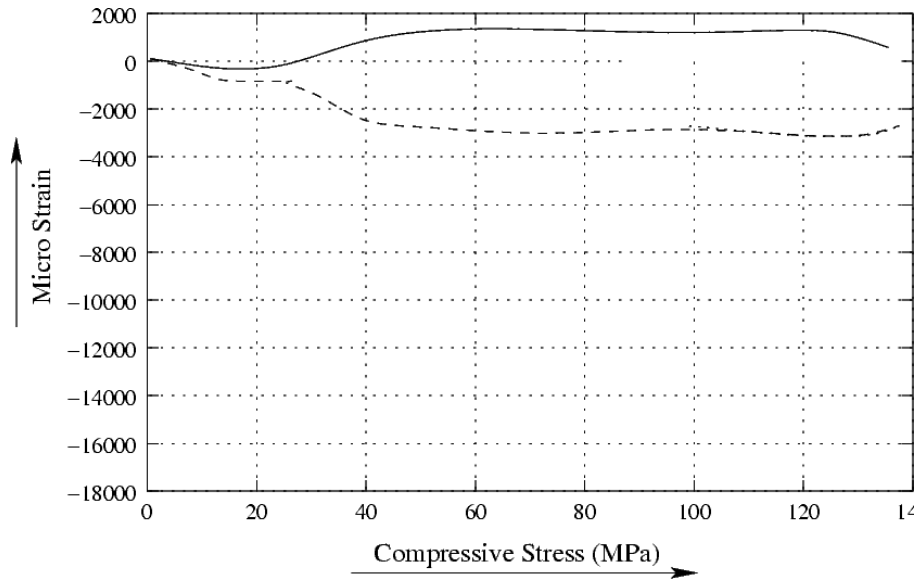


(a)

**Fig. 4.13 GAL specimen (A3), with impact energy of 11.91 J;  
 (a) Stress vs. strain on front and rear strain gauges and  
 (b) Specimen after compression failure; damage area  
 after impact is shown in blue and damage during  
 compression is shown in green.**

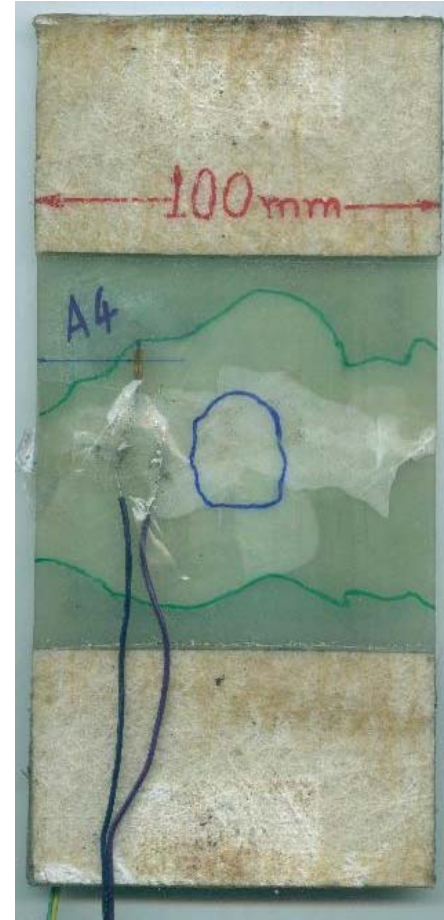


(b)

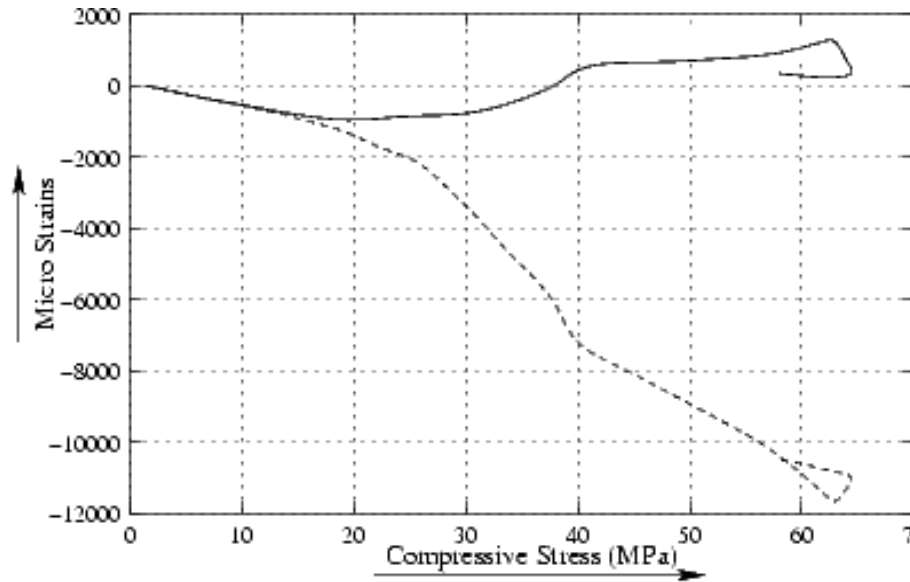


(a)

**Fig. 4.14 GAL specimen (A4), with impact energy of 12.06 J;  
 (a) Stress vs. strain on front and rear strain gauges and  
 (b) Specimen after compression failure; damage area  
 after impact is shown in blue and damage during  
 compression is shown in green.**

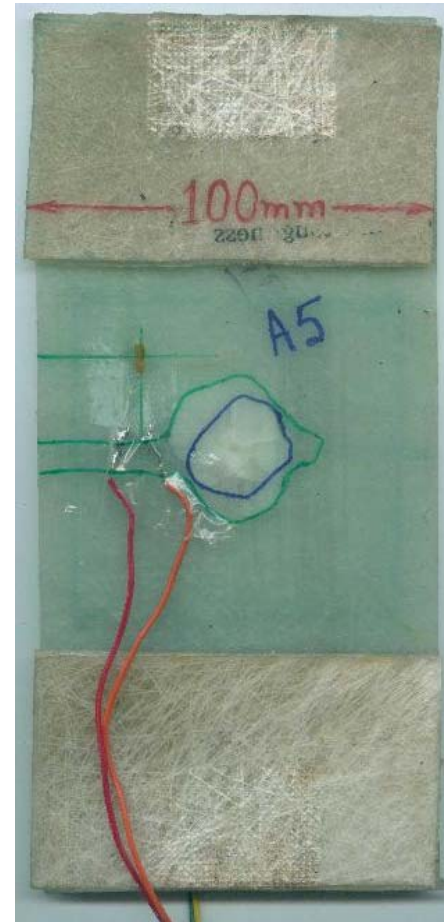


(b)



(a)

Fig. 4.15 GAL specimen (A5), with impact energy of 11.84 J;  
 (a) Stress vs. strain on front and rear strain gauges and  
 (b) Specimen after compression failure; damage area  
 after impact is shown in blue and damage during  
 compression is shown in green.



(b)

# Chapter 5

## Conclusions and Suggestions for Future Work

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### 5.1 Conclusions

The experimental setup is developed to perform the impact test and the compression test on panels for determination of compressive strength of the FRP panels after impact. An air gun setup is used to perform the impact test on the panels. Compressed air is used to accelerate the striker in the gun barrel; a solenoid valve is used to release the compressed air stored in the gas chamber. A laser torch mounted at the mouth of the gun barrel is used to evaluate the velocity of the striker bar with the help of the oscilloscope. The impacted panels were prepared for compression test. An anti-buckling guides are used to suppress the buckling of the specimen during compression.

CAI test was performed on two types of composite laminates. It was found that the compressive strength of impacted GFL specimens is more than three times of the compressive strength of impacted GAL specimens. Thus the GFL specimens are better in CAI tests than the GAL specimens.

To make a large FRP structure, T-joints are extensively used. It is therefore important to characterize the impact behaviour of T-joints. A specially designed T-pull specimen is employed for determining impact behaviour. A fixture for performing tension test after impact on T-pull specimen is designed,

fabricated and make functional. The T-pull specimens were supplied by NAL Bangalore. The developed T-pull test fixture is used to perform a test on the T-pull specimen; the preliminary results show that the developed experimental setup works well.

## 5.2 Future Scope

- Impact energy should be varied to determine the CAI strength.
- Compression after impact test can also perform on different configurations of angleply laminates.
- In order to see the effect on compressive strength after impact by runway debris, ceramic impactor can be used.

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