INFRARED THERMOGRAPHY FOR DAMAGE MONITORING AT INTERMEDIATE STRAIN RATES: APPLICATION TO TRANSVERSE CRACKING EVOLUTION IN CROSS-PLY LAMINATES

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Abstract. With the increase of the use of composite materials, various experimental methodologies have been proposed to characterise the matrix crack density evolution in cross-ply laminates for quasi-static loadings. These methodologies cannot easily be extended to intermediate or high strain rate loadings as they rely on interrupted tests. In this work, a new approach is considered relying on the use of passive infrared thermography to capture the transverse cracking appearance. The objective of this study is twofold. On one hand confirm that the classically used assumption that the crack propagation is instantaneous from side to side in the specimen remains valid with the loading rate increase. On the other hand, study the influence of the loading rate increase on the crack density evolution with respect to the applied load.

1 Introduction

With the increase of the use of composite materials, various experimental methodologies have been proposed to characterise the matrix crack density evolution in cross-ply laminates [1–8]. All these studies have been limited to quasi-static or fatigue loadings and the application of such methodologies to intermediate or high strain rate loadings is not obvious. Indeed, these methodologies rely on interrupted tests in order to evaluate the crack density during this interruption with a specific equipment (X-ray, microscopy,...). In this work, a new approach is considered. It relies on the use of passive infrared thermography to capture the transverse cracking appearance. Passive infrared thermography has been previously used to characterise fracture toughness in a thin woven composite laminate [9] or surface ply appearance during intermediate strain rate tests [10]. The objective of this study is twofold. On one hand confirm that the classically used assumption that the crack propagation is instantaneous from side to side in the specimen remains valid with the loading rate increase. On the other hand, study the influence of the loading rate increase on the crack density evolution with respect to the applied load. In the sequel, all tests have been performed on a servo-hydraulic jack for loading speeds between 5 mm/min and 500 mm/min. The maximum speed reached in this study is limited to 500 mm/min due to the capabilities of the IR camera used in this study (CEDIP JADE III LWIR), higher loading rates should be reached with a new generation high speed IR camera.

2 Crack propagation from side to side

First of all, to access the assumption that transverse cracking propagates instantaneously from side to side in the sample for all the loading rate studied, a specific experimental setup has been used. As shown in Figure 1, the IR camera is oriented with respect to sample in order to be able to monitor at the same time one face and one side of the coupon. As $[0/90_3]_s$

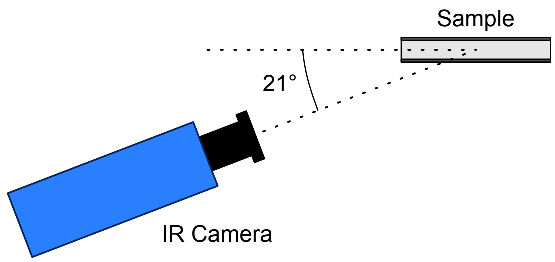

Figure 1: Experimental setup to access the propagation of transverse crack from side to side.

stacking sequence is used, the crack is firstly visible on the side of the specimen and after the propagation of the heating through the 0^o ply, the crack appearance is also visible on the face of the specimen. As shown in Figure 2, a quantitative methodology has been proposed to access the instantaneousness of the crack propagation for the different loading rates. For that purpose, the evaluation of the mean temperature is computed in the area coloured area visible in Figure 2. In order to reduce the influence of the emissivity variation due to the angle between the surface ply and the camera sensor, the evolution of the mean temperature has been normalised in each area. From these results, it clearly appears that the crack propagation remains instantaneous from side to side with the loading rate increase.

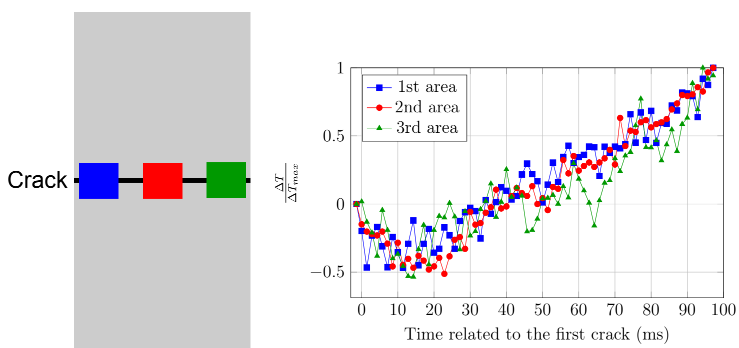

Figure 2: Comparison of the temperature variation in three different areas on the specimen face, for times close to that of the first crack appearance, for a test performed at 500 mm/min.

3 Loading rate dependency

Based on this result, only one side of the specimen can be monitored for the study of the loading rate influence on the crack density evolution with respect to the applied load. This allows to reduce the spacial resolution required and consequently allows to increase the acquiring frequency of the IR camera. The experimental setup used for the study of the loading rate dependency is described in Figure 3. The load applied to the specimen is measured with a

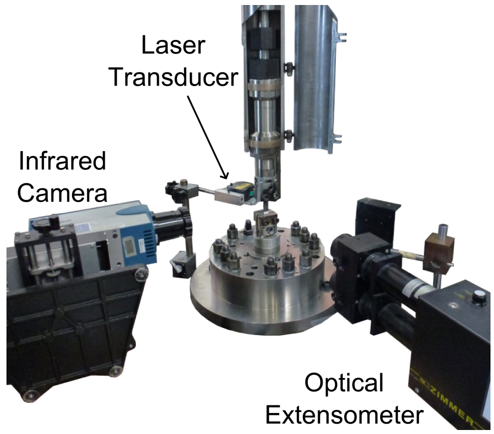

Figure 3: Experimental setup used to study the loading rate dependency.

piezoelectric load cell located between the lower holder and the machine frame. As shown in Figure 3, the strain is measured with an optical extensometer. The initial distance between the two transitions is of approximately 32.5 mm for a total free length of the specimen of 41 mm. The displacement rate of the servo-hydraulic jack is verified with a Keyence laser transducer. At least three specimens have been tested for each loading rate. The stress-strain curves for the different loading rates tested in this study are plotted in Figure 4. Firstly the behaviour is

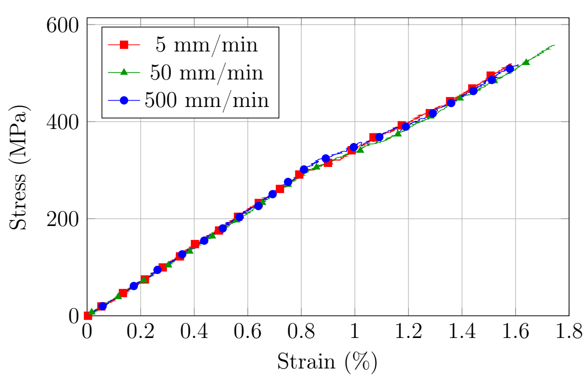

Figure 4: Stress-strain curves of the $[0/90_3]_s$ laminate at different loading rates.

linear with no visible rate dependency regarding the apparent modulus of the specimen. The behaviour becomes non-linear for a stress applied to the laminate close to 300 MPa. This non-linear behaviour is almost superimposed for all the tested loading rates. To better understand this non-linear behaviour, the evolution of the crack density for the different loading rates is plotted in Figure 5. In this figure, a low discrepancy of the experimental results is observed. The crack density starts to growth for a stress close to 300 MPa. The non-linear behaviour observed in Figure 4 is clearly related to crack density initiation and growth in the 90^o ply. On the other hand, no rate sensitivity of the crack density as a function of the applied stress was observed for the studied material within the loading rate interval.

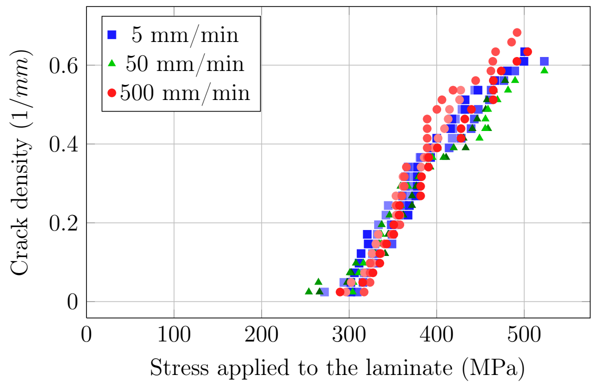

Figure 5: Evolution of the measured crack density with respect to the stress applied, for different specimens tested at different loading rates.

4 Conclusion

In this study, a new experimental protocol has been proposed to measure the evolution of the matrix crack density with respect to the stress applied to the laminate. This protocol can easily be used to study the influence of the loading rate on matrix crack density evolution. Consequently, this methodology has been first applied to access that with the loading rate increase the classical assumption related to the instantaneousness of the transverse crack propagation from side to side remains valid. Secondly, this protocol has been applied to study the evolution of the matrix crack density with respect to the loading rate increase on a $[0/90_3]_s$ laminate. For this particular material (T700/M21) in that range of strain rate, the crack density evolution is not affected by the loading rate increase.

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