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Modeling of Carbon/Carbon Composites under tribological Solicitations

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ABSTRACT

The present work proposes a methodology study of Carbon/Carbon composites under dynamical stress and conditions of rubbing contact. It is based on the use of finite elements method (FEM), and homogenization technique is applied an elementary cell of composite under contact condition. The comparison of random equivalent representative volume element underlines the importance to take into account the contact interface in such process.

INTRODUCTION

Due to their low density and their exceptional thermo-mechanical properties, carbon/carbon composites replaced “metal” materials and are became inescapable today in many industrial applications, such automobile or aeronautical problems. Such materials are composed of a pyrocarbon matrix maintained by carbon strands. The matrix is stiffened by carbon fibers and structured in strata. The strands are orthogonal to the strata and have a higher rigidity than the simple carbon fibers. Due to this composition, three scales could be distinguished: a macroscopic scale which represents the considered whole structure, a microscopic scale related to the scale of a fiber and a mesoscopic scale which represents a representative volume element of the composite (RVE).

Under aeronautical braking conditions for example, strong couplings occur between these different scales. These couplings concern the mechanical properties of the material but also thermal and physico-chemical ones [1]. Even if experiments still necessary to understand the different physics of C/C composite, experimental investigations could become expensive and limited when the local dynamic is investigated. Thus numerical tools are necessary to understand and predict the dynamical behavior of such material under tribological solicitations (pressure and shear velocity).

Among available numerical tools, Finite Element approaches [2, 3] seem the most appropriate. They allow to separate the different phenomena involved during the processes as well as to determine the role of different scales, and consequently the local dynamical behavior (stress, strain, local vibrations...).

Previous works using such approaches [4] have point out stick-slip contact instabilities under tribological solicitations. Four different types of contact instabilities could be distinguished: sliding-detachment, adherence-detachment, sliding-adherence, and sliding-adherence-detachment. For sliding-detachment instabilities, two regimes could be defined:

- LSR regime: regime with Large Sliding Rate, contact points are sliding more than detached;
- LDR regime: regime with Large Detachment Rate, contact points are detached more than sliding.

In this work, Finite Element approaches are applied to the mesoscopic scale of the material. To assure the representativeness of the material, several heterogeneous models, called morphologies, are studied (i.e. different strand repartition within the matrix) with the same percent of strands in the whole volume.

A previous study has been performed on the contact between a C/C composite and a steel plate (cf. figure 1). According to the rigidity of the steel plate (rigid or deformable) and under dynamical conditions (different pressures) heterogeneous models present different instabilities regimes. But a set of heterogeneous models which has a similar instability in contact deformable/rigid has a similar instability in contact deformable/deformable. The regimes of instabilities in contact deformable /deformable and deformable /rigid may be different.

Such differences are characterized by a “skin effect” at the contact interface. Indeed, the analysis of the distribution of strands in the volume point out a relationship between the strand distribution at the contact interface and the behavior of heterogeneous models. In this study, homogenization techniques have been used [5, 6] to reduce the CPU time which could be prohibitive with the type of applications. But the main difficulty remains the use of such techniques under dynamical contact conditions. And homogeneous models could conceal the local behavior.

In the optics of a realistic modeling of the problem of braking, works with conditions of contact between composite is proposed with the same solicitations conditions to check the different influence, particularly the strand distribution at the contact interface, and to determine their role in local dynamical behavior, as well as the mechanical response of the composite in macroscopic scale.

NUMERICAL MODEL

The finite element model used in the present work is based on a forward increment lagrange multiplier method [8, 9], alternative formulation of the lagrange multiplier which is compatible with explicit time integration scheme. The approach is implemented in the code PLAST2 [10]. The local contact problem is solved using Lagrange multipliers and a Prakash-Clifton law to manage the local friction [9]. The law suggests that there is no direct relationship between the normal and tangential evolution of stresses. The law proposes a gradual change of the tangential stress which intervenes after a certain time or on a certain distance. To traduce this purpose, two parameters are necessary: the standard coefficient of friction which describes the relationship between the normal and the tangential stress, and the time regularization κ which intervenes during the disturbance.

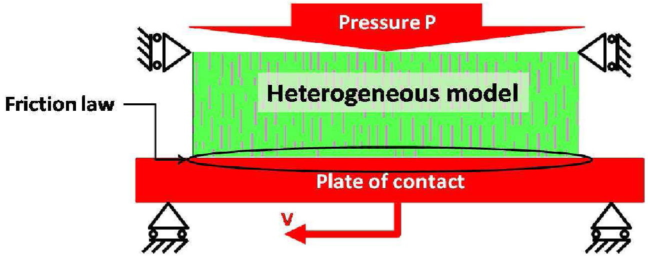

Figure 1: Numerical model

Four heterogeneous models with a random distribution of heterogeneities (strands) have been used. These models (56mm length and 16mm height) have an identical volume rate of heterogeneities (10%). The Young modulus of heterogeneities and the matrix are respectively equal to 240GPa and 30GPa. The matrix and the strands have the same density (1770kg/m3) and the same Poisson ratio (0.2). For each model, a homogenization is performed and lead to a set of homogeneous models with variation in their properties less than 0.3%. In consequence, an equivalent homogeneous is chosen for which the properties are obtained from the average of four homogeneous models properties.

One recall that the driven sliding velocity V is equal to 2m/s, the friction coefficient is equal to 0.25, and the time of regularization is equal to 300dt (with dt=5ns).

As in the previous study, different cases of loading are studied. The global coefficient of friction is obtained as the ratio between the sums of forces in the sliding direction on the sum of force on the orthogonal direction applied on the upper side of the model (cf. figure 1). This coefficient corresponds to the one measured experimentally, and allows to take into account the influence of the dynamics as well as the distribution of the waves in the material. The vibrations inside the contact are also determined locally during the simulation. The internal and external energies, obtained respectively with the internal and the external forces, are determined during the simulation.

RESULTS

Simulations of models show that the temporal evolution of global friction coefficient is characterized by periodic changes of amplitude. This phenomenon known well in acoustics is called beat phenomenon (cf. figure 2). It is the result of neighboring frequency vibrations of two bodies in contact. In such simulations, the period of beats could be different according to models and solicitations.

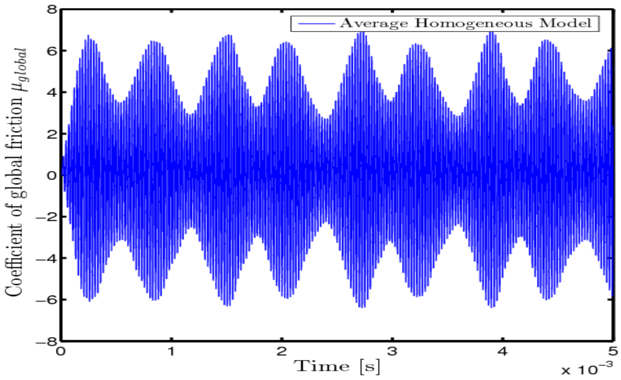

Figure 2: Temporal evolution of global friction coefficient

For an applied load of 0.5MPa, some models present a temporal evolution of coefficient of friction with a decrease of amplitude (cf. figure 3a). This decrease of amplitude comes along with a strong increase of stored energies (cf. figure 3b) and with a strong concentration of shear stress (cf. figure 3c).

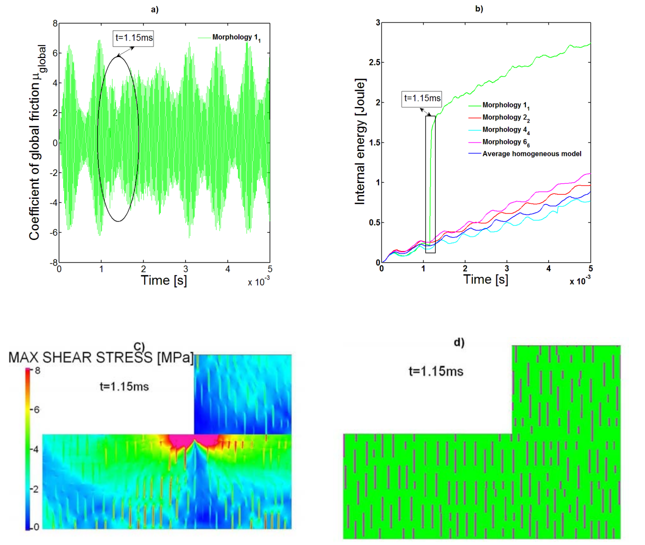

Figure 3: a) Temporal evolution of coefficient of global friction of morphology 1; b) Stored internal energy of models; c) Field of maximal shear stress and d) Position of strands at contact interface to a moment of the simulation

The observation of the geometry of morphology 1 (cf. figure 3d) at the time which the effect are produced shows positions of heterogeneities on the matrix at the contact interface. These positions implicate local impacts which lead to an increase of the local shear stress and consequently modified the local dynamics as well as the global coefficient of friction.

The instabilities at the contact interface are also determined during the simulation. The results (cf. figure 4) show that morphologies have a **LSR** instability regime (≈80%). However, profiles of contact interface are different according to the distribution of heterogeneities in the contact: morphologies 2 and 6 (group 2) have a similar profile while morphologies 1 and 4(group 1) have the same profile.

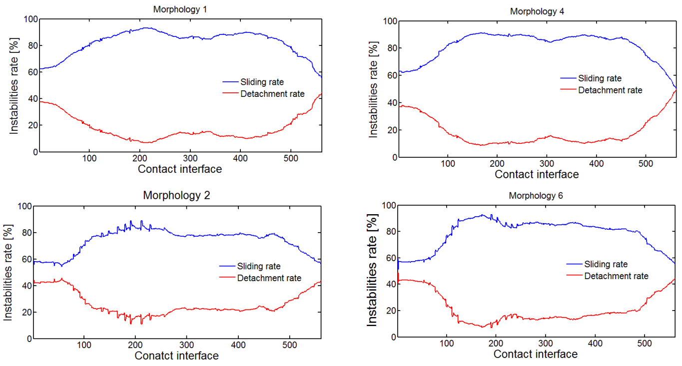

Figure 4: Instabilities rate at the contact interface

These results consolidate the influence of the distribution of strands at the contact interface observed with contact between composite and steel.

CONCLUSIONS

The importance of the choice of the model has been underlined when the contact between C/C composite is investigated.

Representing contact between C/C composite by a contact C/C composite and steel plate do not allow observing the behavior. Even if the grouping of morphology seems independent of the contact properties, response of the material differs from a model to another one. Especially the contact of composite presents the beat effect invisible if the plate is too rigid. Moreover, the contact strand/strand at the interface could create an increase of internal energy which could have large repercussions on the composite structure (local flash temperature, degradations…). Such point underlines the importance of the representativeness of the material.

Thus, a better understanding of strand distribution effects, particularly at the contact interface, could allow controlling the local maximal stresses, consequently to check the damage or the detachments of particles of the material.

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