ANALYSIS OF RIGID CURVED INCLUSION EMBEDDED IN A SOFT MATRIX: EXPERIMENTAL INSIGHTS

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Abstract
The role of fiber curvature in short-fiber thermoplastics can be explored by studying a rigid curved inclusion embedded in an epoxy matrix. Although inclusion enhances global stiffness, it also acts as a source of stress singularity, which leads to failure. The current study employs the 2D digital image correlation (DIC) technique to obtain full-field strain fields over a rigid curved inclusion embedded in a soft matrix. The experiment is performed on a rigid curved inclusion specimen subjected to remote tensile loading of 350N. The experimentally obtained strain field is verified using the finite element technique, and a good match is observed. Finally, the stress intensity factor is defined for the rigid curved inclusion, and it is estimated along with the geometric correction factor.

1. Introduction

The fiber curvature significantly affects the stress transfer and interfacial shear strength of short-fiber thermoplastics (SFTs). Short fibers have higher stiffness than the polymer matrix, and it is convenient to assume the short fibers as rigid inclusions. The rigid inclusions prevent displacement discontinuity while allowing traction and are known as anticracks. Even though the rigid inclusion improves the micro-mechanical properties of the SFTs, the tip acts as a stress raiser initiating damage. The square root singularity exists at the inclusion tip, but behavior differs from the crack. In the last few decades, several researchers have studied the stress fields for rigid line inclusion; however, rigid curved inclusion has relatively received less attention. The current work investigates the stress field for rigid curved inclusion using the digital image correlation technique. Further, the stress intensity factor is defined to quantify the singularity at the tip within the linear elastic fracture mechanics framework. Finally, the experimental strain field is compared with the finite element results, and good coherence is observed.

2. Results

The two-dimensional DIC technique is used to extract the full-field displacement and strain field surrounding the inclusion tip. The experiment is performed on a specimen made of an epoxy resin system with a steel inclusion embedded in it. The epoxy resin system comprised of Epofine-221 and hardener Finehard-1842 mixed in a 10:2 ratio. The steel inclusion has a diameter of 20 mm and 0.1mm thickness. The experimental 2D-DIC setup (see fig 1a) consists of a CCD camera (POINTGREY- GRAS-50S5M-C) with a spatial resolution of 2448 x 2048 pixels, a Tamron macro prime lens, and a LED light source. The specimen is painted with high contrast speckle pattern to track the subset before and after deformation.

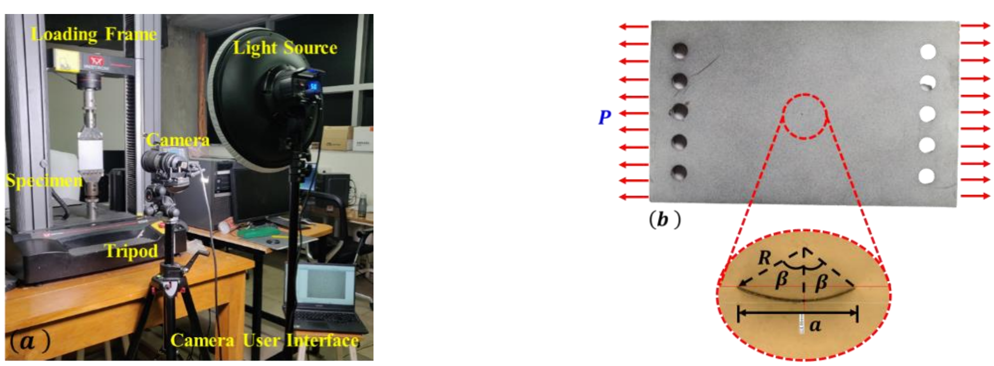

Fig. 1. Experimental setup and actual specimen (a) Experimental Setup (b) Specimen sprayed with speckle pattern

The displacement and strain contours are obtained for the inclusion subjected to remote loading of 350 N and a subset size of 55 × 55 pixels used for strain field extraction (refer to fig 2a, 2b, 2c, and 2d). The finite element simulation is performed using ABAQUS (Version 2018) to compare the strain field from DIC. Figure 2e shows that the ϵ_{yy} strain field obtained from the FEA simulation correlating closely with the experimental DIC strain fields (see Fig 2d). The stress intensity factor is estimated for the rigid curved inclusion using the FEA technique. Finally, the geometric correction factor (F_I) for the rigid curved inclusion is estimated by validating the straight, rigid inclusion case in comparison with the analytical model and FEA. Figure 2f shows the variation of the normalized stress intensity factor with respect to the inclusion length. The stress intensity factor for the rigid curved inclusion is obtained as,

$$K_I = F_I(a, R, \beta)\sigma\sqrt{\pi R \sin\beta} \tag{1}$$

where,

$$F_I = 633.11(h/\beta)^4 - 4099.2(h/\beta)^3 + 9882.8(h/\beta)^2 - 10521(h/\beta) + 4180.6, \qquad h = a/R$$

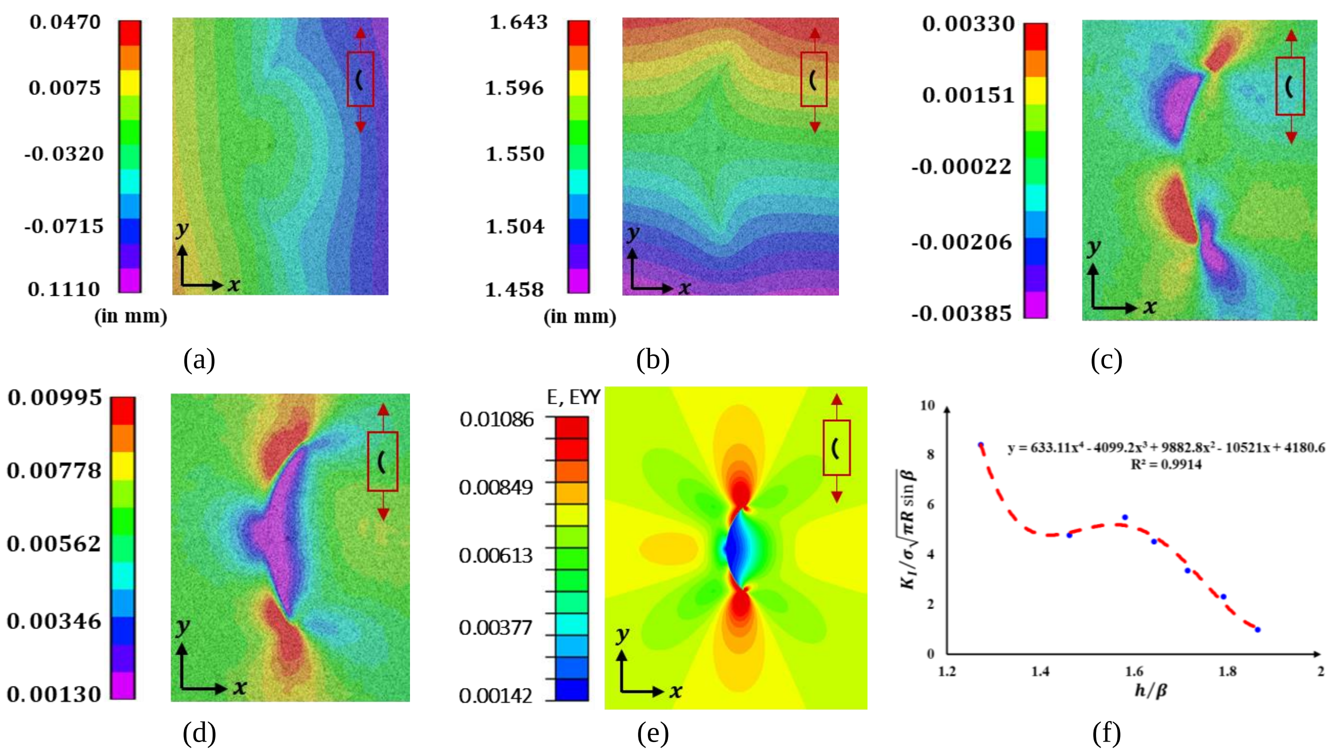

Fig. 2. Displacement and strain contours obtained using DIC and FEA simulation. (a) u_x (b) u_y (c) ϵ_{xy} (d) ϵ_{yy} (e) FEA contours (f) variation of normalized SIF with respect to (h/β) ratio

3. Conclusions

The experimental analysis revealed that the strain fields are symmetric across the inclusion's center line, with a significant difference between the inclusion's convex and concave sides. The matrix material got shielded (zero strain zone) on the concave side, and a reduction in the shielding zone area is seen with reduced curvature. Finally, the geometric correction factor is derived for the rigid curved inclusion involving a finite element model.