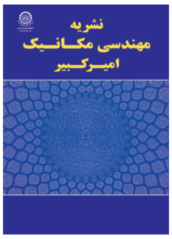

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A Peridynamic Study on Crack Growth in Plates with Two Anti-symmetric Cracks under Various Tensile Velocities

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ABSTRACT: Despite the development of some advanced concepts in fracture mechanics during recent decades, the prediction of crack initiation and its growth in materials is still a major challenge. The main difficulty is because of the continuum based mathematical formulation, which assumes that a body remains continuous as it deforms. In fact, the classical theory is formulated using spatial partial differential equations. This presents a characteristic limitation to the classical theory, as the spatial derivatives in the governing equations lose their meaning due to the presence of a discontinuity, such as a crack. To overcome this problem, Peridynamic theory could be used to improve the analysis of cracked structures. Basically, the peridynamic theory is a reformulation of the equation of motion in solid mechanics that is better suited for modeling bodies with discontinuities, such as cracks. The theory uses spatial integral equations that can be applied to a discontinuity. The present study uses this approach to study the effects of applying tensile loads on crack paths in a plate with two parallel initial cracks located in an anti-symmetric manner. The results are compared with other investigations and it is shown that the velocity of applying load has significant effect on crack path and branching.

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1- Introduction

The problem of crack initiation and growth has been given special attention in the past few decades by fracture mechanics researchers because of its key importance in a wide range of industries like mechanical, civil and aerospace. A lot of concepts are developed to predict crack initiation in materials using classical lamination theory.

Despite all of these developments, it is still a major challenge in using continuum mechanics. The main trouble lies in the mathematical formulation where the classical theory is formulated using spatial partial differential equations, and these spatial derivatives are undefined at discontinuities and they lose their meaning due to the presence of a discontinuity, such as a crack [1].

2- Peridynamic Theory

To overcome the above mentioned problem, the Peridynamic Theory (PD), which is one of nonlocal theories, was introduced by Silling [2] and Silling et al. [3] to deal with the discontinuities. Similar to some other nonlocal theories, the peridynamic theory employs displacements rather than displacement derivatives in its formulation.

The basic equation of peridynamics is the following equation of motion:

$$\rho\ddot{\mathbf{u}}(\mathbf{x}_k,t)=\int_{H_{x(k)}}\mathbf{t}(\mathbf{u}(\mathbf{x}_j,t)-\mathbf{u}(\mathbf{x}_k,t),\mathbf{x}_j-\mathbf{x}_k)\mathrm{d}V_{\mathbf{x}_k}+\mathrm{b}(\mathbf{x}_k,\mathrm{t}) \quad (1)$$

where x is a point in body, t is time, $\boldsymbol{u}$ is the displacement vector field, and ρ is the mass density in the undeformed body.

The vector valued function $\boldsymbol{t}$ is the force density that $\mathbf{x}_j$ exerts on $\mathbf{x}_k$. This force density depends on the relative displacement and relative position vectors between $\boldsymbol{x}_j$ and $\boldsymbol{x}_k$. The dimension of $\boldsymbol{t}$ is force per volume squared. The function $\boldsymbol{t}$ is called the “pairwise force function” and contains all the constitutive (material-dependent) properties. It describes how the internal forces depend on the deformation. The interaction between any two points is called a “bond”. It is usually assumed that $\boldsymbol{t}$ vanishes whenever $\boldsymbol{x}_k$ is outside a neighborhood of $\boldsymbol{x}_j$ (in the undeformed configuration) called the “horizon”. Fig. 1 shows the Peridynamic point and its relative horizon.

3- Problem Setting

The object considered here is an epoxy plate with two anti-symmetrically placed initial cracks shown in Fig. 2 [4]. The material properties of epoxy are shown in Table 1.

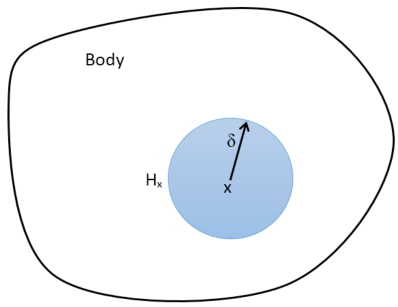

Fig. 1. Peridynamic point and horizon

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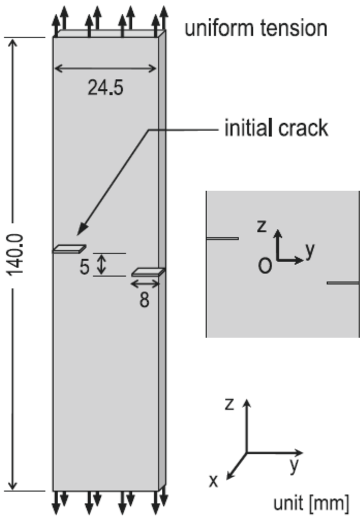

Fig. 2. Plate with a inclined crack under tension with various velocities [4]

Table 1 Mechanical properties of epoxy resin

Value	Unit	Propery
3.3	GPa	E
1/3	-	v
0.9	$MPa.m^{0.5}$	k_{Ic}

4- Verifying the Results

Fig. 3 shows the comparison between presented results with extracted main crack paths from five experiments [4]. Since the branching of the crack takes place during the crack propagation in experiment, the main crack paths are extracted from the images by manual digitization.

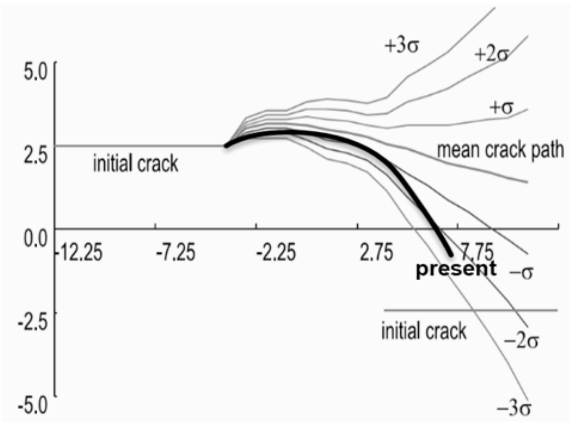

Fig. 3. Comparison of crack growth paths with Ref. [4]

Qualitatively, both experimental and numerical results show the same increasing trend of the deviation of the crack paths according to the distance from the initial crack tip.

5- Effects of Velocity of Applying Loads

The effects of the speed of applying load are shown in Figs. 4 and 5. As can be seen, the pattern of crack growth and propagation is quietly dependent on the speed of load application. With increase in the velocity of loading, the materials gets more brittle and branching of crack occurs in broader region. It proves that a structure from a ductile metal may have brittle fracture when the load is applied with higher velocity [5]

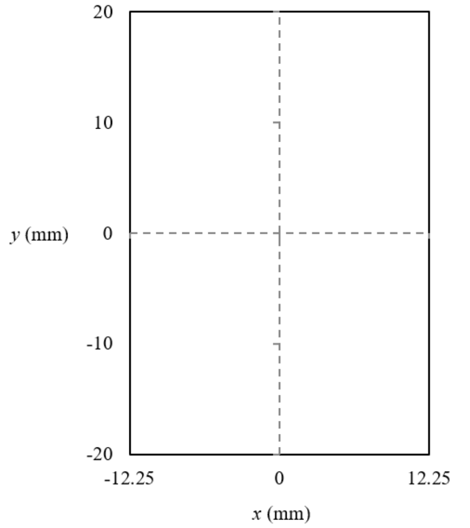

Fig. 4. Crack growth under the tensile load speed of 2 m/s

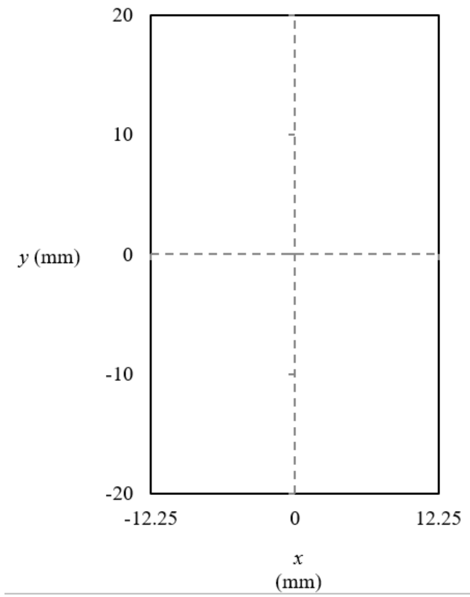

Fig. 5. Crack growth under the tensile load speed of 10 m/s

6- Conclusions

The present paper describes the application of peridynamic theory in crack growth prediction and propagation in materials. The effects of the speed of applying tensile loads on crack paths in a plate with two parallel initial cracks located in an anti-symmetric manner are studied. The results are compared with experimental results of other investigations to prove the ability of the peridynamic theory to predict crack growth paths. The results show that the velocity of applying load has significant effect on crack path and branching.

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