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HOMOGENEOUS APPROACH FOR COMPOSITE UNDER DYNAMIC CONTACT WITH FRICTION

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ABSTRACT

An explicit dynamic 2D finite element model of a composite under dynamic tribological loading is proposed. The software used for this kind of application manages contact conditions thanks to the Lagrange multipliers. The kind of contact is a deformable against rigid surface one.

First of all due to ill-posedness of the classical Coulomb friction law, a regularized Coulomb friction law that allows local and global convergence of the models even under the presence of contact instabilities is proposed. This friction law is experimentally motivated and is similar to the simplified "Prakash-Clifton" law.

In a second time the dynamic tribological behavior of the composite is studied by the mean of different models where the heterogeneities of the material are explicitly introduced. Those heterogeneous models stand for a description of the microscopic scale of the composite. A comparison is made between the results given by these heterogeneous models and the results obtained by the analysis of a homogeneous model.

The elastic properties of the homogeneous model are obtained through classical homogenization process which is suitable here because the scale separation, difference between the size of the heterogeneities and the wavelength of the loading, is sufficiently important. The homogeneous model represents the macroscopic scale of the composite.

Equivalence between heterogeneous models and the homogeneous one is straightforward if the contrast of Young's modulus between the heterogeneities and the matrix is sufficiently low and if the local contact dynamic is stable. This equivalence has been observed for different contact instabilities like slip-separated, and stick-slip-separated ones. When the equivalence between the models is not ensured, because of high contrast of elastic properties for example, an adaptation of the dynamic parameter of the friction law is necessary to retrieve this equivalence.

Finally the determination of the stresses and their evolution along the time in the heterogeneities and in the matrix is performed thanks to the relocalization process. This process is mixing dynamic analysis of the homogeneous models and fast static calculations on heterogeneous model.

This process has already been applied to structures submitted to static loading but to our knowledge this is the first attempt to use it for dynamic contact problems.

So this work highlights a full multi-scale approach for composite under dynamic contact with friction loading.

INTRODUCTION

Numerical or analytical problems of bodies rubbing dynamically against one other have been widely studied in the years before.

Recent works have shown that numeric convergence through grid size reduction of dynamic model using classical Coulomb law is often impossible [1] [2]. In fact the dynamic tribological problem in which classical Coulomb law is used is most of the time ill-posed [3][4][5] depending on the friction coefficient and on the difference of the elastic properties of the materials that are rubbing. Cochard and Rice [1] illustrated this ill-posedness by showing that in the unstable range the numerical solutions do not converge. Ranjith and Rice [6] have shown that the particular friction law named "Prakash-Clifton" law regularizes the problem and then numerical convergence is possible. This friction law is implemented in the laboratory finite element code which is used here and convergence is achieved even if contact instabilities [7] are present, as it will be presented in the first part of this study. All the previous works have been performed considering homogeneous and most of the time isotropic materials. To our knowledge this work is the first attempt to develop a homogeneous model of composite under dynamic tribological loading.

Under scale separation assumption the classical homogenization process allows considering heterogeneous materials as homogeneous ones [8]. Although contact with friction problems are strongly coupling different scales, the work presented here shows that the classical homogenization is most of the time suitable for the study of composite under dynamic tribological loading, but for some particular cases an adaptation of the regularization time of the friction law is necessary. This fact will be developed in a second part of this work.

Finally it will be briefly shown that the relocalization process [9] allows determining the stresses present in the heterogeneities and in the matrix.

DESCRIPTION OF THE MODEL AND CONVERGENCE

The method employed here to solve the equation of dynamic over the volume considered is the finite element method. The temporal integration scheme is an explicit one called "β2 method". The management of the Signorini conditions is performed thanks to the Lagrange multipliers. The structure of the laboratory code is detailed in the work of Linck and al [7].

The boundary conditions and the morphology of the composite are presented in the figure1.

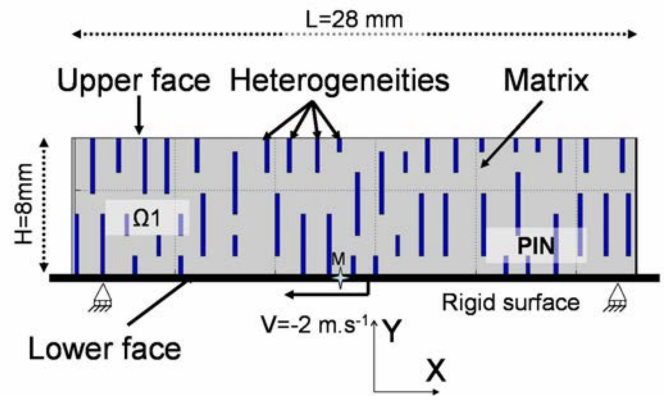

Figure 1 : Morphology of the composite and boundary conditions applied on the model.

The friction law used is resumed in the equation 1. The important fact is that there is a delay, which will be called regularization time, between the normal stress, σ, and the tangential stress, τ, in the contact zone. This regularization time depends on the fraction L^*/V which introduces the time delay in the tangential response of the models. Moreover during slip this friction law tends asymptotically toward the classical Coulomb friction law with an exponential decay rate, L^*/V.

$$\begin{cases} |\tau^*| < \mu|\sigma| \Rightarrow stick : [\dot{u}] = 0; \tau = \tau^* \\ |\tau^*| > \mu|\sigma| \Rightarrow \begin{cases} slip : \dot{\tau} = -\frac{|V|}{L^*}(\tau - \alpha\mu|\sigma|) \\ \exists\gamma \ge 0 \quad s.t. \quad [\dot{u}] = -\gamma\tau \end{cases} \quad \alpha = \begin{cases} 1 & \tau^* \ge 0 \\ -1 & \tau^* < 0 \end{cases} \end{cases}$$

Equation 1 : Regularized friction law.

Here $[\dot{u}]$ stands for the relative tangential speed between a node at the interface and the rigid surface. τ^* is the tangential contact stress calculated under the sticking assumption and V is the sliding speed of the surface. L^* is a length parameter and the dot superscript stands for partial derivative relative to time.

The convergence achieved thanks to this law is illustrated in the figure 2, which represents the tangential speed of the central point, M, of the contact zone against his tangential displacement for 2 different meshes (the element length h is 0.25mm or 0.1mm) and 2 different time steps (Δt=5ns or 2ns).

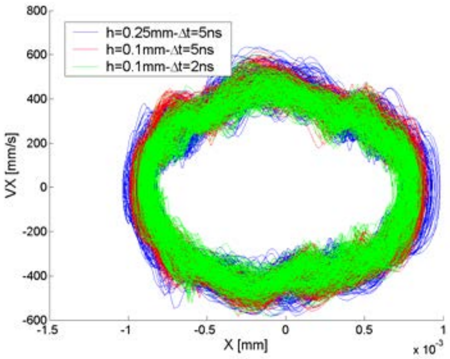

Figure 2 : Convergence through mesh size and time step reduction, using the regularized friction law.

HOMOGENIZATION AND FRICTION

In order to be representative of the composite multiple morphologies have been tested under the same boundary conditions and loading as the one exposed in figure 1. The heterogeneities and the matrix are considered isotropic but have two different Young's modulus. In a first time the Young's modulus of the heterogeneities is 80 GPa and the one of the matrix is 30 GPa. So the contrast of elastic properties is low. For this particular case all the morphologies tested give the same global behavior illustrated by the global friction coefficient which is the ratio of the tangential load measured at the top of the model over the normal load at the same place. It is interesting to note that the local behavior in the tangential direction is also the same for all the heterogeneous models. Moreover the homogeneous model, obtained by classical static calculations, has the same behavior (local or global) as the mean behavior of the heterogeneous models, figure 3. Homogenization gives good results.

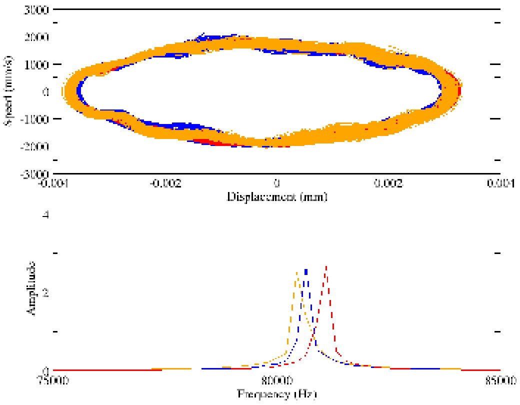

Figure 3 : Local (top: tangential speed of the central node versus his tangential displacement) and global (bottom: spectrum of the global friction coefficient) results for heterogeneous models and homogeneous one. Stick-slip-separated instability.

For other models where the elastic contrast is higher, two morphologies that are macroscopically identical (i.e each of them are identical to the same homogeneous model) exhibit two different behaviours. So the homogeneous model is equivalent only to one of the morphologies. However it is possible to put it equivalent to the other by an adaptation of the regularization time. The new value of the regularization time is determined thanks to a formula that links the local characteristics of the contact instability to the energy passing through the rigid surface toward the composite.

Whatever the elastic contrast is, it is always possible to replace the heterogeneous model by a homogeneous one.

RELOCALIZATION AND FRICTION

In the work presented here the volume taken into account to obtain the homogenized properties of the composite is the same as the one used in the dynamic with friction analysis. It is the same condition as the one encountered by Kruch et al [9]. Those authors have succeeded in determining the local stresses (ie the stresses in the matrix and in the heterogeneities) thanks to the relocalization process. It consists in applying localization tensors, obtained during homogenization process, not, as usual, over the volume averaged stress in the homogeneous model but at each point of the homogeneous model. The same process has been applied here in dynamics and allows a very good determination of the local stresses along the time, figure 4. Just a slight overestimation of normal stress near the contact surface is noted.

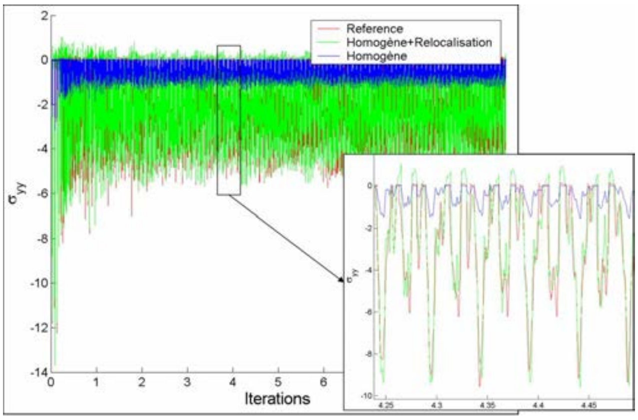

Figure 4 : Comparison of local normal stress obtained by dynamic analysis of heterogeneous model (reference) and by homogeneous model with or without relocalization.

CONCLUSION

This work highlights a full multi-scale analysis of a composite rubbing dynamically against a rigid flat surface. Most of the time the composite can be seen as homogeneous but for high contrast of elastic properties for example a modification of the dynamic part of the friction law is necessary to obtain equivalence between the homogeneous and heterogeneous models.

The relocalization process allows determining the stress in the matrix and heterogeneities and their evolution during simulation without having to mesh the microstructure of the composite. It has been also confirmed that the simplified “Prakash-Clifton” friction law allows good numerical convergence through grid size and time step reduction.

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