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Fretting of glass fibre reinforced composites

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Favourable specific mechanical properties of polymer matrix composites make them an attractive material for application in many engineering structures for which they offer substantial improvements over metals. The paper deals with fretting behaviour of unidirectional glass epoxy composites/metal contacts. Fretting is a plague for many industries: failures, loss of matter, loss of function can be induced by fretting. It occurs in all quasi-static contacts and appears as a complex wear phenomenon where a lot of parameters have been studied. From the interface tribology concept, the velocity accommodation mechanisms are discussed for different fibre orientations versus the contact surface of the glass fibre reinforced epoxy material. Results were analysed in two steps. From friction logs, Running Conditions Fretting Maps (RCFM) were first plotted in order to give an analysis of contact conditions and determine the associated material responses. The tribological degradations were then analysed. Differences between the different fibre orientations are mainly discussed on the basis of the stiffness of the anisotropic material and the velocity accommodation in the contact. *© 1999 Kluwer Academic Publishers*

1. Introduction

It is well known that fretting can reduce the reliability of industrial components. Extensive research has been carried out on the elaboration of new materials and coating, but very few are actually used because of insufficient knowledge of their use properties such as fatigue or wear. Industrial applications of polymer matrix reinforced with continuous fibres (FRP) in unstuck assemblies with metallic components can in particular be limited by fretting processes occurring during small amplitude vibrational contact. Furthermore, any search for palliatives against this damage is made difficult as fretting properties are not intrinsic properties and can not be predicted from well established laws. As a result, fretting behaviour can not be extrapolated from one application to another. Knowledge of the material functional properties in the considered use conditions is therefore required for any improvement of the composite material structure and composition.

This study is focused on the fretting behaviour of unidirectional glass epoxy composites against metallic counterfaces. This behaviour is analysed through wear maps which give an accurate analysis of the loading conditions in the contact area and the associated material response. It is assumed that contact conditions depend on both external loading [1–3] (normal load, displacement amplitude, temperature....) and the fibre orientation and nature [4–6]. The latter are analysed through interface tribology concepts which attempt to describe wear strength from third body behaviour [7] and velocity accommodation mechanisms.

2. Experimental

2.1. Fretting device

Fretting tests were performed using a modified tension-compression hydraulic fatigue device (Fig. 1). A reciprocating displacement is imposed on the first sample (1), mounted on the piston (3). The second sample (2) is attached to the frame via a holder. The electronic signal for imposed displacement has a triangular shape in order to have a constant velocity. The normal load P is imposed at the test start by a brace which is connected in series with a dynamometer (not shown). The holder can be adjusted in two directions to allow a correct localisation of the contact area. Tangential load and displacement are monitored continuously.

Tests were performed in a conditioned room ($22 \pm 2\,^{\circ}$C and 50 ± 10% RH). All the results were obtained under a frequency of 5 Hz. The normal load was 300 N and the imposed displacement was set between 10 and 50 μm.

2.2. Test samples and materials

Spherical metallic specimens are rubbed against a composite flat. The FRP studied was an unidirectional E

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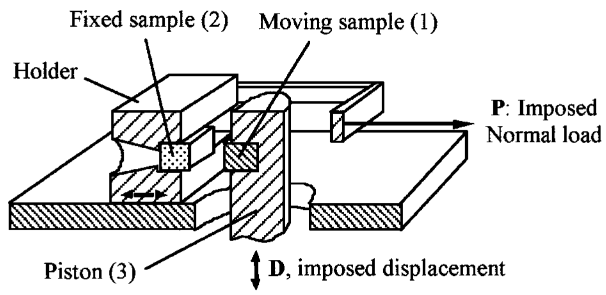

Figure 1 Fretting device.

glass fibre-epoxy resin composite obtained by filament winding. Fibre volumic fraction was 50%. Parallelepipedic specimens 30 × 10 × 3 mm^3 were cut in plates.

In order to locate the contact area, a 20 mm ball made out of 100 C6 ball-bearing steel was used as a metallic counterface.

Two fibre orientations have been considered (Fig. 2):

- Parallel orientation (P): The glass fibres are in plane and parallel to the sliding direction (D).
- Anti-parallel orientation (AP): The glass fibres are in plane but perpendicular to (D).

2.3. Friction logs and local loading conditions

Tangential force F–imposed displacement D cycles were plotted versus the number of cycles in a three-dimensional curve called friction logs. Depending on normal load, displacement amplitude and fibre orientation, three fretting regimes can be distinguished from the analysis of these friction logs (Fig. 3):

- The stick regime is defined from F–D cycles remaining closed due to a linear increase of the tangential load with the displacement. The elastic deformation of the device and the samples accounts for the accommodation of the imposed displacement.
- The gross slip regime is characterised by quasi-rectangular cycles with an initial increase in the maximum tangential load obtained at the end of each cycle.
- Changes from quasi-perpendicular cycles to elliptic cycles during the fretting test are characteristic of the mixed regime. A stuck central contact region associated with sliding around it.

From testing different sets of experimental conditions, it is possible to plot Running Conditions Fretting Maps (RCFM) which localise these three different regimes in a normal load-displacement diagram (Fig. 4). It can be noted that change from P to AP orientation induced an increase in the stick regime area and a shift of the mixed and gross slip regime to high imposed displacement. For a considered set of normal load and imposed displacement, the resulting fretting regime thus depends on the fibre orientation of the anisotropic composite material.

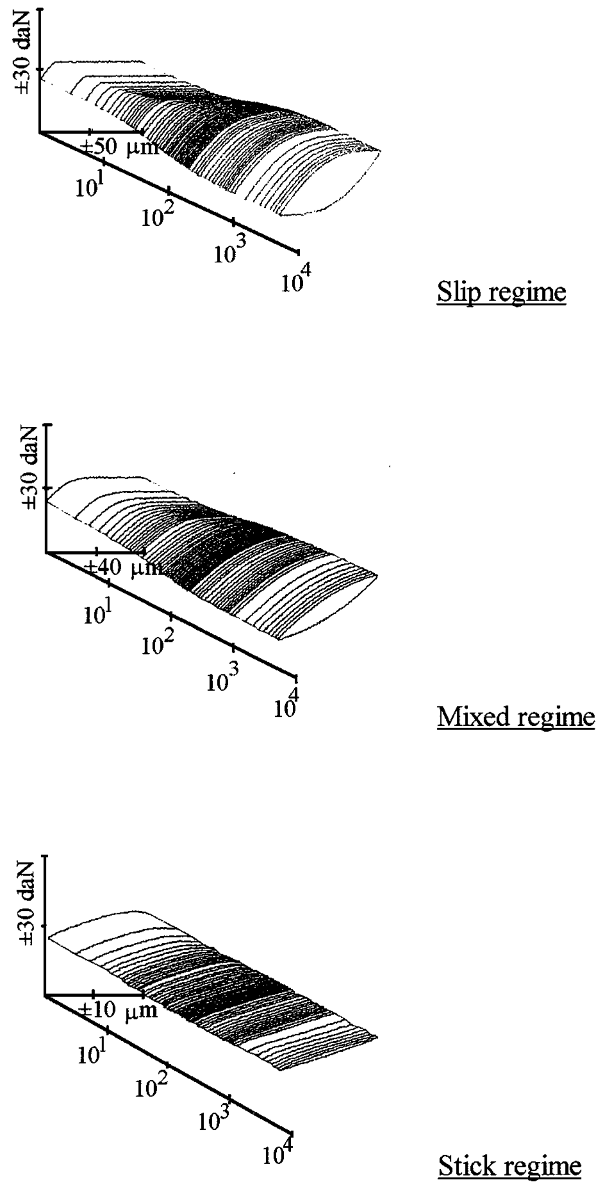

Figure 3 Friction logs corresponding to the three fretting regimes (AP orientation).

This effect can be explained by considering how the velocity is accommodated in the contact and the

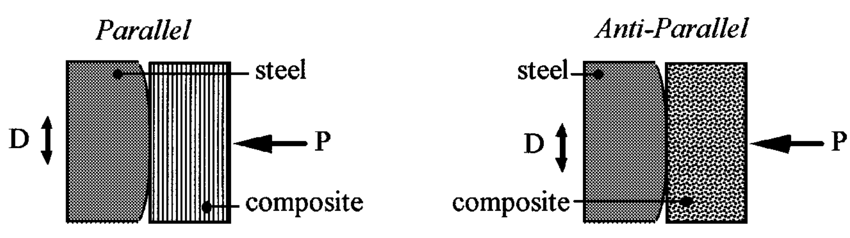

Figure 2 Fibre orientation.

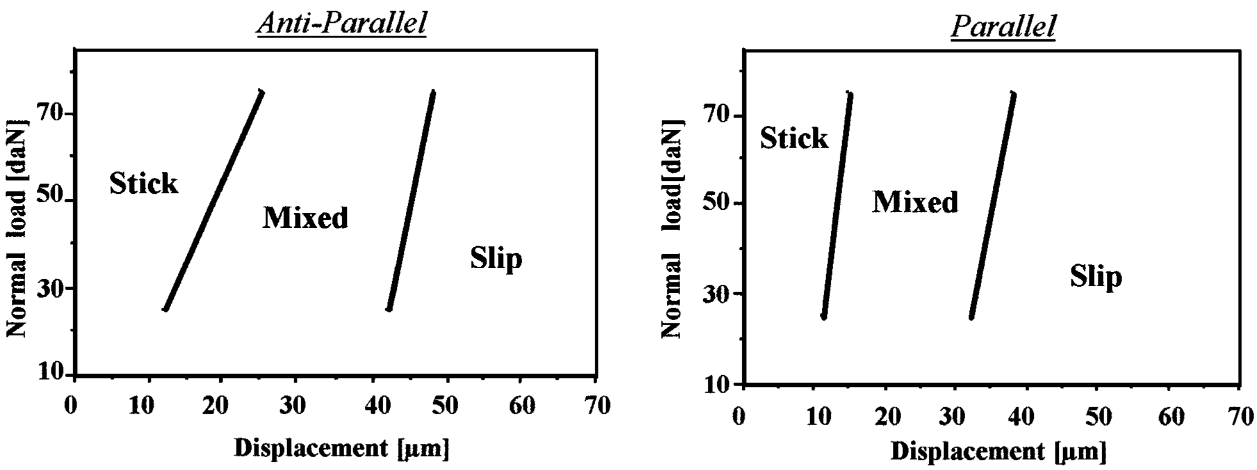

Figure 4 Running conditions fretting maps.

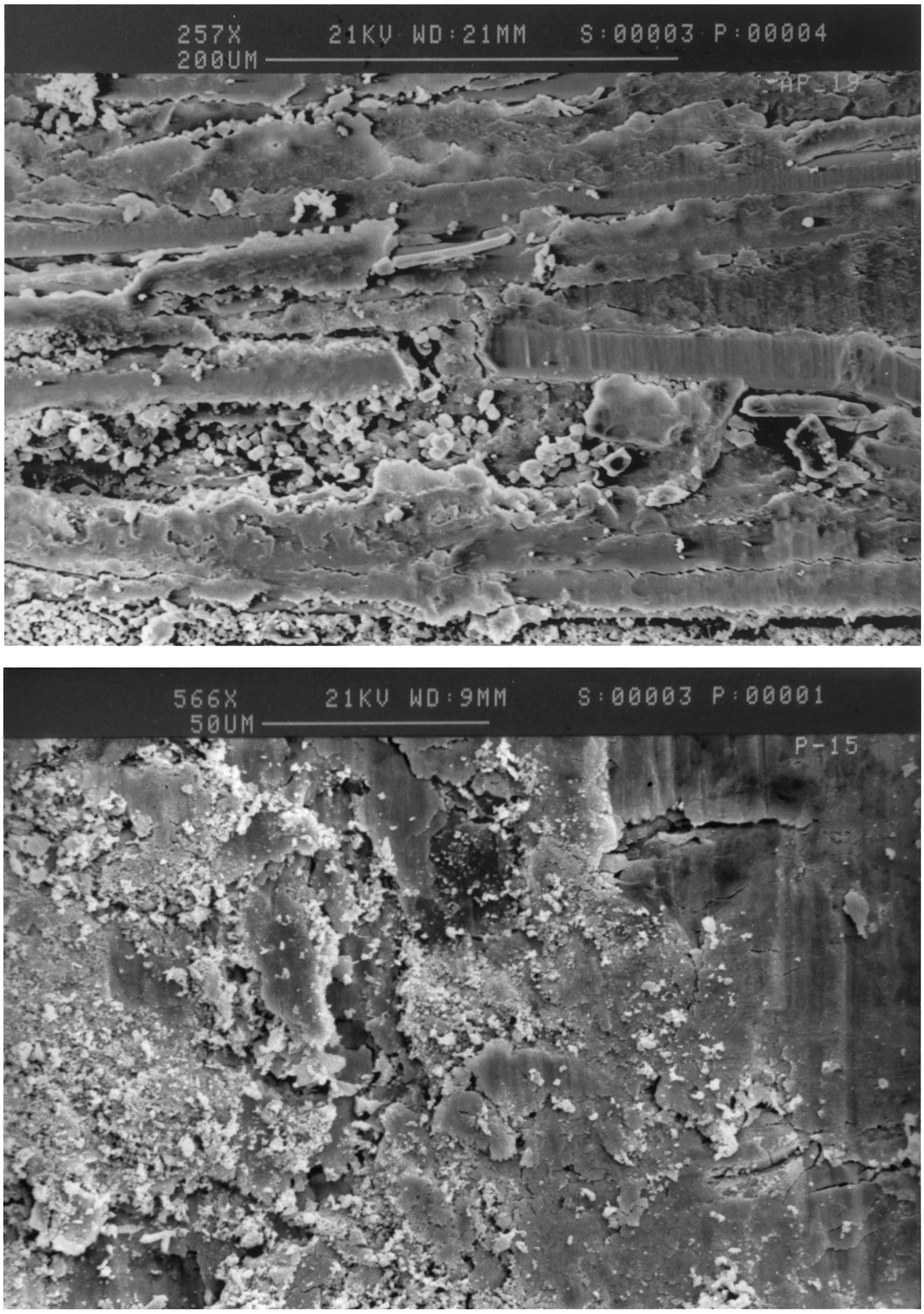

Figure 5 Composite damaging: (a) FMB and (b) PD.

decreasing stiffness of the FRP specimen, from the P to the AP orientation: the displacement accommodation mechanism by bulk elastic deformation is then enhanced and the real displacement in the contact area becomes smaller.

2.4. Material response

After testing, both counterfaces were analysed using optical and scanning electron microscopy (SEM). These analyses permitted the identification of several kinds of damage appearing in the composite materials. Two kinds of damage were simultaneously noted:

- The breaking of glass fibres which could separate from the matrix and form glass fragments.
- Crazing of the matrix with the formation of platelets.

This damage is called Fibre and Matrix Breaking (FMB) (Fig. 5a).

An increasing displacement amplitude could induce the formation of a powder bed (third body) which was shown to contain glass particles, matrix powder and small platelets and also iron oxides. This damage is called Particle Detachment (PD) (Fig. 5b).

3. Conclusion

The fretting behaviour of heterogeneous metal/FRP contacts has been analysed using an approach based on friction logs and fretting maps. The same external loading (normal load, imposed displacement) has been found to induce far different local loading in P and AP orientation. These different local loadings due to composite anisotropy resulted in different damage processes and velocity accommodation mechanisms, especially when metallic debris formation and trapping in the contact are considered.

Predicting differences in the fretting behaviour through material properties must thus be avoided if it is not certain that local loadings are similar.

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