INFLUENCE OF THE STRAIN RATE ON DAMAGE AND FAILURE MECHANISMS OF COMPOSITE BONDED JOINTS AND SUBSTRATES

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The influence of the strain rate on mechanical properties of composite/composite and composite/steel joints has been studied. These joints exhibited an unusual viscoelastic behaviour when the crack initiated and propagated in the composite substrates: the ultimate tensile load decreased when the strain rate was raised from 10^{-4} to 10^{-1} s^{-1}. This phenomenon is attributed mainly to the transverse tensile stress generated at the extremities of the joint. The influence of the strain rate has been compared on both transverse tensile tests and crack propagation in mode I of composite samples. It appears that the strain rate effect on the joints is more due to a stick slip phenomenon during crack propagation in mode I than to the crack initiation.

INTRODUCTION

This paper deals with the mechanical behaviour of glass/polyester laminates used in ship building. The adhesive bonding of those laminates is studied in both composite/composite and composite/steel single lap joints.

It is well known that the polymeric resin can induce viscoelastic effects on the mechanical behaviour of composites. Under fatigue or impact loading, the viscoelasticity can become a critical parameter influencing the strength of a composite structure, and in marine applications such loadings are very common.

In this paper, the influence of the strain rate on mechanical behaviour of composite substrates of adhesive joints is studied. Although the stress field is very complex in the joint, it seems that the transverse tensile component is the determinant factor for crack initiation and propagation in the composite substrate. So, the effect of the strain rate was studied on both the transverse tensile strength and on the value of G_{Ic} of the composite.

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MATERIALS

The composites used in this study are laminates of E glass fibres impregnated by an orthopthalic polyester matrix ("Crystic" PA 115) ; they have 38 vol% of fibres. The laminates were made by lay-up in a room temperature and humidity controlled workshop, at the IFREMER Marine Laboratory ; they were not post-cured. Two sorts of laminates were used:

- For adhesive joints and longitudinal tensile tests, the laminates were made up of six "rovimat" layers (each made up of 0°/90° woven rovings loosely stitched to a random mat) ; the laminate thickness is about 6.5 mm.
- For the fracture tests in mode I, the laminates have 4 unidirectional layers in the centre with 4 layers of stitched 0°/90° fibres on each side. Thickness of the central layers is approximately 1 mm, out of the 6 mm specimen thickness. A polypropylene film of 8 mm thick and 75 mm wide was inserted between the 2nd and 3rd central layers to introduce a starter defect.

For single lap adhesive joints, the composite substrates were glued either together or on a E-24 steel sheet, on a lap length of 12.5 mm, with an epoxy adhesive (Ciba Geigy Redux 410). The thickness of the adhesive layer is about 0.2 mm. The composite is bonded either on the mat or on the roving face.

ADHESIVELY BONDED JOINTS

Stress field and damage mechanisms

The stresses in the joint have been analysed in a previous paper (1), they are (Fig.1): σ_{11} the longitudinal tensile stress in the substrates; τ_{13}: the shear stress in the adhesive and in the substrates ; σ_{33}: the transverse tensile stress in the adhesive and in the substrates, which is due to the eccentricity of the loads P.

The stresses are maximum at the ends of the bond in both the adhesive and the adherends. Due to the thickness of the composite substrates, the normal stress σ_{33} is very high and exceeds the transverse strength of the composite. So a main crack initiates in the composite substrate in the point where σ_{33} is maximum:

- At B_1 in composite/composite joints ; at this point the ratio σ_{33}/τ_{13} is equal to 1.2, inducing a crack propagation in mixed mode I+II;
- At B_2 in composite/steel joints. At this free edge of the composite substrates, the shear stress is nearly equal to 0. In this case, the crack propagates predominantly in mode I.

It has been shown (1) that the crack initiation can be detected by the loss of linearity in the tensile curves of the joints (Fig.2).

Strain rate effect

The mechanical behaviour of the joints is studied as a function of the strain rate. The samples are loaded in tension with different crosshead speeds. For example, the load extension curves of composite/composite joints are given in Fig.2 for three strain rates 10^{-5}, 10^{-3} and 10^{-2} s^{-1} (corresponding to 0.05, 5 and 50 mm/mn). Those joints exhibit an "unusual viscoelastic" behaviour: the ultimate tensile stress decreases when the strain rate increases. Furthermore, it seems that this rate effect is more due to the crack propagation than to its initiation because the non linear knee is nearly the same for the three strain rates (Fig.2). To confirm this strain rate effect, a large number of tensile tests have been made on both composite/composite and composite/steel joints with strain rates of 10^{-4} and 10^{-1} s^{-1}, the results are summarised in Fig.3.

It can be seen on those that:

i) At the higher strain rate (10^{-1} s^{-1}), the fracture strength is nearly the same for all the samples whatever the type of joint, composite/composite or composite/steel and whatever the fibre layer mat or roving near the bonding. The joints fail just after the crack initiation without a propagation stage, that means that strain rate does not effect the damage initiation level. Furthermore, the previous study has shown (1) that the crack initiation depends only on the mechanical properties of the resin of the composite substrate and not on the fibre layer roving or mat.

ii) At the lower strain rate (10^{-4} s^{-1}), the fracture strength of the joints depends on the type of the bonding and it has been shown (1) that the propagation stage depends on the fibre/resin interface. So, this confirms that the strain rate influences essentially the crack propagation stage.

iii) Globally, the loss of strength with the increasing strain rate is more pronounced on composite/steel samples than on composite/composite joints. That means that this « unusual viscoelastic » effect is due to the particular mode of crack propagation which depends on the stress field in the composite substrate, namely it seems that this strain rate effect is due mainly to the mode I propagation which is predominant in composite/steel samples.

TRANSVERSE TENSILE AND MODE I FRACTURE TESTS

The transverse tensile tests have been made on 6.5 and 12 mm thick square samples (25 mm^2) from 6 10^{-5} to 6 10^{-1} s^{-1} (0.05 up to 500 mm/mn). The influence of rate on the rupture strength of the composite is very slight (Fig.4).

Fracture tests have been made in mode I on Double Cantilever Beam samples from 0.5 mm/mn to 1 m/s corresponding to mean crack speeds from about

15.10^{-6} up to 6 m/s. The analysis of these tests was made as recommended in the ESIS protocol (2), G_{Ic} was calculated with the corrected beam theory. In fact, the crack propagates in an unstable manner with a succession of high speed propagations and arrests. Fig.5 shows G_{Ic} at the initiation (G_{ci})and arrest (G_{ca}) of the first load jump versus the crosshead speed, G_{ci} decreases when the crosshead speed increases The crack jumps are very large at the lower speed (0.5 mm/mn) and become smaller and smaller as the speed increases, they disappear between 50 and 500 mm/mn. This is characteristic of stick slip phenomena which has been highlighted on epoxy resins (3,4).

CONCLUSION

Although the stress field is much more complex in the joints than in the above tests, the strain rate has a greater influence on the crack propagation than on the crack initiation in the composite substrates. So for composite/composite and composite/steel joints, when the rupture occurs in the composite substrate, the tensile strength of the joints decreases with an increase of the strain rate owing to a stick slip phenomenon during the crack propagation. In the case of uncured polyester resin, this behaviour is very influenced by the structure of the polyester which is unstable, it has been shown that the crosslink ratio and the Tg have a strong influence on the rupture mechanisms of the resin (5).

SYMBOLS USED

G_{Ic} = energy release rate in mode I (J/m^2)

G_{ci} = energy release rate at the crack initiation

G_{ca} = energy release rate at the crack arrest

σ_{11} = longitudinal tensile stress (MPa)

τ_{13} = shear stress (MPa)

σ_{33} = transverse tensile stress (MPa)

m/m = composite/composite joint with the composite glued on the mat face

r/r = composite/composite joint with the composite glued on the roving face m/s = composite/steel joint with the composite glued on the mat face

r/s = composite/steel joint with the composite glued on the roving face

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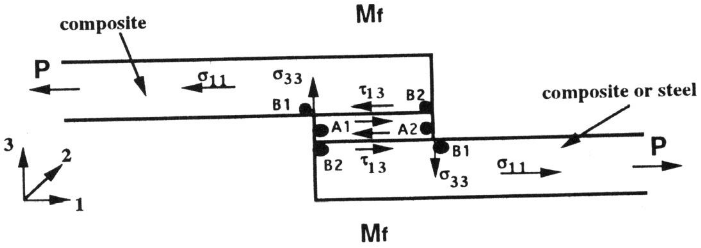

For P = 2000 N

composite/composite joint

	in B1 :	**in B2 :**
σ_{11}	**= 70.7 MPa**	**2 MPa**
τ_{13}	**= 14.4 MPa**	**-> 0**
σ_{33}	**= 17.5 MPa**	**5 MPa**

composite/steel joint

	at B1 :	**at B2 :**	**Fracture strength**
σ_{11}	**= 52.2 MPa**	**3.6 MPa**	**176.5 MPa**
τ_{13}	**= 16 MPa**	**-> 0**	**25.8 MPa**
σ_{33}	**= 8 MPa**	**25 MPa**	**8.3 MPa**

Figure 1 Stresses in composite/composite and composite/steel bonded joints

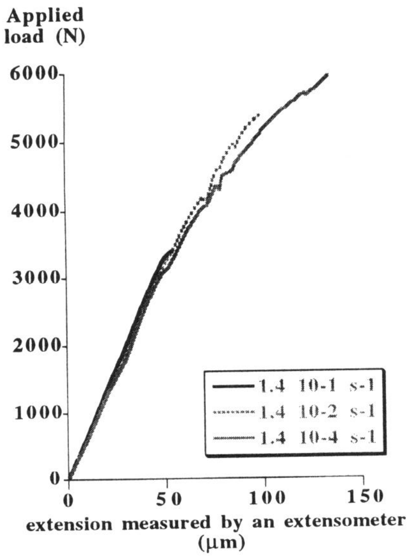

Figure 2 Load/extension curves for composite/composite joints.

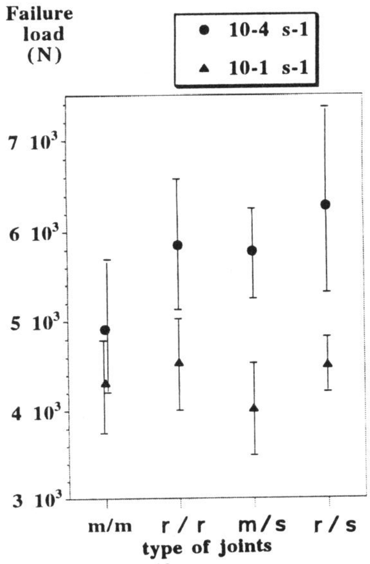

Figure 3 Failure strength at two strain rates for different type of joints.

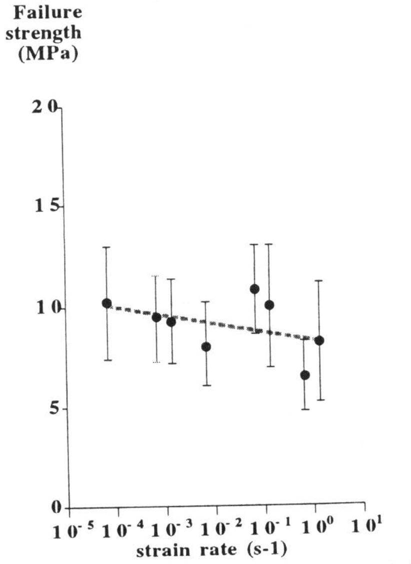

Figure 4 Transverse tensile strength of the composite as a function of the stain rate.

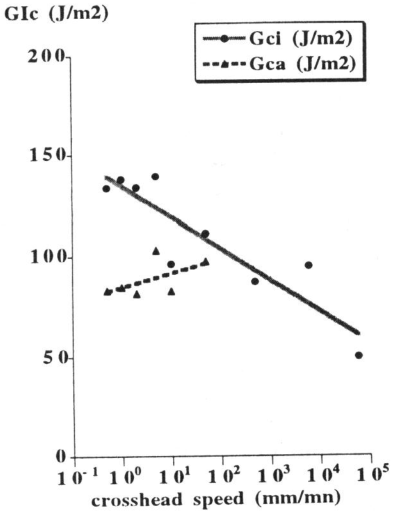

Figure 5 G_{Ic} of the composite as a function of the strain rate.