EVALUATION OF FATIGUE DAMAGE IN PLATE COMPOSITE WITH A HOLE CONTRIBUTION OF INFRA-RED THERMOGRAPHY

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ABSTRACT

Fatigue failure is by far the most common type of failure in service loading of structural materials, including composites. It has been estimated that over 80% of service failures can be attributed to fatigue degradation. Experimental observations show the various damage of composites under cyclic load. An analytical model is developed to determine the evolution of the damage during tests. The fatigue tests of the perforated specimens are controlled with an infra-red thermography system. So the change of temperature can provide information on the most degraded zones of our specimens.

1. INTRODUCTION

In the aeronautical industry, the use of polymer matrix composite materials raises the problem of service life assessment for several types of working conditions, notably fatigue or creep loading. The general problem of the fatigue of the structures appeared more than one century ago when technicians confronted themselves with ruptures of machine elements subjected in service to variable requests but of intensities lower than those involving the static rupture. Consequently, many studies were undertaken in order to prevent ruptures Wohler (1858) and Griffith (1920) [1]. The catastrophic aspect of the fractures by fatigue always requires an entire examination and a knowledge of material used. For that, a great efforts has been devoted to studying the fatigue behaviour of materials by non-destructive methods (NDM). We finds in the literature various systems of analysis non-destructive used in the examination of starting and the evolution of the damage, including ultrasounds, the sound emission, the eddy current, x-ray [2-8]. Few work were used to characterize the fatigue behaviour of the composites by using thermography.

2. THERMOGRAPHY

Thermography is a measurement technique which allows obtaining a thermal image taking again the distribution of the temperature on the surface of the examined object. Thermography proceeds by decoding, using an adapted detector, information "temperature" resulting from the infra-red radiation emitted by any object. The principal advantage of infra-red thermography is its no intrusive character. Indeed, it forms part of the techniques of non destructive testing and can be carried out on installations in service. The deformation of solid materials is almost always accompanied by releases of heat. When the material becomes deformed or is damaged and fissured, a part of energy necessary to starting and the propagation of the damage is transformed in an irreversible way into heat [9]. The use of an infra-red camera makes it possible to quantify without contact the heating gave rise to a measurement technique called thermoelasticimetry. This technique is used for its speed and its simplicity of implementation. The principal applications concern several sectors (engineering automotive, aeronautical,..) and more recently, the determination of fatigue limit and the localization of zone of damage [10]. Recent research showed the capacity of thermography to detected the mechanical damages of the materials [11-16]. However, Investigations and more practical analyses are necessary to characterize by the system of analysis per thermography the process of degradation by fatigue.

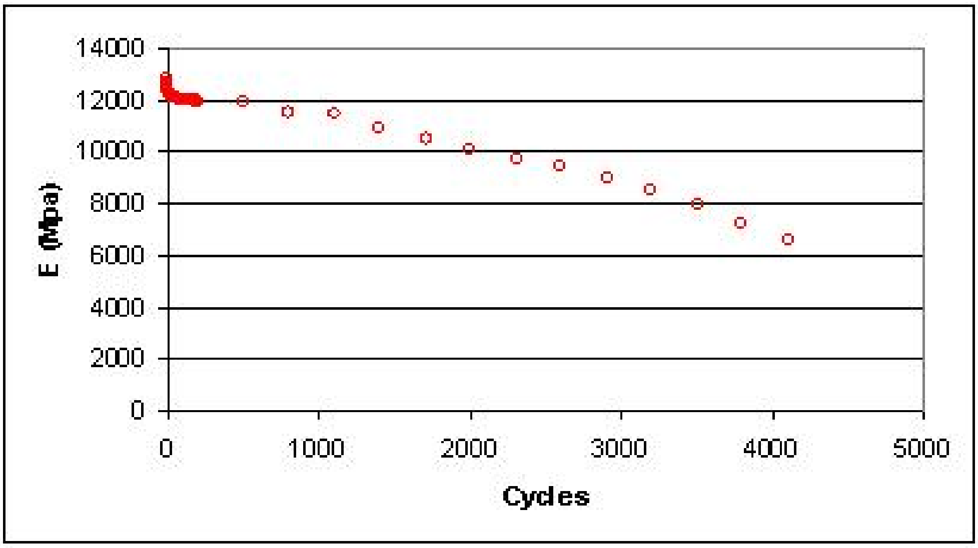
3. EXPERIMENTAL

Fatigue tensile tests were then performed according to rupture values. The fatigue tests with a stress ratio of 0.1, are load controlled and the measurement of the deformation is ensured by a mechanical extensometer. Plate specimens with and without holes were tested. In this work, we have the results obtained for a specimen perforated [±45°]2s for a maximum effort of 5250 N (70% of the load with rupture) Fig. 1.

“**Fig. 1**. Fatigue machine.”

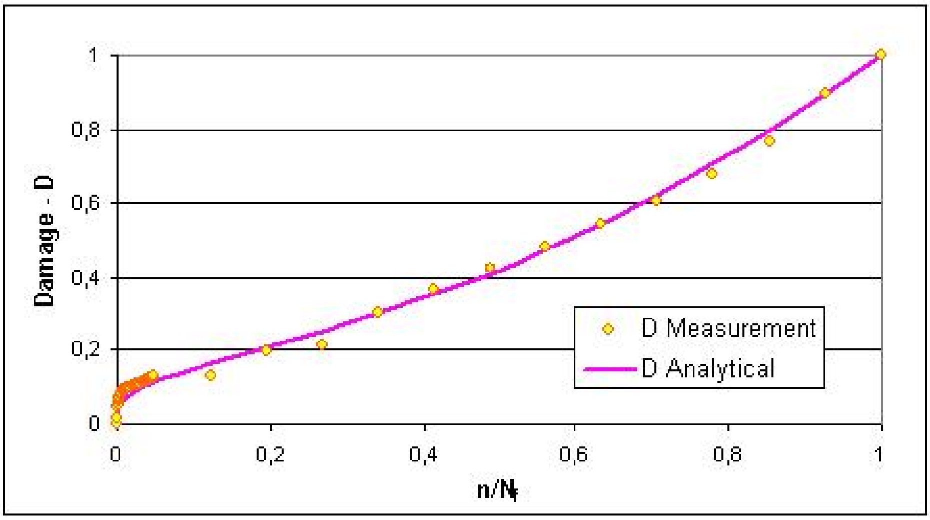
4. RESULTS & DISCUSSION

Fig. 2. shows the evolution of the Young modulus according to the number of cycle. The damage is represented by parameter D. The evolution of D is obtained in experiments starting from the expression ($D = \frac{E_0 - E}{E_0 - E_f}$), E, E_0 and E_f being respectively the residual, initial and final Young modulus.



“**Fig. 2.** Evolution of the modulus of elasticity according to the number of cycle.”

The relation of Mao [17] gives an analytical form of this same variable: ($D = q\left(\frac{n}{N}\right)^{m_1} + (1-q)\left(\frac{n}{N}\right)^{m_2}$) (Fig. 3); D is the normalized accumulated damage; q, m_1 and m_2 are material dependent parameters; n is the number of applied loading cycles; and N is the fatigue life at the corresponding applied load level.

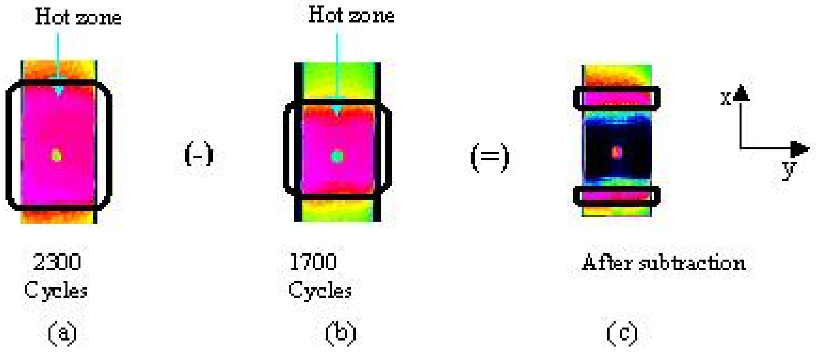


“**Fig. 3.** Experimental observation and model prediction of damage.”

It can be seen that the prediction results agree well with the experimental results for the tested composite material. The values of the parameters for the proposed damage function are also shown in table 1. The damage evolves quickly at the beginning of the test then linearly until the final rupture.

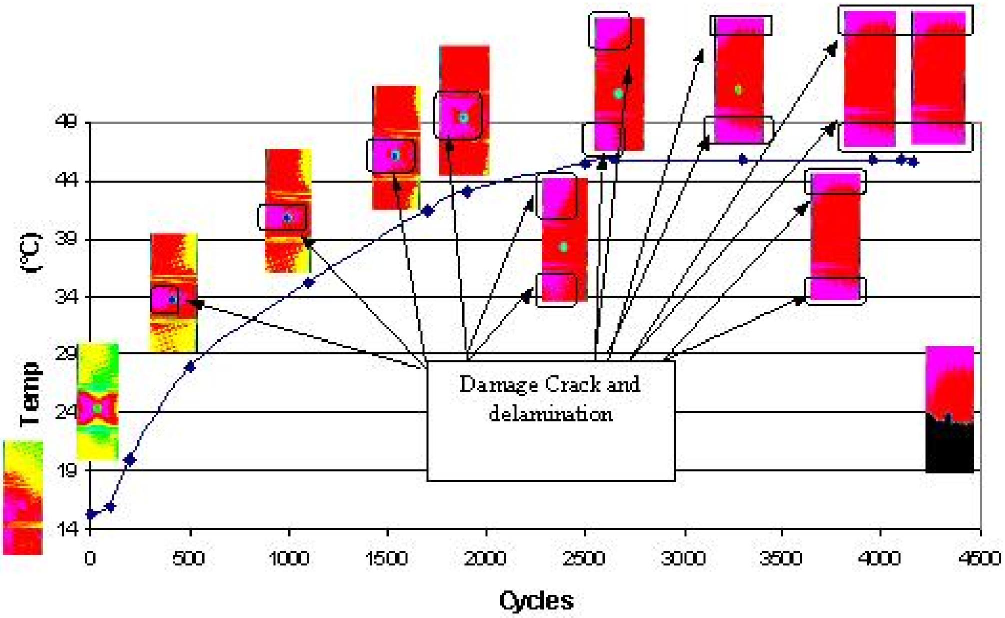
“**Table 1.** Parameters for the proposed damage function.”

q	m_1	m_2
0.32	0.35	2



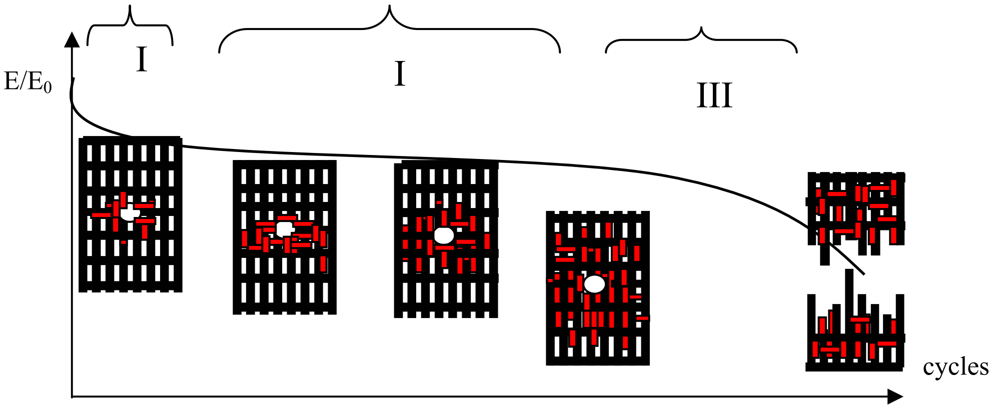
“**Fig. 4.** Infra-red cartography.”

The Fig. 4a. and Fig. 4b. show the distribution of the temperature for 2300 and 1700 cycles respectively. The hot zone on the specimen situ in the medium of this one. The subtraction of the distribution of the temperature with 1700 cycles of that with 2300 cycles is shown on the Fig. 4c. One distinguishes two parallel hot zone compared to the axis y, this supposed is located at the end of a "longitudinal crack and delamination", where the generation of heat is largest. The subtraction of the thermal fields of the various cycles makes it possible to note that the propagation of the damage is carried out according to direction X in the same way as the temperature. The final rupture arrives after stabilization of the temperature (saturation) Fig. 5.



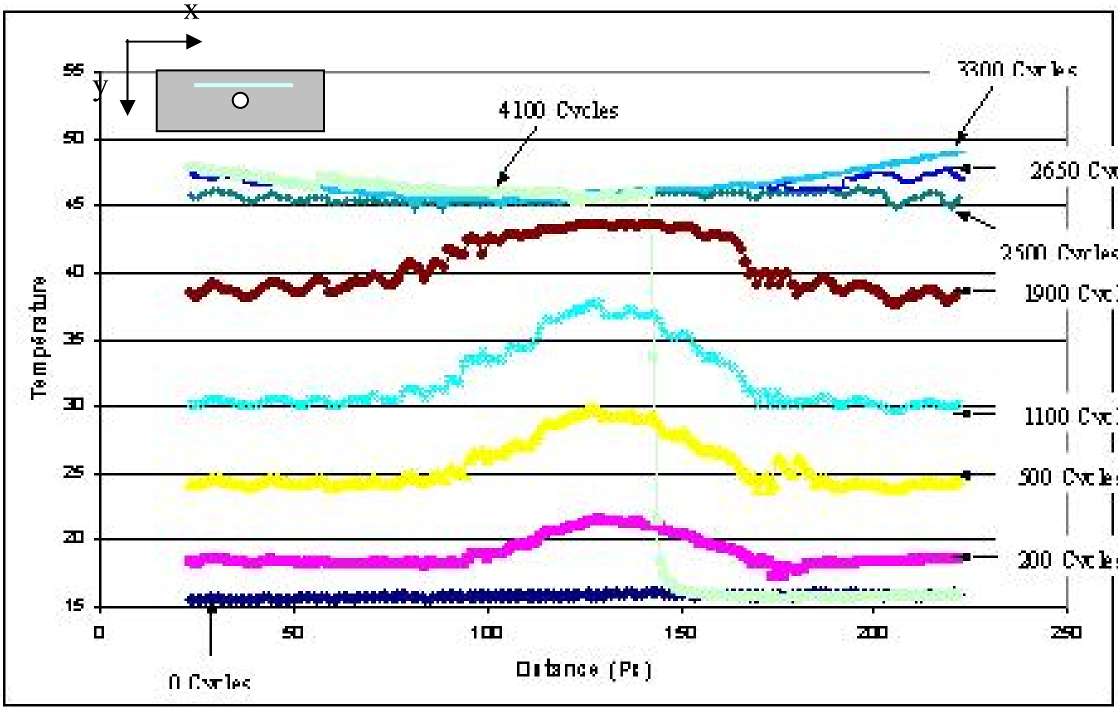
"**Fig. 5.** Evolution of the damage and the temperature."

The change of the temperature translates the energy released at the time of the process of damage (cracks and delamination) as one can see it on Fig. 5., the temperature is stabilized after 2000 cycles. With the resulting one from this stage the final rupture of the specimen takes place. The evolution of the damage appears according to three stages. Initially a loss of rigidity is observed but it is not very important; it is due to the appearance of several transverse cracks, and hard until the CDS (crack Density Saturation) [18], then a weak reduction of rigidity, linearly dependent on the number of cycles appears. It characterizes the regular development of another type of damage : delamination. Lastly, the loss of rigidity and more rapid, the development of the damage is unstable and several damaging modes can develop simultaneously Fig. 6.



"**Fig. 6.** Description of the evolution of the rigidity of a composite material according to the number of cycle."

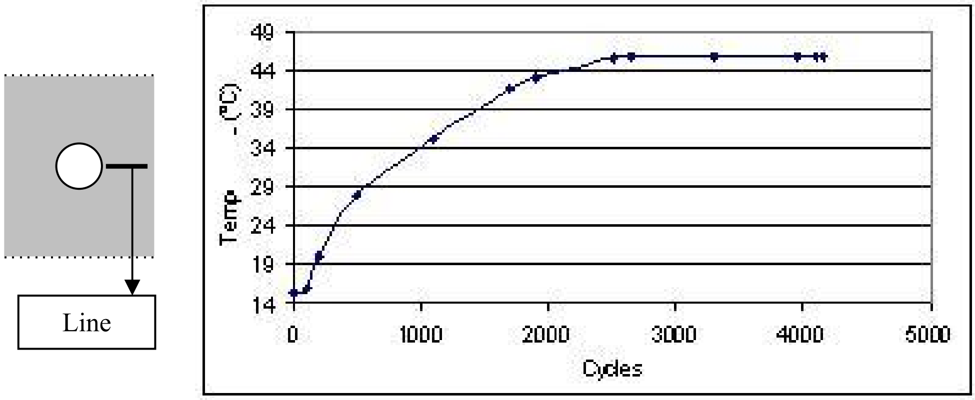
The preceding results show that thermography can be employed to follow the presence and the propagation of a degradation during the fatigue test.



“**Fig. 7**. Temperature line profile.”

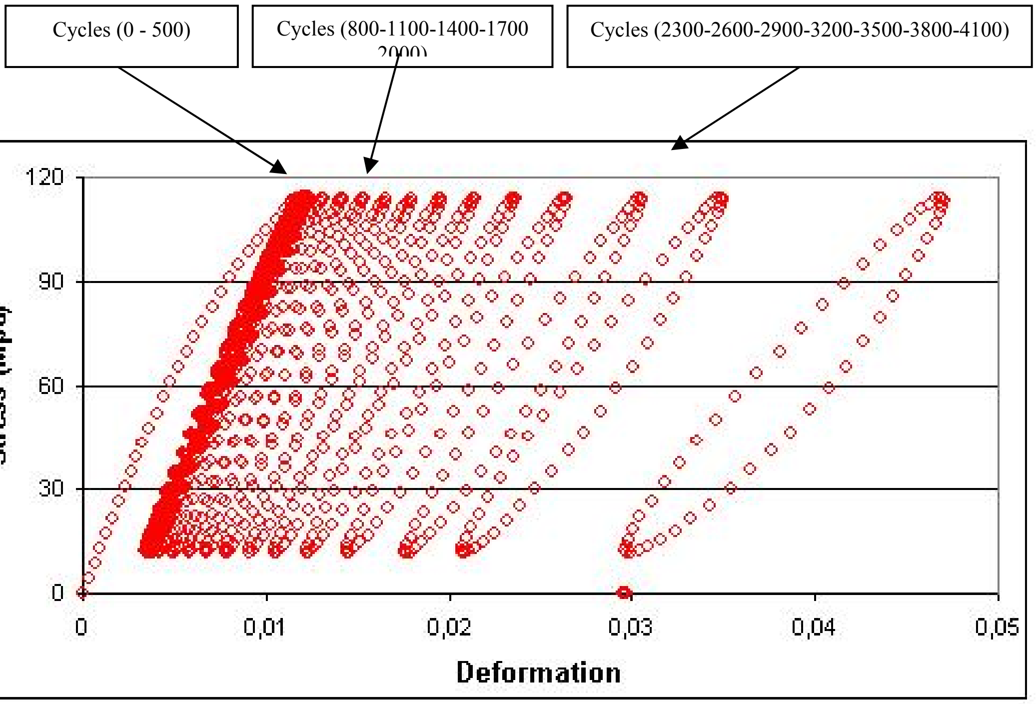
Fig. 7. shows the distribution of the average temperature in the vicinity of the hole following x. The temperature is important in the centre of the specimen. It rises quickly between 200 to 1900 cycles, after it becomes stable until the rupture. The distribution of the temperature along the measured zone further shows at the beginning of the test an important variation between the temperature with the medium of the specimen compared to a zone from the centre (38°C - 30°C for 1100 cycles). This distribution becomes increasingly homogeneous until the end of the test. With the end of the test the temperature at the ends and slightly more important compared to the centre of the specimen, that is with the propagation of delamination and damage which starts in the centre of the specimen is propagated towards the ends of the specimen.

The variation in the average temperature on lines in the medium of the specimen is presented in Fig. 8.



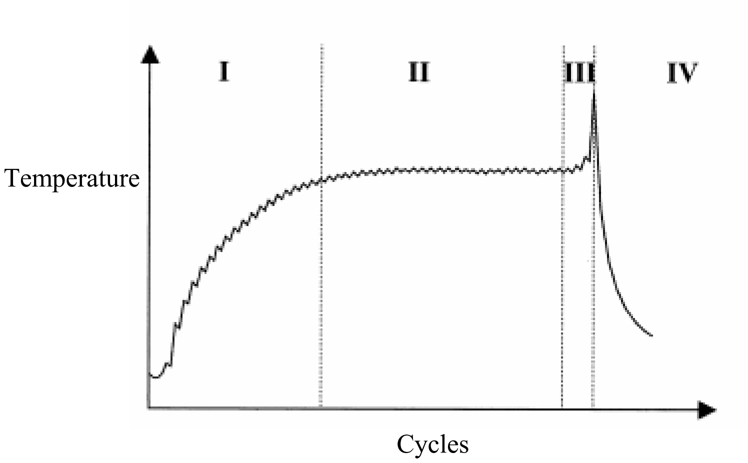
“**Fig. 8.** Variation in the temperature in the medium of the specimen.”

At the beginning the temperature evolves with the number of cycle then it reaches a stable value. The variation in the temperature is closely related to the deformation [14], a reasonable explanation of the change of the temperature Fig. 8. can be obtained starting from the learning curve on Fig. 9.



“**Fig. 9.** Curve stress/deformation.”

For our specimen and on the first 1000 cycles, one does not note a variation of the deformation because the surface of the damaged zone is small compared to the total surface of the specimen. After 1000 cycles, one observes a more important variation of the deformation. The quantity of heat loss is also important. The damage of the sample is closely dependent this dissipation. The rupture of the specimen arrives at the end of 4100 cycles. Liaw [16] summarizes the change of the temperature during a fatigue test according to the diagram on Fig. 9.



“**Fig. 10.** Evolution of the temperature during a fatigue test [16].”

In the 1st part (I), the variation in the temperature is due to frictions (fibres/fibres, fibres/matrice) and to the damages which start and are propagated during the fatigue test. In the 2nd part the temperature reaches a balance that is due A a saturation in the damage. This stability is followed of an abrupt increase of the temperature of the test-tube corresponding to the rupture. The fourth part of the diagram represents recalled at the ambient temperature.

5. CONCLUSIONS

This paper aimed to show that thermography techniques could be used with benefit to observe the calorific effects accompanying the localisation phenomena. These techniques propose to pass from temperature information given by the infrared camera to a distribution of heat sources on surface of the composites. The characteristics of damage accumulation in composite materials are studied. The experimental results of damage growth show that there are three different stages during the damage evolution in composites under fatigue loading. During the first stage, fatigue damage grows rapidly due to the occurrence of multiple damage modes within the material. The damage increases steadily and slowly during the second stage. During the third and final stage, the damage again grows rapidly due to the fracture of fibres. Parameters of the proposed model are obtained with experimental data. An image subtraction technique in the infrared detection system can be used to monitor crack initiation and propagation behaviour.

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