EFFECTS OF RESIDUAL STRESSES INDUCED BY SHOT-PEENING ON CRACKS PROPAGATION

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Shot-peening is a surface-treatment which induces some important residual stresses of compression. The problem of a plane crack under residual stress field in a tridimensional elastic body is studied, within the scope of Linear Fracture Theory. The energy release rate is computed using two methods that take into account of residual stresses. Numerical results are compared for different types of Shot-peening and with different sizes of cracks.

INTRODUCTION

Shot-peening is a surface-treatment used by many aeronautical firms. It consists in projecting some shots on surface (for example, in this case, disks for motor planes), that generate some residual stresses of compression after a certain period. Obtained stresses extend to a small depth compared to the entire width of structure. S.N.E.C.M.A., participating to these studies, checked this phenomenon increased the life-time of certain engine parts and would like to take into account of shot-peening in life-time computations. Firstly, the purpose of this work is to study the effects of residual stresses on parameters of Linear Fracture Theory for a plane crack in a tridimensional geometry. In this aim, two energetic processes have been computed : G-θ method (1) and Virtual Crak Extension Technique (VCE) (4).

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RESIDUAL STRESSES

H. GUECHICHI et al. (5) have developed a complete procedure to simulate shot-peening. Our purpose is not to do the same, but we are assumed to take the same assumptions, particularly to consider shot-peened structure as a semi-infinite body. Consequently, a linear relation could be established between plastic strain induced by shot-peening and associated residual stress. Then, the procedure consists in simulating condition of semi-infinite body by an elastic Finite Element calculation, after introducing experimental values of plastic strain at Gauss points. Therefore, one can simply obtain residual stresses, only by the knowledge of plastic strain due to shot-peening. This simple process could also be used in two-dimensional cases with generalized plane strain assumption.

ENERGETIC METHODS

G-θ method

Computation of θ-field. This theory was developed by DESTUYNDER (1). Virtual-kinematic of crack-front is described by θ-field. In our case, θ has two components in the crack-plane, θ_1 and θ_2, that are interpolated by B_3-splines (2), (3). This interpolation allows us to disconnect representation of crack-front and θ from Finite Element Mesh. θ-field is defined in a domain Ω which surrounds crack-front γ_f. Then, θ_1 and θ_2 are given by

$$\theta_i\left(\xi_1, \xi_2, \xi_3\right) = f^i\left(\xi_1\right) g^i\left(\xi_2\right) h^i\left(\xi_3\right) \quad ; \quad i=1,2 \tag{1}$$

$$\text{where } f^i\left(\xi_1\right) = \sum_{j=1}^{4} p_j\left(\xi_1\right) \beta_i^{j+n-1} \tag{2}$$

and g^i and h^i are bell-shaped third order polynomial functions. The spline coordinates β_i^j are unknown and act as parameters.

Computation of Energy release-rate G. First of all, let us assume that during crack propagation, domain Ω becomes Ω^η. Therefore, one can define a mapping F^η that represents physically the virtual growth of crack. Then, we have to differentiate the potential energy P with respect to η, during this virtual growth. This variation is noted

$$\partial P = -\lim_{\eta \to 0} \frac{P^{\eta}(\Omega^{\eta}) - P^{0}(\Omega^{0})}{\eta} \tag{3}$$

This relation can be rewritten as

$$\partial P = -\frac{1}{2}\int_{\Omega} \mathrm{tr}\left(\sigma\frac{\partial u}{\partial M}\right)\mathrm{div}(\theta) + \int_{\Omega} \mathrm{tr}\left(\sigma\frac{\partial u}{\partial M}\frac{\partial \theta}{\partial M}\right) \tag{4}$$

Interpolation chosen for θ allows us to rewrite equation (4) as

$$\partial P = \{f\}^{t}\{\theta\} \tag{5}$$

$\{f\}$ can be viewed as a generalized force and $\{\theta\}$ is the vector of values interpolated by B_3-splines. On the other hand, (1) ∂P can be expressed as

$$\partial P = \int_{\gamma_f} G(s)\,\theta(s)\,ds \tag{6}$$

To go back to nodal values of G along crack-front, let us assume that G(s) has the same discretization than θ(s). Then, G(s) is determined by solving a linear system of equations

$$[M]\,\{G\} = \{f\} \tag{7}$$

where M is a symmetric definite positive matrix.

PARKS method

This theory, well-known in two-dimensional cases, allows also to derive potential energy P. But discretization used in this procedure depends on Finite-Element Mesh. In fact, (4) P could be derived as

$$\partial P = -\frac{1}{2}\{u\}^{t}\partial[K]\,\{u\} \tag{8}$$

$\{u\}$ are the displacement values calculated by F.E.M. and [K] is the stiffness matrix. For each node of the crack-front, let us define a small perturbation da. The associated perturbation of stiffness matrix is expressed as

$$\partial[K] = [K]_{a+da} - [K]_{a} \tag{9}$$

Of course, $\partial[K]$ computation involves elements containing only the perturbed nodes. Furthermore, ∂P can be rewritten as

$$\partial P = \int_{\gamma_f} G(s)\,\Delta l(s)\,ds \tag{10}$$

Δl(s) is a vector normal to crack-front and represents the virtual node extension. With equations (10) and (11), G(s) is given by a scalar equation at each perturbed node.

Numerical Applications

Meshing. A KB specimen (figure 1) of rectangular cross-section was studied using 20-node elements. The θ-support is a torus of rectangular cross-section surrounding the crack-front. It is meshed by four rows of elements in each transverse direction and by eight elements along the front. Different types of cracks have been meshed to see the accuracy of energetic methods. But, in shot-peening cases, the most interesting form of crack is semi-circular. That's the reason why results will be discussed in this situation.

Results and discussion. Two types of shot-peening have been introduced : the first, noted F15A, has a shot-peened depth d_s smaller than radius of crack a. For the other, noted F30A, d_s is larger than a. Figure 2 describes influence on G of different shot-peenings for an uniform loading σ_o. One notices that values of energy release rate decrease with increasing d_s. Then, we check numerically that crack could grow more slowly in presence of residual stresses with a shot-peened depth greater than radius of crack. Furthermore, there is a good agreement between energetic methods in the different cases. Besides, Figure 3 depicts G/G_m versus beta, angle of semi-circular crack, where G_m represents the maximal value of G corresponding to the solution without residual stresses. Considering shot-peening F15A, the energy release rate was computed by increasing radius of crack. These results show that shot-peening has no influence for a radius larger than (50*a). Above this value, results reach those without residual stresses.

CONCLUSION

To begin with, one has implemented a simple process to introduce a known residual stress field due to shot-peening in a standard tridimensional Finite Element program. In the same time, two energetic methods have been processed in order to be able to calculate energy release rate along a crack-front in a tridimensional elastic body. These methods permit to take into account numerically of shot-peening and in the future, to build a tridimensional model of cracks propagation.

SYMBOLS USED

σ_r = residual stress

β_i = spline components

p_j = spline interpolation functions

n = number of spline elements

$\frac{\partial}{\partial M}$ = gradient of a vector

ξ_i = local coordinates

REFERENCES

(1) P. DESTUYNDER, M. DJAOUA, S. LESCURE, Quelques remarques sur la mécanique de la rupture élastique, J. de Mécanique Théorique et Appliquée, Vol.2, No 1,1983,p. 113-135.

(2) A. BENJEDDOU, Une méthode d'élements B-splines pour l'analyse des coques homogènes et sandwich à coeur élastique ou viscoélastique, Thesis of Université Technologie Compiègne,1994.

(3) Y. OUSSET, F. ROUDOLFF, Computation of the delamination force in multilayered composite plates, ICCM10, August 1995, Whistler (Canada).

(4) D.M. PARKS, A stiffness derivative element technique for determination of crack tip stress intensity factors, Int. J. of Fract., Vol.10, No 4, Dec. 1974.

(5) H. GUECHICHI, L. CASTEX, J. FRELAT, G. INGLEBERT, Predicting residual stresses due to shot-peening, 10eme journée nationale sur le grenaillage de précontrainte, Sept. 1986.

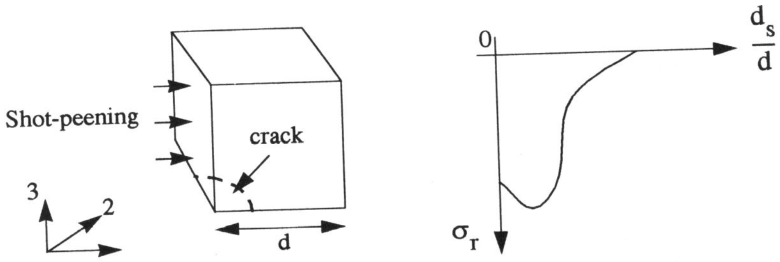

Figure 1.Description of KB specimen and residual stress profile.

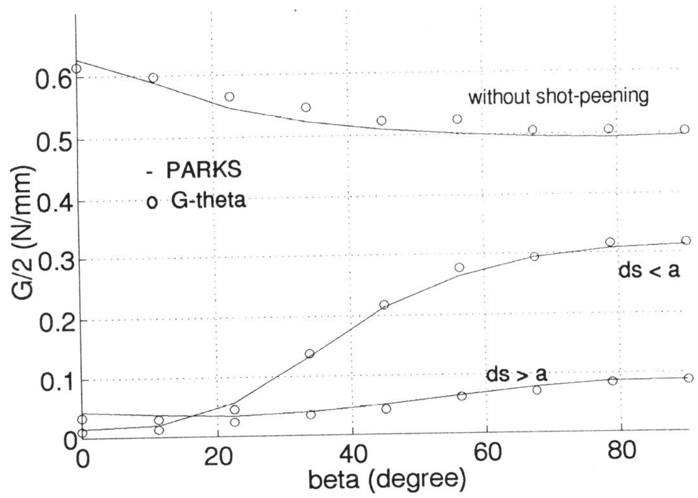

Figure 2.Influence of shot-peened depth.

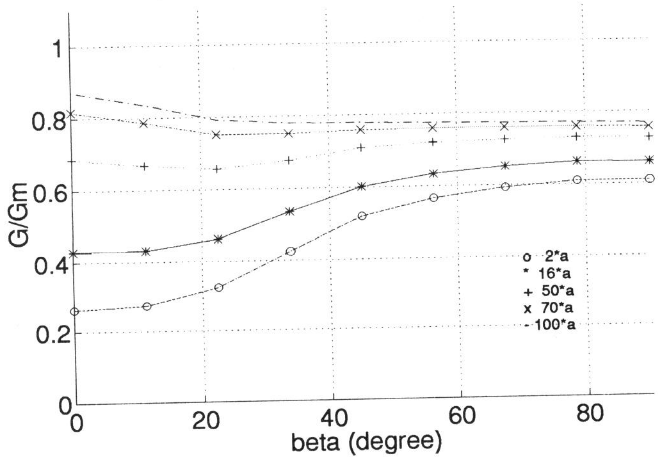

Figure 3.Calculation of energy release rate for different sizes of cracks in presence of shot-peening F15A.