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INITIATION AND CRACK GROWTH PROCESS IN VISCOELASTIC ORTHOTROPIC MATERIALS

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ABSTRACT. A numerical approach about the crack initiation and the crack growth process in a viscoelastic media for mixed mode configurations is proposed in this work. This numerical model couples a resolution algorithm for viscoelastic behaviour and the *Mθ* integral providing mixed mode separation in terms of stress intensity factors and energy release rate. The numerical application is based on the 2MCG specimen allowing, in the same time, different mixed mode ratios and crack growth stability. The algorithm, implemented in a finite element software, allows to model the crack tip advance by taking into account the crack lip decohesion in the process zone. Its size is redefined with complex stress fields in the crack tip vicinity. Finally, the crack growth speed is evaluated by operating a dichotomy resolution in the time step increment required at the crack tip advance.

1. Introduction

The important use of polymers or composites in engineering structures required the best understanding of their fracture mechanical behavior. Also, these materials are often characterized by a viscoelastic response and orthotropic or anisotropic characters. In the most case, these structures are submitted to complex solicitations modifying their mechanical properties and leading to the important damaging and the local micro-crack. In the durability context, it appears very important to drive the evolution speed of the different defaults. That way, new numerical and experimental approaches enable us to understand the crack initiation and the crack growth process in viscoelastic orthotropic materials is required.

In fracture mechanics, the viscoelastic behaviour requires the use of the energetic approaches. The orthotropic character requires also the separation of mixed-modes fractures in the case of complex solicitations. That way, a new tool providing the crack initiation and a numerical crack growth process in time dependent materials is proposed. The analytic method is based on the $M\theta$ integral, generalized by Moutou Pitti [1] [2], in order to separate mixed-modes during the crack tip advanced. The new 2MCG (Mixed Mode Crack Growth) specimen, developed by Moutou Pitti et al. [3] [4], is the combination between the modified DCB (Double Cantilever Beam) specimen [5] and CTS (Compact Tension Shear) specimen [6]. This specimen provides a stable crack growth in imposed load and displacement for different mixed-modes ratios [3]. In this case, the crack process introduces the development of a new process zone on the basis of the Schapery's theory [7].

According to the conservative laws and a combination of real and virtual mechanical fields, the development of the non-dependant integral parameter $M\theta$ in viscoelastic crack growth process is recalled. After, the 2MCG specimen is described. The subroutine of the crack initiation and the crack growth process is based on an energetic criterion. In the process zone, the crack tip advanced is operated by a dichotomy method by computing the corresponding crack growth time and speed. Finally, numerical results providing the energy release rate during the propagation are posted in mixed-mode ratios.

2. Integral parameter

On the basis of the Chen and Shield's works [8], Moutou Pitti et al. [1] have proposed a *M* integral generalized to viscoelastic behaviour. For numerical modelling reason, the $M\theta$ integral, defined on a

surface contour Ω introduced by $\vec{\theta}$ field [9], is preferred. The viscoelastic behaviour is introduced according to a generalized Kelvin Voigt model. In this case, the $M\theta$ integral takes the following form:

$$M\theta_v^{(p)} = \frac{1}{2}\cdot\int_\Omega \left(\sigma_{ij}^{(p)}(u)\cdot v_{i,k}^{(p)} - \sigma_{ij,k}^{(p)}(v)\cdot u_i^{(p)}\right)\cdot\theta_{k,j}\,\mathrm{d}\Omega$$
$$+\frac{1}{2}\cdot\int_\Omega \left(\left(\sigma_{ij}^{(p)}(v)\cdot\left(u_{i,j}^{(p)}\right)_{,k} + \sigma_{ij}^{(p)}(u)\cdot\left(v_{i,j}^{(p)}\right)_{,k}\right) - \left(\left(\sigma_{ij}^{(p)}(v)\cdot\left(u_{i,j}^{(p)}\right)\right)_{,k} + \left(\sigma_{ij}^{(p)}(u)\cdot\left(v_{i,j}^{(p)}\right)\right)_{,k}\right)\right)\cdot\theta_k\,\mathrm{d}\Omega \qquad (1)$$
$$p\in\{0,1,\ldots N\}$$

$\sigma_{ij}^{(p)}(u)$ and $\sigma_{ij}^{(p)}(v)$ represent the real and virtual stresses in the pth spring of the rheological model of which associate displacement are $u_i^{(p)}$ and $v_i^{(p)}$. With equation (1) and virtual stress intensity factor ${}^vK_I^{(p)}$ and ${}^vK_{II}^{(p)}$, the real stress intensity factor, in opening mode ${}^uK_I^{(p)}$ and shear mode ${}^vK_{II}^{(p)}$, are given by :

$${}^uK_I^{(p)} = 8\cdot\frac{M\theta_v^{(p)}\left({}^vK_I^{(p)}=1,\ {}^vK_{II}^{(p)}=0\right)}{C_1^{(p)}} \quad\text{and}\quad {}^uK_{II}^{(p)} = 8\cdot\frac{M\theta_v^{(p)}\left({}^vK_I^{(p)}=0,\ {}^vK_{II}^{(p)}=1\right)}{C_2^{(p)}} \qquad (2)$$

The viscoelastic energy release rate is separated into open and shear parts as follow:

$$G_v^{(p)} = {}^1G_v^{(p)} + {}^2G_v^{(p)} = C_1^{(p)}\cdot\frac{\left({}^uK_I^{(p)}\right)}{8} + C_2^{(p)}\cdot\frac{\left({}^uK_{II}^{(p)}\right)}{8} \qquad (3)$$

${}^1G_v^{(p)}$ and ${}^2G_v^{(p)}$ are the energy release rate of the pth spring in mode I and II respectively. $C_1^{(p)}$ and $C_2^{(p)}$ designate the associate viscoelastic complaisance. That way, the viscoelastic energy release rate summations are given by:

$${}^1G_v = \sum_k {}^1G_v^{(p)} \quad\text{and}\quad {}^2G_v = \sum_k {}^2G_v^{(p)} \quad\text{with}\quad p\in\{0,1,\ldots,N\} \qquad (4)$$

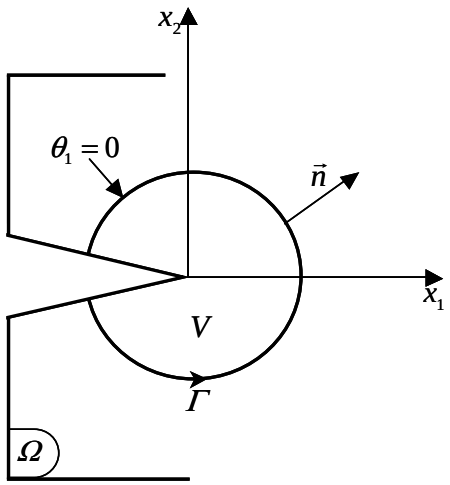

Figure. 1 – Integration domain

3. Mixed mode crack growth specimen

The 2MCG specimen [1] [3], figure 2, is due to, on the one hand, of the combination between a modified DCB specimen [5] and CTS specimen [6], and on the other hand, of the observation of a stability range of the energy release rate, versus crack length, computed numerically with $M\theta$ [3]. In

these conditions, only viscoelastic effects are the cause of the crack tip advanced during creep tests. The new geometry, figure 2, is framed by Arcan fixtures where symmetric holes corresponding to load point application *F*, applied according to mixed mode ratio β , are machined. An initial crack of 20 mm is also machined on wood specimen.

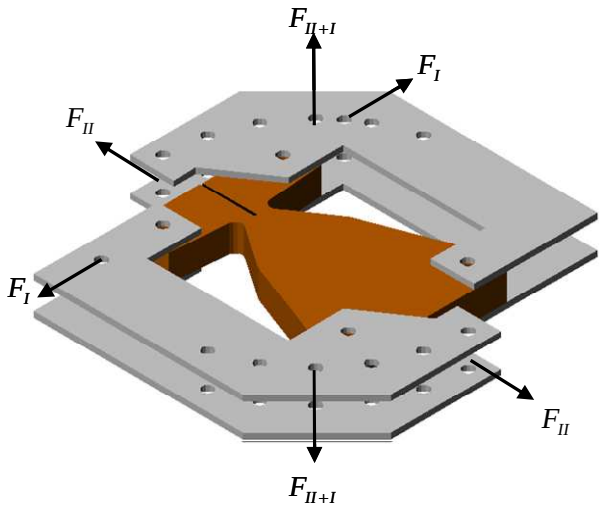

Figure. 2 – 2MCG specimen

4. Numerical algorithm

For mixed mode crack problems, the loading and geometry symmetries are affected by the crack tip advance. In this case, a re-meshing of the numerical model is necessary after each crack tip step. To overcome this difficulty, the hereditary mechanical fields have been projected in the transformed mesh. This complex algorithm must separate the time and geometry variations, figure 3. This algorithm has been explained in detail by Moutou Pitti et al. [1]. Therefore, the crack initiation and the crack growth process introducing by the dichotomy method are added in this complex algorithm and justified in the figure 4.

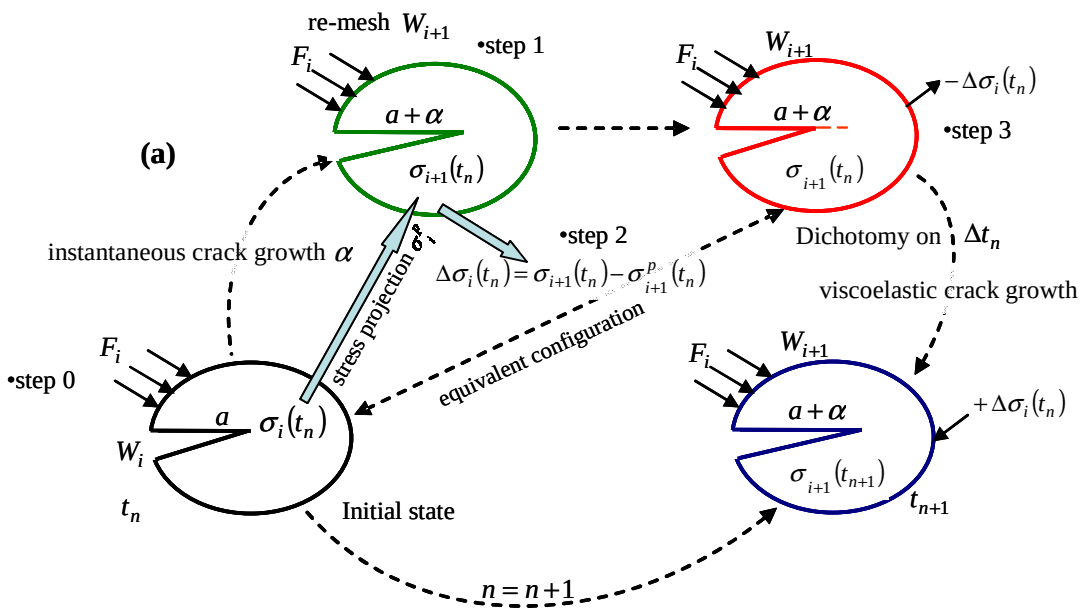

Figure. 3 – Viscoelastic crack growth algorithm

In a viscoelastic and orthotropic media, according to the relation (4), the fracture criteria introduced by the functional f takes the following form:

$$\text{If} \quad f\left(\frac{{}^{1}G_v(t)}{{}^{1}G_c} + \beta \cdot \frac{{}^{2}G_v(t)}{{}^{2}G_c}\right) = 1 \quad \Rightarrow \quad \text{Crack growth process}$$
$$\text{If} \quad f\left(\frac{{}^{1}G_v(t)}{{}^{1}G_c} + \beta \cdot \frac{{}^{2}G_v(t)}{{}^{2}G_c}\right) < 1 \quad \Rightarrow \quad \text{Stationary crack} \tag{5}$$

${}^{1}G_c$ and ${}^{2}G_c$ are the critical experimental values in opening and shear modes [2]. In this work, the coupling factor β is equal to 1.
On the basis of the Schapery's theory, the length of the process zone α in mixed mode is translated by the following equation:

$$\alpha = \frac{\pi}{8} \cdot \left(\frac{{}^{u}K_I}{\sigma_1^{(m)}} + \frac{{}^{u}K_{II}}{\sigma_2^{(m)}}\right)^2 \tag{6}$$

$\sigma_1^{(m)}$ and $\sigma_2^{(m)}$ represent the constant tensile stresses assumption in opening mode and shear mode. In fact, $\sigma_1^{(m)} = 4{,}7 \text{ MPa}$ [1], and $\sigma_1^{(m)}$ is considered as six times more important than $\sigma_2^{(m)}$ ($\sigma_2^{(m)} = 27 \text{ MPa}$). The real stress intensity factor ${}^{u}K_I$ and ${}^{u}K_{II}$, are given numerically by the equation (2) [3].

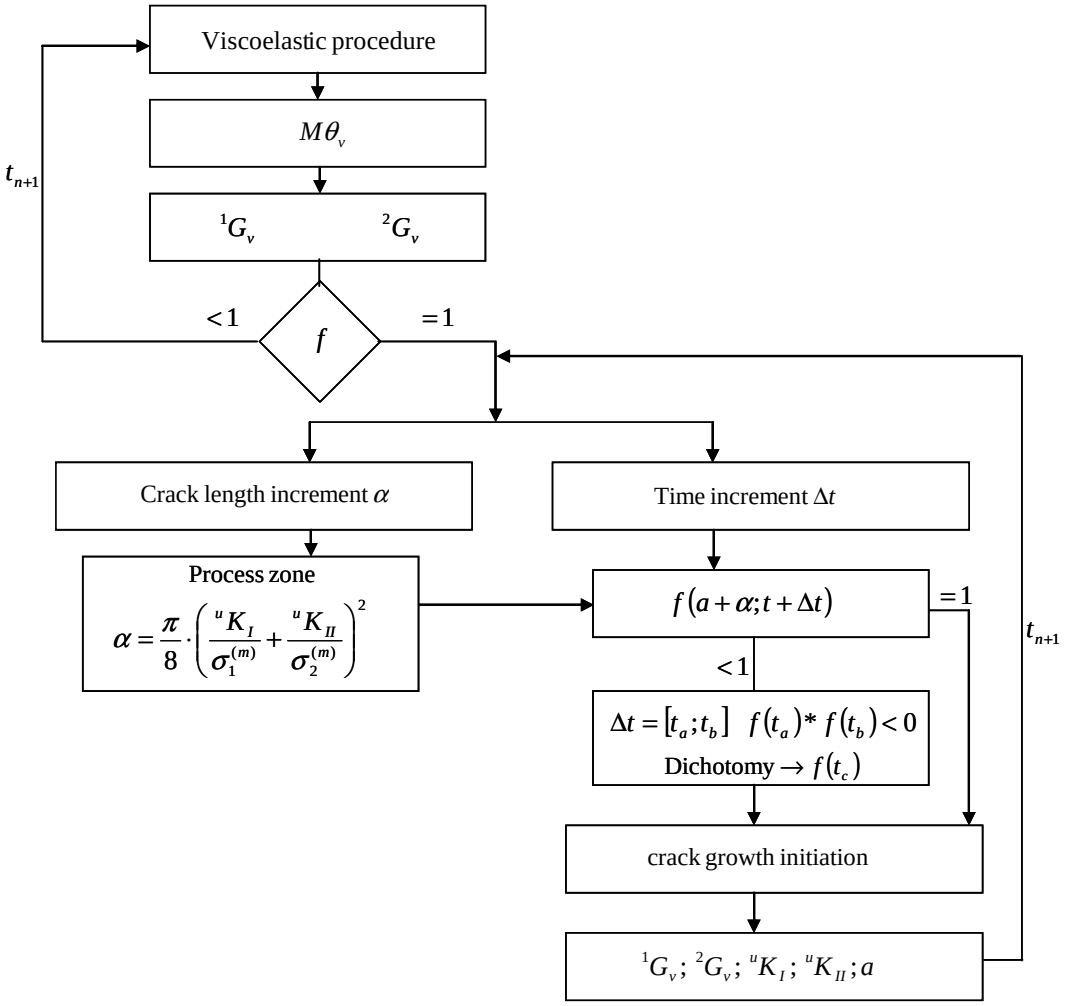

Figure. 4 – Initiation and viscoelastic crack growth algorithm

Figure 4 shows the initiation and the crack growth algorithm including the dichotomy method and the evaluation of the process zone α :

- The first test on the functional f initiate the propagation criteria in mixed mode by taking into account the critical values of energy release rate in opening and shear modes, equation (5). The viscoelastic energy release rates ${}^1G_v$ and ${}^2G_v$ are given by equations (3) and (4) applied in the viscoelastic procedure, figure 3.
- If $f = 1$, two simultaneous calculations have performed: the length of the process zone α with equation (6), and the time increment Δt .
- In that specific case, if $f(a+\alpha; t+\Delta t) = 1$, the crack growth process is initiated. Should this happen, Δt takes different values in order to obtain the critical time trigging the crack propagation: it's the dichotomy method.

That way, at every step of crack length $a_i = a + \alpha$ and at time $t + \Delta t$, the fractures parameters are continuously computed until the fracture instability translated the collapse of the structure.

5. Numerical results

On figure 5, the different partitions of viscoelastic energy release rate ${}^1G_v$ and ${}^2G_v$ for a specific mixed mode configuration ($\beta = 45°$) are posted in opening mode and shear mode, respectively. These results are obtained according to equation (4). The evolutions of the both partitions are the same until the crack length $a = 75\,\mathrm{mm}$. Also, it's observed that, the viscoelastic energy, in opening mode, is less important than in shear mode after the crack length $a = 90\,\mathrm{mm}$ (respectively 2450 J/m^2 in mode I, and 3250 J/m^2 in mo*d*e II). It means that the shear mode necessitates more energy in order to cause the crack tip advanced. After, it's observed an important instability caused by a suddenly crack growth process leading to the collapse of the structure. Figure 6 shows the evolution of crack length versus time. We remark that the length of the process zone α is very small during the first 64 hours, and the crack length is 50 mm. After, the increase of α and the crack length a are observed until 90 hours traducing, in the same time, the crack instability and the collapse of the structure.

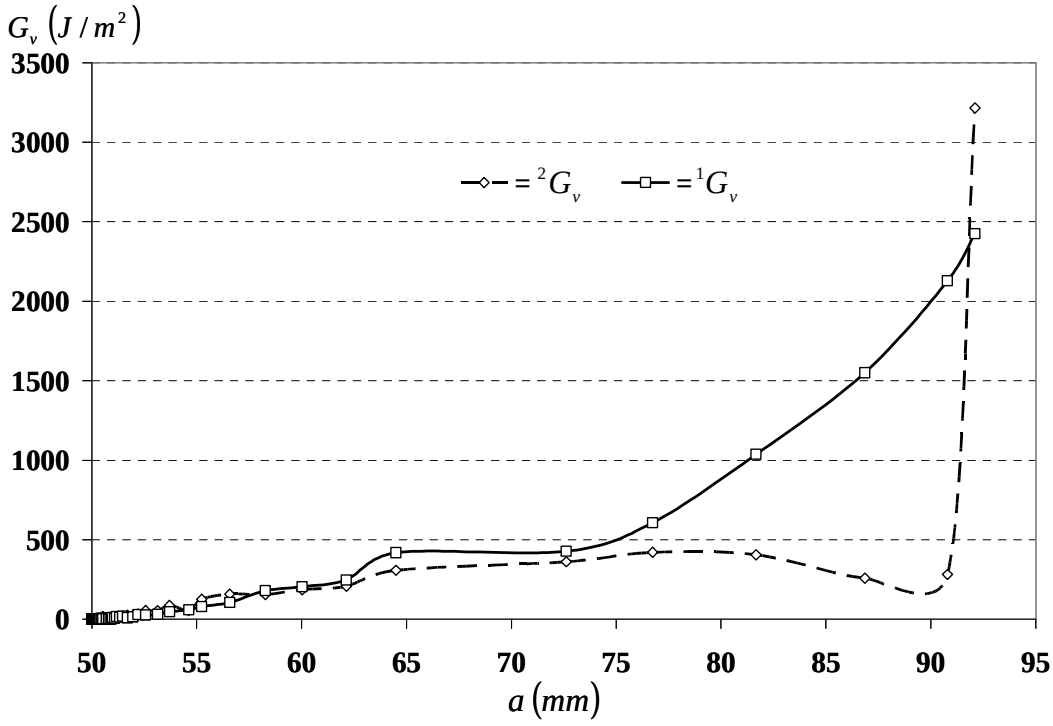

Figure. 5 – Energy release rate in mixed mode 45° (part of mode I and mode II)

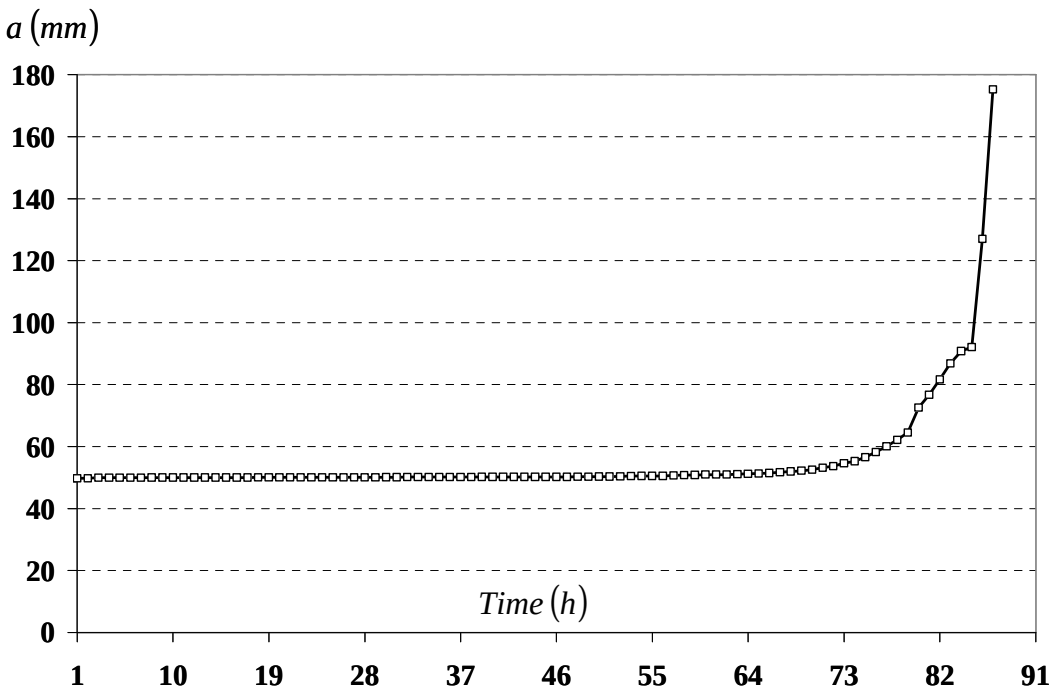

Figure. 6 – Crack length versus time (h)

6. Conclusion

A new method providing crack initiation and crack growth process in viscoelastic orthotropic materials have been proposed. The fracture separation has been introduced according to the non-dependence integral $M\theta$. In order to take into account mixed mode ratio, a new 2MCG specimen providing the fracture stability during the crack tip evolution has been used. To be inspired by the Schapery's theory, a new definition of the length of process zone, in mixed mode has been developed. Finally, a complex subroutine combining the crack initiation and the crack propagation has been written and the crack speed given by a dichotomy method. That way, the capacity of the proposed model to translate viscoelastic effects and the crack growth stability are clearly shown. In the near future, the creep tests will be performed in order to compare with the simulations proposed in this paper.

7. References

[1] Moutou Pitti R., Dubois F., Petit C., Sauvat N., Pop O., A new M-integral parameter for mixed-mode crack growth in orthotropic viscoelastic material, Eng Fract Mech, 75 (15), 4450-4465, 2008.
[2] Moutou Pitti R., Mixed-mode fracture separation in viscoelastic orthotropic materials: modelling and experimentation, PHD Thesis, Limoges University, 2008.
[3] Moutou Pitti R., Dubois F., Octavian P., On a specimen providing stable mixed mode crack growth in wood material, C.R Mecanique, 336 (6), 744-749, 2008.
[4] Moutou Pitti R., Dubois F., Octavian P., Mixed-mode fracture in viscoelastic material, XXII ICTAM, Adelaïde, ISBN 978-0-9805142-0-9, 2008.
[5] Dubois F., Chazal C., Petit C., Viscoelastic crack growth process in wood timbers: An approach by the finite element method for mode I fracture, Int J Fract, 113 (4), 367-388, 2002.
[6] Valentin G., Caumes P., Crack propagation in mixed mode in wood: a new specimen, Wood Sci Technol, 23 (1), 43-53, 1989.
[7] Schapery R.A., Correspondence principles and a generalized J integral for large deformation and fracture analysis of viscoelastic media. Int J Fract 25,195-223,1984.
[8] Chen F.H.K., Shield R.T., Conservation laws in elasticity of the J-integral type, J Appl Mech Physics, 28 (1), 1-22, 1977.
[9] Destuynder P.H., Djaoua M., Lescure S., Some remarks on elastic fracture mecanics, J Mec Theor Appl, 2 (1), 113-135, 1983.