ACOUSTIC EMISSION STUDIES DURING FATIGUE TESTING OF GFRP ELLIPTIC SPRING ELEMENTS

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SUMMARY : GFRP elliptic spring elements can be used for automotive suspension. GFRP spring elements were fabricated by Filament Winding method. Static stiffness of the spring element was 150 N/mm and major to minor axis ratio 1.5. Two types of laminate configurations were studied, viz-UD glass fibre/epoxy and UD glass fibre & woven glass fabric (alternate layers) / epoxy. Conventional epoxy modified with CTBN and cured with DDM or piperidine was used. Acoustic Emission studies were performed during fatigue cycling. Type of fatigue damage and rate of damage progression were evaluated from Acoustic Emission studies. Acoustic emissions are sensitive to failure mechanisms in composite laminates. Typical observations and analysis of Acoustic Emission signal characteristics during fatigue cycling are presented.

KEYWORDS: Elliptic Spring, Fatigue, Acoustic Emission, Glass Fibre Reinforced Plastics, Failure Mechanisms

INTRODUCTION

Polymer matrix composites have superior mechanical, damping and weathering properties as compared to the conventional materials. Attempts are being made to replace the conventional steel front suspension spring in automobiles with polymer matrix composite spring. This will result in superior vehicle handling characteristics, performance and cost saving on suspension components such as hydraulic dampers. One of the important requirements of an automotive suspension system is good fatigue performance. It is well known that optimally tailored polymer matrix composites can match or even exceed fatigue performance of isotropic materials [1]. Generally, polymer matrix composites have multiple modes of fatigue failure viz-fibre/matrix debonding, matrix cracking, fibre breakage and delamination. Overall fatigue damage of a structure can be expressed in many ways such as, S-N plots, modulus degradation plots and using suitable mathematical models. The type and rate of damage progression can be evaluated by monitoring the fatigue process continuously from the start of the experiment. This can be accomplished by non-destructive techniques such as Acoustic Emission (AE). AE technique can effectively evaluate the condition of the material under stress and the technique is sensitive to different failure mechanisms which occur in a composite laminate. In the present study, the fatigue characteristics of composite elliptic spring elements was evaluated using AE technique.

EXPERIMENTAL WORK

The experimental work comprised of the following :

a. Fabrication of Composite Elliptic Spring Element : To perform fatigue testing and AE studies, sufficient number of different types of spring elements were fabricated by Filament Winding method using a metal mandrel. Static stiffness of spring element is 150 N/mm. Minor and major axes of elliptic spring are 100 & 150 mm respectively.

b. Fatigue Testing : A fatigue test set up was designed and fabricated to subject composite spring element to flexural fatigue type of loading along its minor axis. Fatigue load was applied through an eccentric disc (deflection controlled fatigue test).

Fatigue test parameters are :

Displacement : 30 and 25mm
Frequency : 0.60 Hz

Details of fatigue tests are given in Table.1.

Table.1 Details of fatigue tests

Laminate type	CTBN, %	Deflection, mm	No. of cycles (X 10^3)	No. of samples tested
UD	0	30	300	2
UD	15	30	300	2
UD/WF	0	30	300	2
UD/WF	15	30	300	2
UD/WF	0	25	600	3
UD/WF	15	25	600	3

UD-Unidirectional, UD/WF - Unidirectional / Woven Fabric (alternate layers)

c. Acoustic Emission Experiments : The AET-5500 (Hartford Steam Boiler Inspection Technology) testing machine was used for AE studies. The piezo-electric sensor was located at minor axis of the spring element. The sensor was firmly clamped onto the spring element. Silicone grease was used as couplant between the sensor and spring laminate. The AE signal is fed into the signal processing unit of the AE equipment, where they are processed and stored. These stored signals can be post processed using a software.

Parameters such as threshold voltage and amplitude gain are fixed to that no extraneous or machine noise is recorded.

Main source of AE in polymer composites are [2] :

Fibre / matrix debonding
Crack initiation and propogation at defect sites
Matrix cracking
Sliding friction between fractured surfaces
Ply failure and delamination
Fibre fracture

Damage initiation, progression and damage growth pattern can be monitored in real time by AE approach. The AE studies can be used to assess the structural integrity of the specimen. With proper analysis of AE signals, it is possible to identify different failure mechanisms associated with composite materials.

RESULTS AND DISCUSSION

Results of Fatigue Studies :

Following observations are made from fatigue tests on spring elements made of UD glass fibre/epoxy and UD/WF glass fibre/epoxy :-

a. Stiffness reduction with fatigue cycling is very marginal upto 3,000 fatigue cycles. For spring elements made of UD/WF glass fibre and unmodified epoxy, stiffness reduction is 5%, while for spring elements made of UD glass fibre and unmodified epoxy, stiffness reduction is 7%. Corresponding stiffness reduction with CTBN modified epoxy are 3.5% and 5%.

b. Above 3,000 cycles the stiffness reduction is very fast and at the and of 2.5×10^5 cycles reduction is 27-30%.

c. In all the cases, fatigue performance of UD/WF/epoxy composites is little superior compared to UD/epoxy composites. This is due to better ability of arresting cracks in case of UD/WF/epoxy composites because of presence of transverse fibres.

d. Use of CTBN modified epoxy gives better fatigue performance than unmodified one, though the improvement is marginal. Improvement in fatigue performance is mainly due to better toughness of CTBN modified epoxy matrix.

e. For 25mm spring deflection, stiffness reduction is much smaller as compared to 30mm deflection. At the end of 2.5×10^5 cycles, stiffness reduction in case of UD/WF/epoxy spring element with modified epoxy is 20% for 25mm deflection as against 27% for 30mm deflection. This is due to higher stresses and strains for 30mm deflection resulting in higher fatigue damage rate.

Results of AE Studies :

Following observations are made from AE studies carried out during fatigue loading of elliptic spring elements :-

a. Variation of ring down counts (RDC) and rise time (RT) with fatigue cycles for UD/WF/modified epoxy (25mm deflection) was studied.

b. Both RDC and RT are higher at the start of fatigue cycling and decrease upto 3,000 cycles. The fall in both RDC and RT can be attributed to the occurrence of burst signal due to the initiation of brittle fracture. The brittle fracture results in a sudden rapid (burst type) AE signal, which dies down quickly. As a result of this, the number of times the AE signal crossing the threshold value reduces, resulting in reduction of RDC.

Similarly, because of the burst type of emission, the time taken to reach the peak also reduces, resulting in reduction of RT.

The emission of AE from the very start of fatigue cycling indicates the initiation of change of material state from the beginning of fatigue test. Polymer composites possess isolated weak spots due to the following :-

i. Presence of voids
ii. Misalignment of fibre bundles
iii. Insufficient wetting of some fibres

The damage to the spring element starts by initiation and formation of cracks at some weak spots in the composite laminate.

c. Above 10,000 cycles, both RDC and RT increase rapidly reaching peak value around 27,000 cycles. This trend suggests the occurrence of micromechanical deformations resulting in continuous type of AE. These signals take a long time to die-down (or to fall below the preset threshold value). Once emission from weak spots are exhausted, stress redistribution within the spring element occurs. On further fatigue cycling, material exhibits good resistance to deformation. Increase in RDC and RT indicate the accumulation of micro-mechanical damage within the material with fatigue cycling.

d. After reaching the peak value around 27,000 cycles, both RDC and RT begin to reduce. This can be due to the saturation of the micromechanical failures. Reduction in RDC and RT is an indication of deterioration of quality or structural integrity of the spring element.

e. Though there is a rapid reduction in RDC and RT values, AE never ceases. RDC and RT increases (a small peak) again around 55,000 cycles. This rise in RDC and RT is due of emission of continuous type AE signals. For rest of the fatigue life, this type of oscillating trend in AE signal continues.

Correlation between the fatigue and AE studies :

Following correlation has been observed between fatigue and AE studies :-

a. First visible sign of stiffness reduction appears after around 400 fatigue cycles and correspondingly AE parameters RDC and RT register a small rise at 400 cycles indicating onset of deformation mode (continuous signals). This is attributed to the deformation of spring material after initial matrix crazing during the early phase of fatigue testing (prior to 400 cycles). This trend continues upto about 1000 cycles.

b. During 10,000-25,000 cycles, there was small reduction in stiffness of UD/WF/epoxy spring elements. The structure experiences increasing deformation without any material damage. This is indicated by increase in RDC and RT over this range of fatigue cycling.

c. Beyond 2.5 x 10^4 cycles, degradation of material results in higher stiffness reduction and RDC/RT values also register a decreasing trend.

d. For UD/epoxy spring elements also, a good correlation between the stiffness reduction and AE signal parameters was observed.

CONCLUSIONS

AE studies on GFRP elliptic spring elements during fatigue cycling reveal that :-

a. Fatigue performance of UD/WF/epoxy composite is superior compared to UD/epoxy composite. This is due to better ability to UD/epoxy composite. This is due to better ability of arresting cracks in case of UD/WF/epoxy composites because of presence of transverse fibres.

b. Use of CTBN modified epoxy gives slightly better fatigue performance than unmodified one due to higher toughness of CTBN modified epoxy matrix.

c. Study of AE parameters (RDC and RT) during fatigue cycling shows a good correlation between stiffness reduction and variations in RDC and RT.

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