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ANALYSIS OF THE INFLUENCE OF VISCOELASCITY ON THE OCCURRENCE OF UNSTABLE CRACK PROPAGATION USING THE R-CURVE

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Abstract. *The present work analyzed the influence of the viscoelasticity of concrete at early ages on the occurrence of unstable crack propagation. The analysis was based on the R-Curve method and on the time-dependence of the Energy Release Rate ($\mathcal{G}$). For this purpose, the chosen case for analysis was a single edge notched bending specimen subjected to a concentrated load at its center. The creep compliances chosen for analyses were selected from literature for different loading ages. The results showed that with the increase of the initial loading age, the viscoelastic characteristics of the material decreased whilst the crack resistance increased.*

Keywords: *Viscoelasticity, Fracture Mechanics, Energy Release Rate*.

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1 INTRODUCTION

Viscoelastic materials are characterized by presenting both elastic and viscous deformations simultaneously (Christensen, 1982). These materials are known for presenting two phenomena: relaxation and creep. With the increase in speed of constructions, which leads to the use of concrete in earlier ages, the viscoelastic characteristics of concrete need to be considered since they can lead to greater deflections and early age fractures (Briffaut et al, 2012). One of the critical problems associated with early age structures is the occurrence of cracks. Therefore, it is important to analyze a fundamental parameter of fracture mechanics: the Energy Release Rate ($\mathcal{G}$), that represents the energy available to propagate the crack.

This work analyzed how the loading age, being a parameter that influences the viscoelasticity of the concrete, influences in the unstable propagation of a crack using the R-curve and the Energy Release Rate approach.

2 BACKGROUND

2.1 Energy Release Rate ($\mathcal{G}$)

By definition, the Energy Release Rate for plane stress is given by Eq. 1.

$$\mathcal{G}(a,t) = \frac{K(a)^2}{E(t)} = \int_0^t J(t-\tau)\frac{\partial K(a)^2}{\partial \tau}\partial\tau \tag{1}$$

According to Anderson (2011), the Stress Intensity Factor (K) for the case of single edge notched bend is given by Eq. 2.

$$K(a) = \frac{P}{B\sqrt{W}}\frac{3\frac{S}{W}\sqrt{\frac{a}{W}}}{2\left(1+2\frac{a}{W}\right)^{3/2}}\left[1.99-\frac{a}{W}\left(1-\frac{a}{W}\right)\left\{2.15-3.93\frac{a}{W}+2.7\left(\frac{a}{W}\right)^2\right\}\right] \tag{2}$$

2.2 Resistance Curve (R-Curve)

Bažant and Jirásek (1993) define the Resistance Curve, or R-Curve, as the curve that characterizes the variation of the critical Energy Release Rate with the crack propagation length. In their study, Bažant and Jirásek (1993) presented an R-Curve obtained from experimental tests performed on a single notch bending concrete specimen. The R-Curve equation is presented in the form observed in Eq. 3.

$$R(a) = G_f\,\rho(\gamma) \tag{3}$$

Where G_f is a constant determined experimentally (considered as 52.1N/m), $\rho(\gamma)$ is shown in Fig. 1 and γ is given by Eq. 4, where a represents the size of the crack, a_0 is the first size of crack tested (which was considered as a_0=1cm) and c_f is a constant (considered as 24.36mm).

$$\gamma = \frac{a - a_0}{c_f} \tag{4}$$

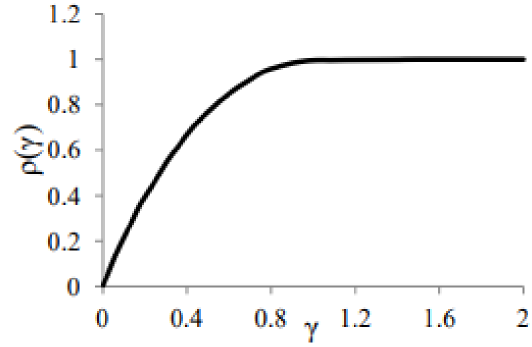


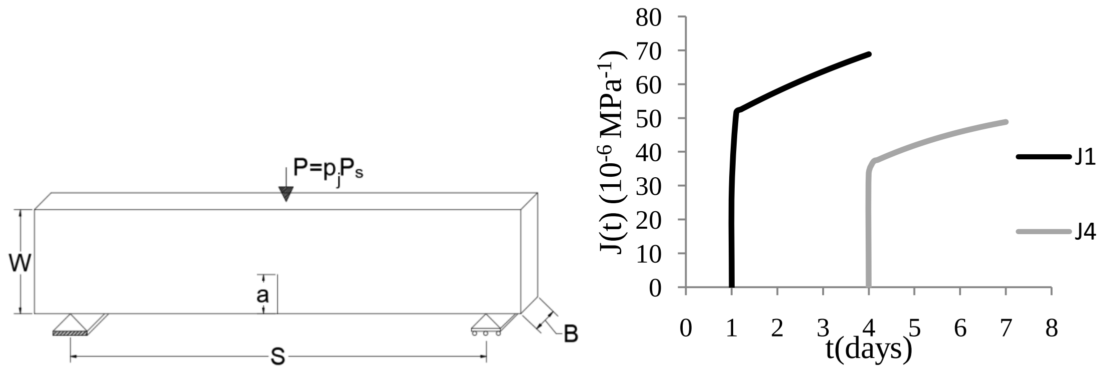
Figure 1.R-Curve parameter ρ(γ) (Bažant and Jirásek, 1993)

3 MATERIAL AND METHOD

3.1 Geometry and creep compliances

The selected case for analysis was a single edge notched bending specimen, as illustrated in Fig. 2a. The applied load P was defined as a function of the self-weight of the specimen (P_s). Therefore, p_j represents the number of times the applied load is higher than the self-weight of the specimen. The density of concrete was considered as 25kN/m³. The dimensions used for the analysis were: W=0.4m, S=1.6m and B=0.15m. As for the size of the notch and the load, each one of those was defined as a vector of different values.

The creep compliance of concrete was based on the results presented by Atrushi (2003) for the loading ages of 1 ($J_1(t)$) and 4 days ($J_4(t)$), which are illustrated in Fig. 2b.



(a) (b)

Figure 2.Geometry and J(t) (a) single edge notched bending specimen (b) analyzed creep compliances

3.2 Unstable Crack Propagation Criteria

When using the R-Curve approach, for there to be unstable crack propagation, which is the critical case of crack propagation, two conditions (Eqs. 5 and 6) must be verified.

$$\mathcal{G}(a,t) \geq R(a) \tag{5}$$

$$\frac{\partial \mathcal{G}(a,t)}{\partial a} \geq \frac{\partial R(a)}{\partial a} \tag{6}$$

In order to study the unstable propagation of a crack in a single notch bending specimen, a code was implemented in the software MATLAB. The main idea of the code was to check the conditions presented in Eqs. 5 and 6. The first step was to define the dimensions of the specimen (W, B, a_0, S), the creep compliance and the vectors of a and of p_j. Then, vector R(a) was calculated. For each combination of a and p_j, $\mathcal{G}$(a,t) was calculated starting from t=0 until the its value was higher than R(a). Using interpolation, the value of t for which $\mathcal{G}$(a,t)=R(a) was found. Then, the condition presented in Eq. 6 was checked. At the end, the result was a matrix composed by all the combinations for which there was crack propagation.

4 RESULTS AND DISCUSSION

The results obtained for the unstable crack propagation are presented in Figs. 4 and 5. Figure 4 illustrates the evolution of $\mathcal{G}$(t) until the occurrence of the crack propagation for four combinations of data. Figure 5 shows all the combinations tested of a/W and p_j for which unstable crack propagation was observed.

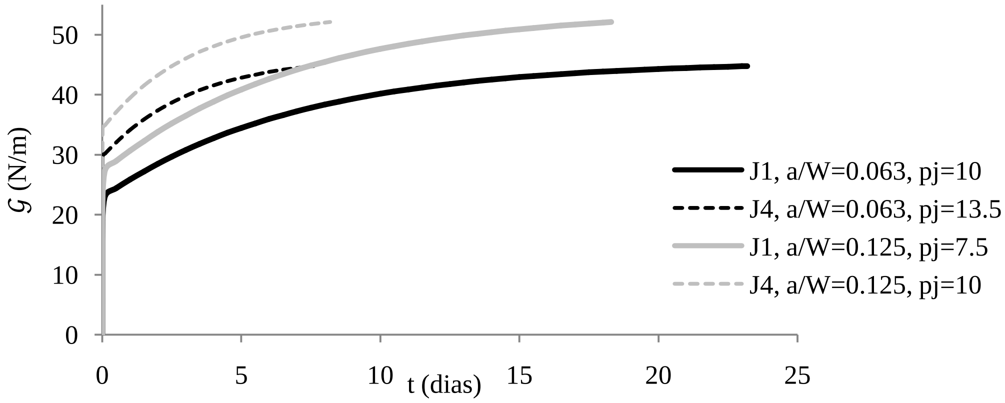


Figure 4. Evolution of $\mathcal{G}$(t) until the occurrence of unstable crack propagation for selected cases

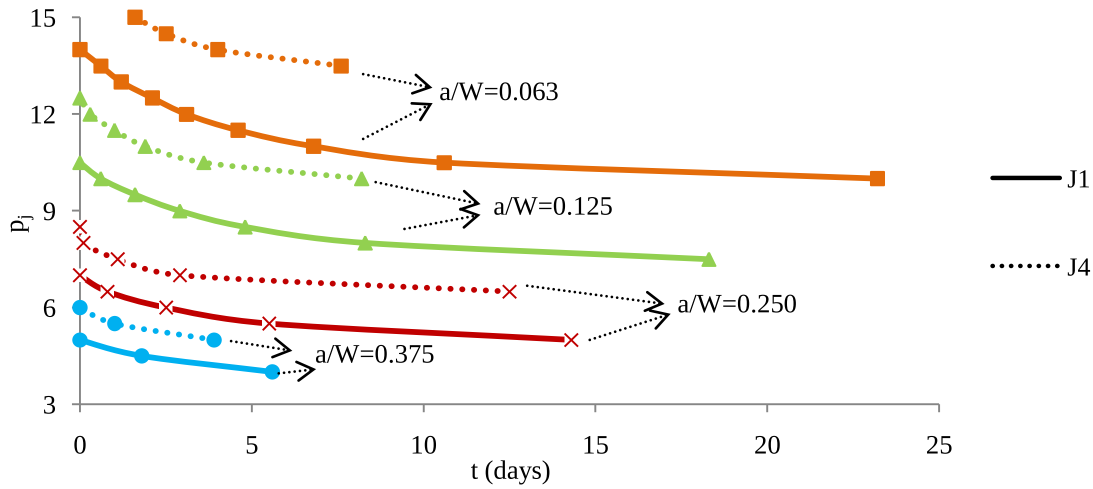


Figure 5. Time (t) for the occurrence of unstable crack propagation for different p_j

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The results presented in Fig. 4 make it clear how important it is to take the viscoelasticity of the material into consideration when analyzing the stability of a crack. For all cases shown, if only the elastic behavior of the material had been taken into consideration, the crack would have been considered stable, when in reality instability would happen in a matter of days. It is also possible to notice that for the loading age of one day, the final value of $\mathcal{G}(t)$ is around 2.3 times higher than its instantaneous value, whilst for the age of four days, the final value of $\mathcal{G}(t)$ is around 1.5 times higher than the instantaneous one, which shows that with the increase in the loading age there is a decrease of the viscoelastic behavior of the material. It can also be noticed that the increase in the loading age results in an increase of resistance of the crack, since the values of $\mathcal{G}(t)$ for which there was instability were higher for the loading age of four days.

Figure 5 shows that with the increase in the loading age there is an increase of the crack resistance. This can be concluded due to the fact that for the same a/W relation, it was required a higher load for there to be instability for the loading age of four days. It can also be verified that with the increase of the size of the notch, the value of p_j for which crack propagation is observed decays.

5 CONCLUSIONS

This work presented an analysis of the influence of viscoelasticity of early age concrete on the occurrence of unstable crack propagation in a single edge notched bending specimen, focusing on the influence of the loading age. The results showed that with the increase in the loading age, there is an increase of the crack resistance and a decrease of the viscoelastic behavior of the material. Overall, it is possible to conclude that in order to analyze the stability of cracks in early age concrete, it is important that the viscoelasticity of the material is taken into consideration.

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