Bhoominathan et al. 2018. *Int. J. Vehicle Structures & Systems*, 10(1), 6-9
ISSN: 0975-3060 (Print), 0975-3540 (Online)
doi:10.4273/ijvss.10.1.02

International Journal of
Vehicle Structures & Systems
Available online at www.maftree.org/eja

Infra-Red Thermography based Inspection of Hybrid Composite Laminates under Flexure Loading

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ABSTRACT:

Generally, the aircraft structural parts are economically high in cost so the materials need to be inspected for defects or damages using various non-destructive testing (NDT) methods like ultrasonic, thermography and acoustic emission. The aim of this project is to characterize the defects in composite laminates before and after the flexural loading using infra-red thermography NDT method. GFRP and hybrid (GFRP+CFRP) composite laminates are fabricated with different orientation such as uni-directional, cross ply, anti-symmetric and angle ply and then tested under flexural loading according to ASTM D790 standard. The volume fraction of the fibre and matrix needs to be found out to know the void content and the mixing ratio of reinforcement and binder.

KEYWORDS:

Glass fibre reinforced plastic; Flexural test; Delamination; Infra-red thermography; Non-destructive testing

CITATION:

R. Bhoominathan, P. Divyabarathi, R. Manimegalai, T. Nithya and S. Shanmugapriya. 2018. Infra-Red Thermography based Inspection of Hybrid Composite Laminates under Flexure Loading, *Int. J. Vehicle Structures & Systems*, 10(1), 6-9. doi:10.4273/ijvss.10.1.02.

1. Introduction

The composite materials are widely used in a number of engineering sectors like aviation, automotive and space due to their better properties such as high strength to weight ratio and low thermal expansion. The fabrication of composites is a compound process. It requires instantaneous deliberation of different parameters such as component section geometry, production volume, reinforcement, matrix types, tooling requirements and process and market place economics. Armour is distinct as a defensive layer designed to present safety from a precise shape of attack. The armour can be classified depending upon the intended applications such as personal armour, light armour and aircraft armour [1]. Considerable researches [2-4] were reported in making the composite fabrics stronger and increased ballistic penetration resistance while still maintaining their flexibility (fit, form and function).

Non-destructive testing (NDT) methods such as ultrasonics, computer tomography, radiography and acoustic emission are widely used for inspection of carbon fibre reinforced plastic (CFRP) and glass fibre reinforced plastic (GFRP) laminates to quantify the defects such as voids, porosity and inclusions. NDT methods [5-6] are also used to characterise and study the delamination and crack propagations during destructive testing. In this paper, infra-red thermography (IRT) NDT method is used to characterise the defects (before test) and delamination regions (post test) for a number of flexural test composite specimens. The GFRP and hybrid (GFRP+CFRP) composite laminates are fabricated with different orientation such as uni-directional (UD), cross ply (CP), anti-symmetric (AS) and angle ply (AP). All the fabricated specimens are then tested under flexural loading according to ASTM D790 standard.

2. Experimental work and FEA

Glass fibre reinforced with epoxy resin is used to fabricate composite laminate specimens of unidirectional, cross ply, anti-symmetric, angle ply construction. Hybrid (glass and carbon fibre reinforced with epoxy) laminate specimen is also fabricated. The ratio of epoxy and fibre is maintained as 1:1 and the excess resin in the specimen was squeezed. All the specimens are cured at room temperature for 24 hours. The fibre volume fraction (FVF) of the CFRP and GFRP laminated specimens are given in Table 1. The specimens were trimmed according to ASTM D790 standards. The flexural test specimens are cut by using jig saw for 90mm×25mm×4mm and a photograph of all fabricated specimens is shown in Fig. 1. The flexural tests were carried out using a 3-point bending fixture on universal testing machine as shown in Fig. 2. The test is stopped when the specimen reaches 5% deflection or the specimen break before 5%.

Table 1: FVF of laminated composite specimens

Fibre orientation	W_f (g)	W_m (g)	V_f	V_m
UD CFRP	0.021	0.044	0.31	0.69
UD GFRP	0.345	0.394	0.434	0.565
AP GFRP	0.35	0.342	0.473	0.527
CP GFRP	0.33	0.336	0.462	0.538

Fig. 1: Fabricated specimens for flexure test and IRT inspection

Maximum fibre stress and maximum strain are calculated for increments of load. The flexure test results are plotted in a stress vs. strain diagrams in Fig. 3 to Fig. 7 for UD, CP, AP, AS GFRP and hybrid (CFRP+GFRP) CP specimens respectively. The AP GFRP specimen does not break and its strength is 216.705 N/mm^2 for the given load of 50 kN. Flexural strength is defined as the maximum stress in the outermost fibre. This is calculated at the surface of the specimen on the tension side. The calculated ultimate stress from the test results are given in Table 2. The results of experimental test are compared with the numerical analysis using ANSYS finite element analysis (FEA) software. The bending stress distributions across the specimen thickness from FEA are shown in Fig. 8 to Fig. 9 for UD and CP GFRP specimens respectively. The peak stress obtained for each specimen is presented in Table 2. The experimental results correlate well with the FEA predictions.

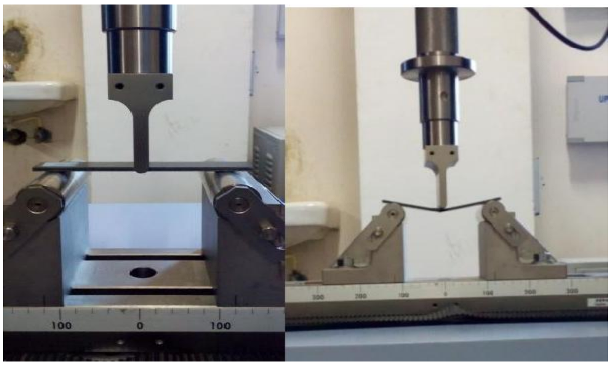

Fig. 2: 3-Point bending before (left) and after (right) flexure test

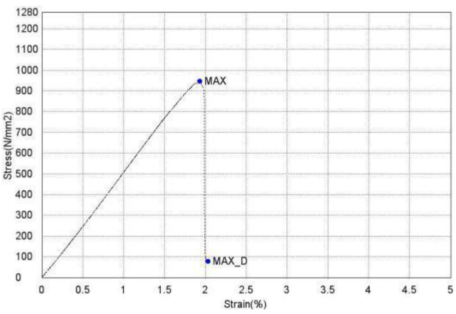

Fig. 3: Stress vs. Strain for UD GFRP specimen

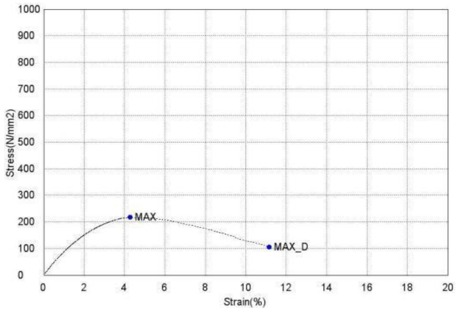

Fig. 4: Stress vs. Strain for CP GFRP specimen

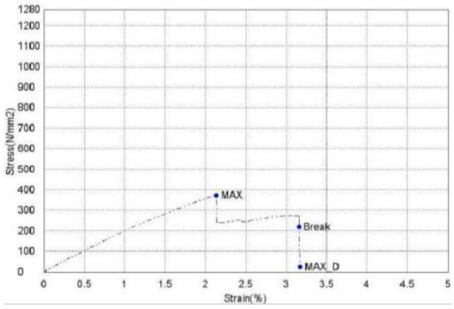

Fig. 5: Stress vs. Strain for AP GFRP specimen

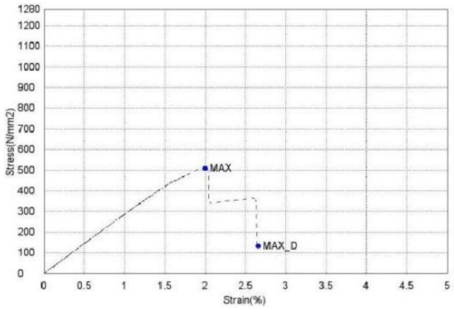

Fig. 6: Stress vs. Strain for AS GFRP specimen

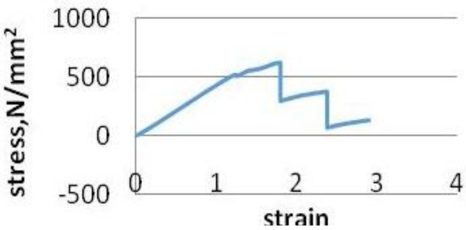

Fig. 7: Stress vs. Strain for hybrid specimen

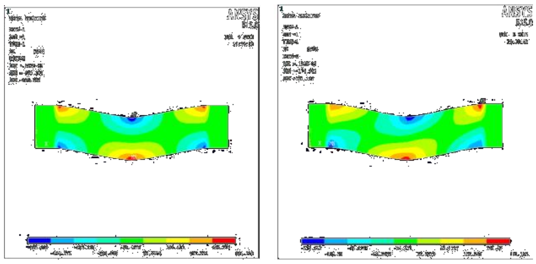

Fig. 8: Stress in UD (left) and AP (right) GFRP specimens

Table 2: Flexural test results and FEA predictions

Material	Test: break load (N)	Test: ultimate stress (MPa)	FEA: ultimate stress (MPa)
UD GFRP	1760.44	945.89	895.21
AP GFRP	413.33	207.165	181.193
AS GFRP	486.287	373.764	411.906
CP GFRP	1760.44	509.026	489.866
CP Hybrid	1243.7	573.27	-

3. Thermographic inspection procedure

The active thermography method is used to detect the defects in the composite laminates by using Fluke TI-32 infra-red (IR) camera as shown in Fig. 9. Initially the emissivity of the composite laminate is set in the camera. Then the heat is applied to the laminates for 10 minutes using hair drier having the heating capacity of 2 kW. After heating, the image is captured and these images are further analyzed to detect the defects in the laminates using smart view software.

Fig. 9: Heating of specimen by hair drier (left) and thermographic image capture using IR camera (right)

4. Results and discussion

The thermographic inspection is done to detect the defects in the specimens before and after the flexure test. Fig. 10 shows the thermographic image of UD GFRP specimen before and after bending. The void and debonds observed in the specimen before testing are marked in circular and rectangular shapes. The void is formed in the specimen due to uneven load distribution on the laminate during hand layup technique. The debonding between the fibre and matrix is due to the improper application of resin. The delamination observed in the specimen post-test is marked in rectangular shape. The debonding or matrix cracking and micro cracks are detected in the specimen due to moderate volume fraction of GFRP and this leads to brittle failure with fibre pull out or breakage during flexure. Fig. 11 shows the temperature variation in UD GFRP specimen before and after bending. The temperature goes down wherever the voids are present and the temperature rises in the regions where the delaminations or debonding of fibre and matrix occur.

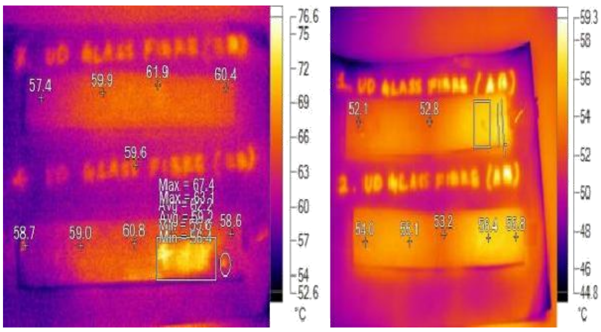

Fig. 10: Thermographic image of UD GFRP specimen before (left) and after (right) bending

As observed in Fig. 12 and Fig. 13, the debonding of fibre and matrix is found in CP GFRP specimen before bending. The fibre breakage and debonding is occurred in the CP GFRP specimen after bending. As observed in Fig. 14 and Fig. 15, the crack and debonding is occurred in the AS GFRP specimen due to the improper mixing of resin. The fibre breakage and debonding is found in the specimen due to load distribution.

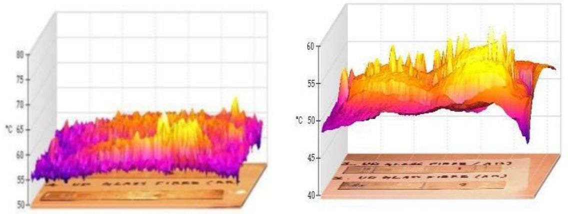

Fig. 11: Temperature variation in UD GFRP specimen before (left) and after (right) bending

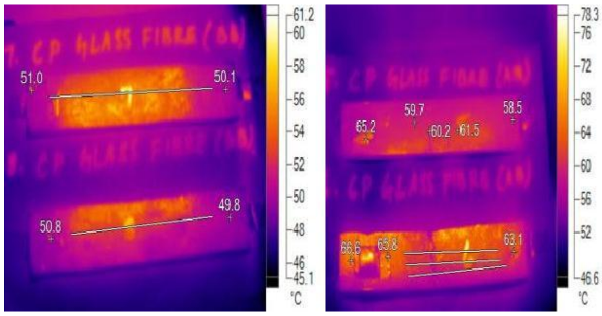

Fig. 12: Thermographic image of CP GFRP specimen before (left) and after (right) bending

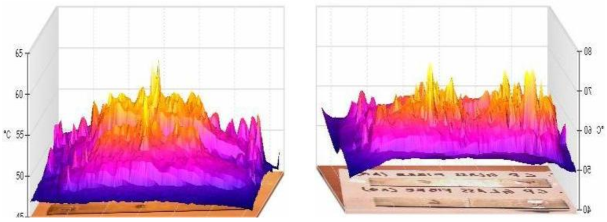

Fig. 13: Temperature variation in CP GFRP specimen before (left) and after (right) bending

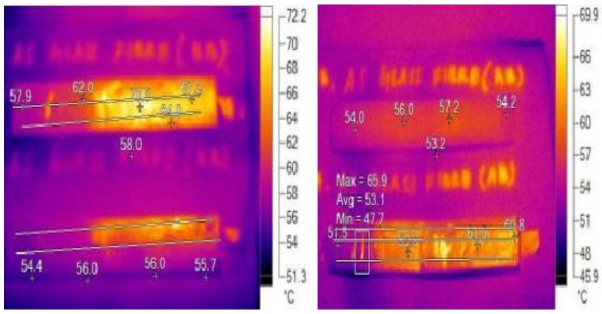

Fig. 14: Thermographic image of AS GFRP specimen before (left) and after (right) bending

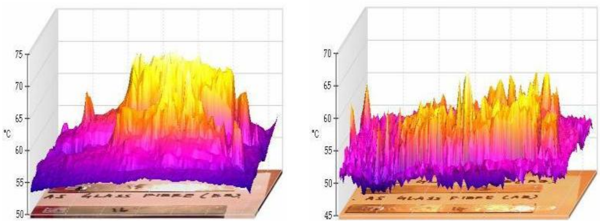

Fig. 15: Temperature variation in AS GFRP specimen before (left) and after (right) bending

Fig. 16 indicates that there are no voids and cracks found in the AP GFRP specimen before bending. There is a small change in temperature due to the micro cracks post test (see Fig. 17). Fig. 18 indicates that there are voids present in the hybrid CP composite specimen due to the improper mixer of resin and it is marked in rectangular shapes. Fig. 19 shows the temperature changes in the hybrid CP specimen after bending. This indicates that the matrix cracking and fibre breakage due to the load distribution in the specimen.

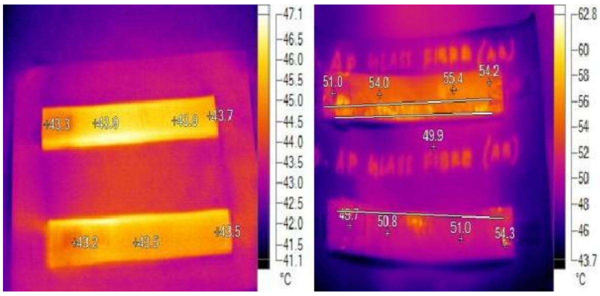

Fig. 16: Thermographic image of AP GFRP specimen before (left) and after (right) bending

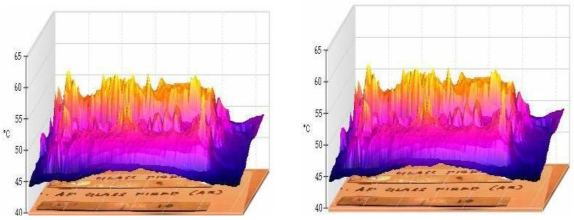

Fig. 17: Temperature variation in AP GFRP specimen before (left) and after (right) bending

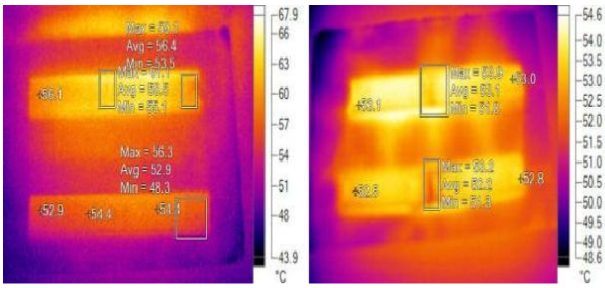

Fig. 18: Thermographic image of hybrid CP composite specimen before (left) and after (right) bending

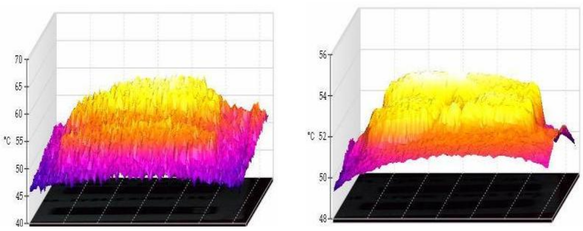

Fig. 19: Temperature variation in hybrid CP composite specimen before (left) and after (right) bending

5. Conclusion

This paper deals with the NDT evaluation of composite laminates. The mechanical properties are found in the specimens by conducting flexural tests. From the flexural tests, it can be concluded that the UD GFRP gives more flexural strength when compared to AP, AS and CP GFRP specimens. The comparison of experimental and computational analysis gives 10% of error due to coarse mesh and approximations. There are two types of failures detected on the specimens by infra-red thermographic inspection. The voids are due to the uneven load distribution. The debonding or matrix cracking is owing to moderate volume fraction leading to a brittle failure and fibre pull out.

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