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Simulation of Orthotropic Damaged Zone Behavior Using Viscoelastic Models

M. Fakoor[1]*, N. Mehri Khansari[2]

1- Assistant Professor, Department of Aerospace Engineering, Faculty of New Sciences and Technology, University of Tehran, Iran
2- PhD Student, Department of Aerospace Engineering, Faculty of New Sciences and Technology, University of Tehran, Iran

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ABSTRACT

In fracture phenomenon of orthotropic materials, generally in crack tip vicinity, an area called damaged zone appears that in quasi-brittle materials, is known as fracture process zone. This area contains a multitude of micro cracks which due to various reasons, failure analysis and fracture process of these materials have been difficult. Determination of mechanical properties in this region can help to predict value or even direction of crack growth in orthotropic materials. So far, several models have been proposed to determine the mechanical properties of this region, but due to the immense complexity of this region, the results have not expressed the behavior of this region, properly. Moreover, the existing methods have not been verified with new experimental and numerical data. In the present paper, by proposing a new numerical model based on viscoelastic theory (Prony series), the mechanical properties of the damaged zone is simulated. Furthermore, numerical results are compared with experimental and FEM results. The results indicate convenience compatibility with experimental and FEM results.

KEYWORDS:

Mechanical Properties, Damaged Zone, Orthotropic Materials, Micro Crack, Viscoelastic

* Corresponding Author, Email: mfakoor@ut.ac.ir

1- Introduction

Fracture phenomenon of orthotropic materials, generally associated with area in crack tip vicinity that called fracture process zone. This damaged area contains a multitude of micro cracks and bridging structure which cause difficulties in failure and fracture analysis.

Although, the mechanical properties of the area could be described by viscoelastic method, there is no identified viscoelastic approach to have a convenience compromising with real behavior of damaged zone.

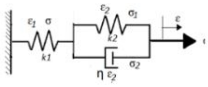
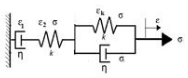
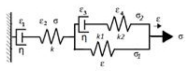
Thomson published the preliminary idea of interpreting of material's behavior with viscoelastic modeling [1]. Barenblatt [2] employed a fictive time and linear viscoelasticity theory to propose a method for computing the viscoelastic modulus of crack tip vicinity. Schapery [3] demonstrated that indeed viscoelastic creep crack growth could be described for metals, too. Furthermore, Bradley [4] declared that various approaches for modeling the viscoelastic fracture in the process zone can be taken depending on the assumption of constitutive properties of the isotropic materials. Allen et al. [5] proposed a micromechanical model for a viscoelastic cohesive zone by take in to account of the physically-based continuum mechanics model of the damaged region ahead of the crack tip. In numerical consideration, Pitti et al. [6] assumed a slow crack propagation velocity in which the kinematic energy dissipation (quasi-static case) can be neglected. Also, Dubois et al. [7] performed a new finite element approach to investigate the effects of viscoelastic characteristics of the creep crack growth process in wood timbers. Taking into account the linear viscoelastic orthotropic behavior, they present an incremental formulation based on a rheological representation of creep tensor components.

As mentioned previously, there are some attemps that have been made to describe the crack tip vicinity but none of them are used for orthotropic materials. Therefore, in the present paper, a new numerical model based on viscoelastic Prony series is proposed to describe the orthotropic damaged zone behavior. In this new approach, experimental and FEM methodology were investigated and the mechanical behavior of damaged zone was simulated.

2- Methodology

Considering complexity in mechanical behavior of damaged zone, Prony series were executed. In this regard, various kinds of Prony series were investigated and convenience approaches were chosen. Table 1 is consisting of well-known Prony series that are performed in present research.

Table 1. Well-known Prony series

Name	Creep Response	Model
Two-Element	$\varepsilon(t)=\sigma\left(\frac{K_2+K_1(1-e^{-\frac{t}{\tau}})}{K_1K_2}\right)$	
Three-Element (4-Parameter)	$\varepsilon(t)=\sigma_0\left[\frac{k_1+k_2}{k_1k_2}\left(1-e^{-\frac{t}{\tau}}\right)+\frac{\sigma_0}{k_1}+\frac{\sigma_0 t}{\eta_1}\right]$	
Three-Element (5-Parameter)	$\varepsilon(t)=\frac{\sigma_0(k_1+k_2)}{k_1k_2}+\frac{\sigma_0 t}{\eta_1}+\frac{\sigma_0}{k_1k_2}\left[1-e^{-(\frac{k_1}{\eta_1}+\frac{k_2}{\eta_2})t}\right]$	

According to the presenting of micro cracks in fracture process zone, total strain of the region could be divided as elastic and viscoelastic ones (Eq. 1):

$$\varepsilon_{FPZ}=\underbrace{\varepsilon^{e}}_{\substack{elastic\\strain}}+\underbrace{\sum_{i=1}^{n}\varepsilon_i^{v}}_{\substack{viscoelastic\\strain}} \tag{1}$$

Where, ε^e is the elastic strain and ε^v is the viscoelastic strain. The main differences among the viscoelastic modeling of crack tip vicinity are related to the viscoelastic strain. According to the Table 1, the three-element model (5-Parameter) due to its viscoelastic strain, has more compatibility with experimental and FEM results.

3- Simulation Results

Taking into account of mechanical properties of orthotropic materials in different direction; S_{11} and S_{22} (fiber direction) as compliance matrix were investigated in the present study. In this regards, these parameters are plotted versus increasing microcrack density for three-element model (5-Parameter) (Figure 1). The results could be investigated for S_{22} (Figure 2).

Figure 1 and 2 indicate that, mechanical properties of damaged zone are diminished within the increasing of the number of mirocrackes. On the other hand, by increasing the time, compliances S_{11} and S_{22} are decreased by the time and increasing the microcrack density. These results also are compared with FEM methodology for three-element model in Figures 3 and 4.

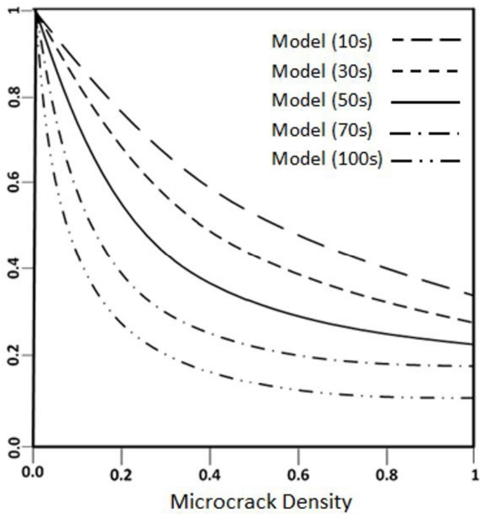


Figure 1. Microcrack Density Versus S_{11}

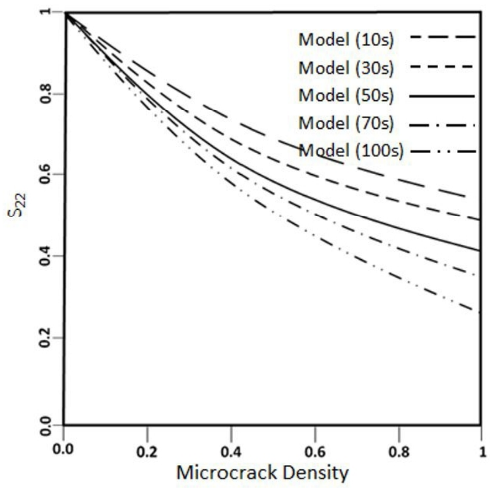


Figure 2. Microcrack Density Versus S_{22}

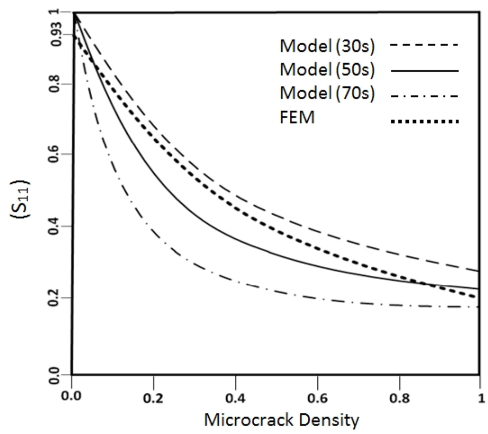


Figure 3. FEM results of three-element model for S_{11}

The results could be investigated for fiber direction (S_{22}), too.

As it shown in Figures 3 and 4, FEM results have a good compatibility with three-element model (5-Parameter).

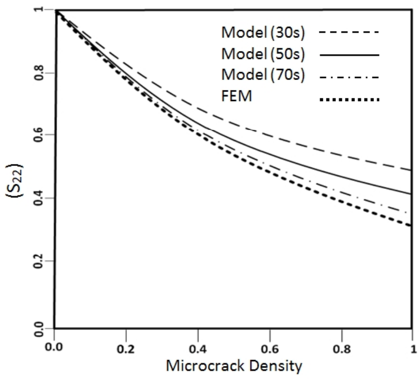


Figure 4. FEM results of three-element model for S_{22}

4- Conclusion

Although various researches have been made for investigation of orthotropic materials, the properties of damaged zone have not been studied by viscoelastic Prony series. In present paper, by proposing a new numerical model based on viscoelastic theory (Prony series), the mechanical properties of the damaged zone were simulated.

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