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FATIGUE AND STATIC DAMAGE MODELLING OF CONTINUOUS GLASS FIBRE/EPOXY COMPOSITE

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Abstract
Continuous fibrous composites are found to be increasingly used in many lightweight structures such as automotive applications which are mostly subjected to cyclic loads. Recent investigations are interested in composites durability.

The purpose of this work is to study the onset and growth of types of damage occurred under static and fatigue loadings such as transverse cracks and delamination.

The material under investigation is E-glass fibre reinforced epoxy matrix.

Experimental tests were carried out to identify types of damage occurred under both static and fatigue loadings. Damage modes are identified using microscopic observations and acoustic emissions recording as a non-destructive technique to detect damage during a tensile loading and to identify the chronology of micro-level damage development.

1. Introduction
This study deals with the modelling of the behaviour of laminated glass/epoxy composites under static and fatigue loading. Both Acoustic emission and microscopic were used in order to provide a better characterization and discrimination of the different damage mechanisms.

2. Material and methods

2.1 Material
In this work, a glass/epoxy woven fabric was studied. Specimens are cut into the epoxy resin based 2D glass fibre woven fabric RTM laminated.

Resin Transfer Moulding (RTM) is the processing technology used to manufacture laminates.

Figure 1 shows the glass woven fabric without resin.

The composite consists of 10 layers. Each ply is a 2D glass fibre woven fabric: 97% of the glass woven fabric are in the warp direction (0°). While 3% are in the weft direction (90°).

In order to determine material elastic properties, quasi-static tensile tests at 0°, 45° and 90° were performed in addition to short beam shear tests at both 0° and 90° directions.

The table 1 summarizes the material properties obtained by mechanical characterization tests.

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<th>E2 (MPa)</th>
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<th>G12 (MPa)</th>
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<td>7000</td>
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</table>

Fig.1. 2D glass fibre woven fabric
The testing program consisted of quasi-static and constant-amplitude cyclic loading of laminated specimens.

2.2 Quasi-static tests
Monotonic tensile tests were performed under displacement control with a fixed cross head velocity of 1 mm/min. Specimens 250 mm long by 25 mm wide with a thickness of 4 mm were cyclically tested at a loading rate of 1MPa/s in a servo-hydraulic testing machine. Figure 2 shows the loading/unloading procedure used. An observation period at each level of stress was scheduled to microscopic observations of specimen side.

Fig.2. Quasi-static loading/unloading test procedure

Stress and longitudinal strain were monitored by means of the machine load cell and a 25 mm extensometer.

To provide a better characterization and discrimination of the different damage mechanisms, both acoustic emission and microscopic observations were used. (Fig.3)

2.3 Tensile-tensile fatigue tests
Tensile-tensile fatigue experiments were performed at a frequency, f = 5Hz, with a stress ratio R=0.1 (R= \( \sigma_{\text{min}}/\sigma_{\text{max}} \)). The specimens’ dimensions are the same used in quasi-static tests. Also, acoustic emission records and microscopic observations after a certain number of cycles were used to understand fatigue damage mechanisms.

3. Results and discussion
3.1 Damage mechanisms
a. Static loading
Different damage modes occurring during tests were identified using microscopic observations during quasi-static tensile loading. Furthermore, the chronology of micro-level damage development was established.
At a stress level state of 300 MPa, main damage modes observed are: debonding, weak fibres failure and matrix cracking. These types of damage create the first macro defect: transverse cracks.
The formation of transverse cracks in the fibres perpendicular to the loading direction can be explicated by the stress concentration due to the weaving. (Fig.5)

Then, the main modes of failure are delamination between wefts and wrap fibres, and fibres breaking as it shown by Fig.6.

Finally, (at a level stress of 850MPa) a longitudinal crack was created by the formation of microcracks in the matrix and then the fibres (Fig.7).

Due to the brittle behaviour of the material, the final failure is coincident with the rupture of the sample.

Figures 8 and 9 show the cumulative AE energy and cumulative AE event count. The damage onset is detected already at the beginning of the test (at 200 MPa stress), when a few low energy occur with low frequency. The corresponding stress level is denoted as E1 and can be attributed to initiation of new transverse cracks in the weakest locations.

Up to this level stress, the number of transverse cracks increases rapidly up to saturation density. Delamination initiation between wrap fibres (0°) and weft fibres (90°) is shown by figure 6.
By the end of the test, the frequency increases, both the energy content and event count rise quickly, and the specimen starts to emit popping sounds indicating extensive appearance of relatively larger transverse and longitudinal cracks. The corresponding stress level is denoted as E2.

![Fig.8. Evolution of absolute energy with stress level (using AE)](image)

![Fig.9. Evolution of acoustic events number with stress level (using AE)](image)

**b. fatigue loading**

It was difficult to achieve tensile-tensile fatigue tests at direction 0° because of high clamping stress at the heels.

Fig.10 shows that highest temperature is localized at the heels of the specimen. This information is an indication of stress concentration in these zones.

This problem was solved by reducing plate’s thickness to 2 mm.

![Fig.10. Temperature profile of the sample under fatigue loading](image)

To investigate damage mechanisms, acoustic emissions recording were used to detect cracks. Microscopic observations of specimens’ side at a given number of cycles provided more accurate description of damage mechanisms evolution.

Fatigue damage includes mainly these failure modes: transverse matrix cracking, delamination, splitting and fibre fracture. (Fig.11)

![Fig.11. Microscopic observation of damage modes under fatigue loading](image)

We notice that failure modes under fatigue loading are the same as static damages.

Figure 12 shows acoustic emissions records during a tensile-tensile fatigue test at direction 0°.

We can distinguish two damage modes: transverse cracks and final longitudinal cracks.
Another result similar to static behaviour is that no loss of stiffness to be mentioned under fatigue loading.

![Graph showing evolution of acoustic events number with stress level](image)

**Fig.12. Evolution of acoustic events number with stress level (using AE sensors)**

### Conclusion

This paper discussed experimental results damage mechanisms under both static and fatigue loading.

This work demonstrates the potentiality of acoustic emission to understand the damage mechanisms that occurs during a tensile test;

Fatigue tests allow a better comprehension of damage mechanisms by establishing damages chronology.

Damage mechanisms are similar under both static and fatigue loadings.

Future work will be focused on how to use a “classic” failure criterion such as Tsai-Wu criterion in the case of real automotive part where stress distribution is not homogeneous.

As observed damages have no effect on stiffness loss, we will try to determine the threshold size of damaged zone from which macroscopic properties can be affected.

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### References

