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(Statement A)

Multi-Scale Strain Measurements of a Polymeric Material

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Introduction

It is well known that, on the microscopic scale, polymeric materials may be considered inhomogeneous materials. When these materials are stretched, the different crosslinking densities of polymeric chains can produce highly nonhomogeneous local stress and strength fields. Depending on the magnitude of the local stress and the local strength, damage can be developed in the material. The damage developed in the material may be in the form of microvoids or microcracks in the mater. The developed damage will not be confined to a specific location; rather, it will diffuse into a relatively large area or zone. The growth of damage in the material may take place by tearing the material or by successive nucleation and coalescence of the microvoids. These damage processes are time dependent and are the main factor responsible for the time sensitivity of strength degradation as well as the fracture behavior of the material. Therefore, in order to gain an advanced understanding of the failure process in these materials, a detailed knowledge of deformation process as well as damage initiation and evolution mechanisms are required.

In this study, the strain fields, on the meso and macro scales, in a polymeric material, Solithane 113, were determined using Speckle Interferometry with Electron Microscope (SIEM)(1). The size of the region in which the strain fields were determined varied from 2.5 mm x 2mm to 0.065 mm x 0.055 mm. Experimental data were analyzed and the results are discussed.

The Experiments

Uniaxial tensile specimen with a cross-section of 4.5 mm × 3.5 mm were cut from a Solithane 113 sheet. Tests were performed in a Hitachi scanning electron microscope (model S-2460N) which equipped with a displacement controlled loading device which crosshead can travel continuously. The application of SIEM consists of three procedures: the creation of micro/nano speckles on the specimen surface, which are nothing but displacement transducers; recording and digitization of the speckle patterns before and after specimen deformation and deformation analysis of the speckle patterns using an efficient program called CASI (Computer Aided Speckle Interferometry)(2)(3).

The selection of speckle size is determined by the size and deformation magnitude of the specimen and the image magnification selected. For this particular study four different magnifications were analyzed: 40x, 80x, 200x, and 1500x. SiC particles of about 1 μm in size were used for all the first three magnifications and physical vapor deposition process was used for the last magnification. The speckle size for the 1500x was about 0.2 μm. The digitally recorded speckle patterns before and after deformation were subdivided into 32×32 pixels array subimages. A corresponding pair of subimages were "compared" through the CASI software (a 2-D two-step FFT) to yield the displacement vector averaged over the subimage. The physical size of a pixel is a function of the magnification and the total number of pixels with the recorded image. In the current system the image size is 4.5 inch × 3.5 inch digitized with a 2048 × 2048 pixels array. For a 1500x image, the resulting physical size of a pixel is 37 nm in x (or horizontal) and 29 nm in y (or vertical) directions. CASI usually has a 0.5 pixel displacement resolution. Thus, the sensitivity of SIEM at this magnification is about 19 nm in x and 15 nm in y directions, respectively. The physical size at 40x, 80x, 200x and 1500x are 2.5mm.×2.0mm., 1.5mm.×1.5mm., 0.50mm.×0.45mm., and 0.065mm.×0.055mm, respectively. CASI calculation gives displacement components directly. Strains are obtained via appropriate displacement-strain relations.

Results and Discussion

Plots of normal and transverse strain fields for different areas are shown in Figs.1-4. According to Fig.1-4 it is seen that the strain distributions vary with the size of the area, A, in which the data were analyzed. When the sizes of A are equal to 2.5 mm. x 2.0 mm. and 1.5 mm. X 1.5 mm., the normal and the transverse strain distributions are relatively uniform, indicating the material's microstructure has no significant effect on the strain distributions. However, as the size of A is smaller or equal to 0.5 mm .x 0.45mm. the nonuniformity of the strain distributions is increased. Especially, when the size of A is equal to 0.065 mm. X 0.055 mm, both tensile and compressive strain fields exist in the small area. These experimental observations reveal that there exists a length scale below which the material's microstructure has a significant effect on the strain distributions. In other words, a representative area, which is defined as an area in which the material's microstructure has no significant effect on the strain distribution, of 1.5 mm x 1.5 mm. exists for the material investigated in this study.

In addition to determining the strain fields, the damage mechanisms near the crack tip were also investigated. Figure 5 shows that a highly damaged region was developed at the crack tip. Inside the damage region, voids were formed. The crack growth mechanism involved voids formation ahead of the crack tip and the coalescence of the main crack tip with the void.

Conclusions

Experimental results revealed that the strain fields varied with the size of the area considered in this study. In addition, the damage mechanisms and the failure behavior near the crack tip involved voids formation and the coalescence of the main crack tip with the void.

Reference

(1) Chiang, F.P., Wang, Q. and Lehman, F., 1997, "New Developments in Full Field Strain Measurements Using Speckles", *Nontraditional Methods of Sensing Stress, Strain and Damage in Materials and Structures, ASTM STP 1318*, George F. Lucas and David A. Stubbs, Eds., ASTM, pp. 156-169.

(2) D.J. Chen and F.P. Chiang, "Computer Aided Speckle Interferometry Using Spectral Amplitude Fringes", Applied Optics 3(2), 225-236, Jan., 1993.

(3) D.J. Chen, F.P. Chiang, Y.S. Tan, and H.S. Don, "Digital Speckle-Displacement Measurement Using a Complex Spectrum Method", *Applied Optics*, 32(11), pp1839-1849, 1993.

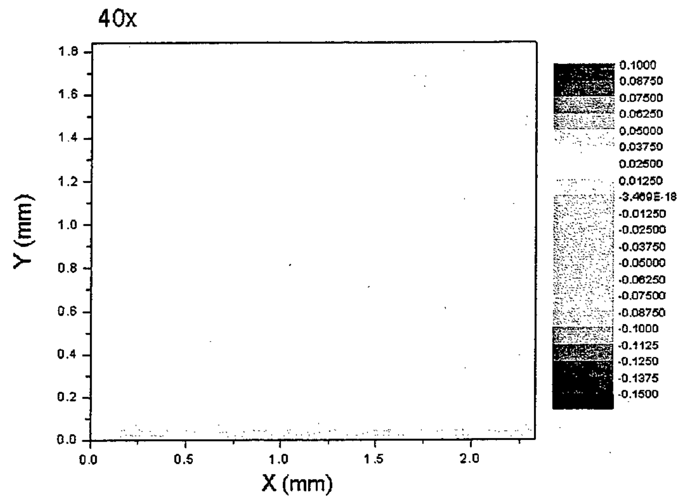

Fig. 1. Distribution of Normal Strain in a 2.5mm x 2.0mm Area

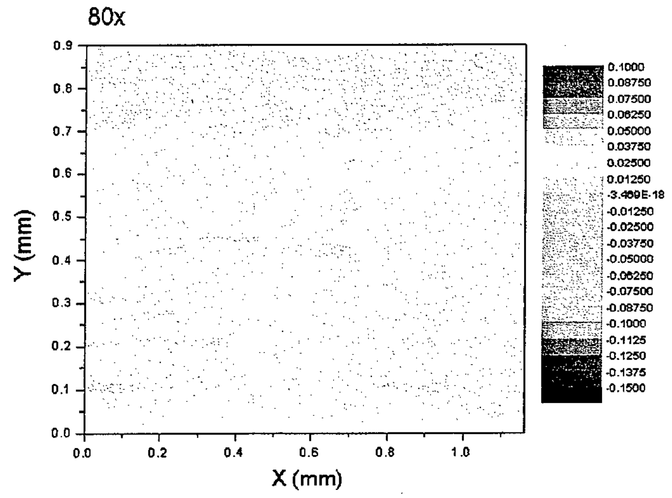

Fig. 2. Distribution of Normal Strain in a 1.5mm x 1.5mm Area

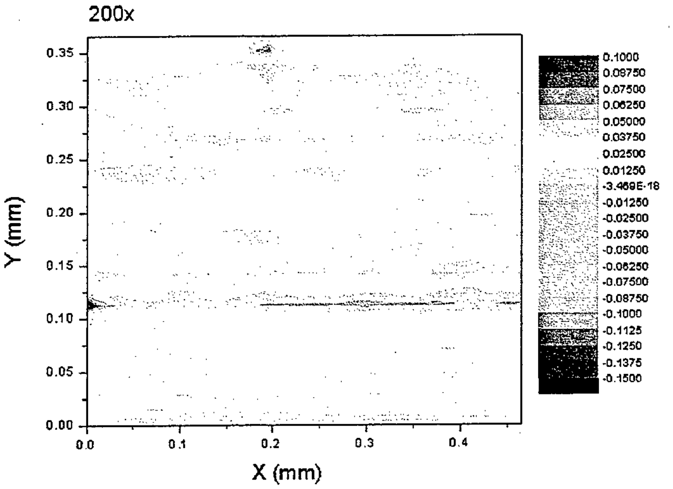

Fig. 3. Distribution of Normal Strain in a 0.5mm x 0.45mm Area

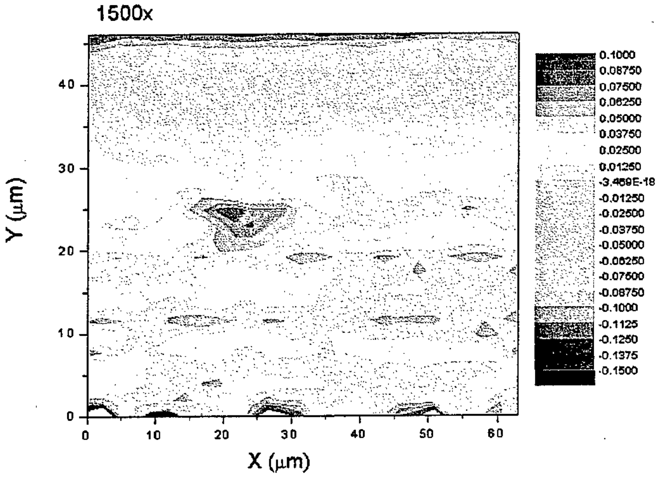

Fig. 4. Distribution of Normal Strain in a 0.065mm x 0.055mm Area