Micromechanics Study of a Polymer with/without Microparticles

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ABSTRACT

SIEM (Speckle Interferometry with Electron Microscopy) is a micro/nano experimental mechanics technique that is able to perform the full field displacement mapping over a region of only several microns in size. In this study we tested specimens made of a pure binder material, a polymer, and binder material mixed with 6 micron aluminum particles under uniaxial tension. The binder material with microparticles was made by adding 10% by weight aluminum particles into the pure binder material. The technique SIEM was used to map the strain distributions of the specimen under various magnifications, 40x, 200x, 800x, and 1500x. The relationships between the coefficient of variation of ε_{yy}, ε_{xx} and the examined area were obtained. We found at magnification about 200x the microstructure had a significant effect on the strain distributions in the binder material with microparticles whereas, for pure binder material, the effect was not observed until at 1500x.

INTRODUCTION

For the development of polymer systems with improved mechanical properties, it is important to understand the relationship between the morphology and micromechanical behavior of modified polymer systems. Many researchers have studied the structure-property relationships in polymers[1-4]. In their studies, electron microscope was used as a tool for morphology study during the polymers deformation, and the mechanical properties of polymers were usually obtained by measuring their bulk material properties. The much more complicated strain distributions in micro scale have not been observed to the best of our knowledge. In this study, Speckle Interferometry with Electron Microscopy (SIEM)[5] was used to map the full field deformation of polymers at various micro scales.

The speckle interferometry (speckle photography) method is a full field technique of nondestructive evaluation (NDE). A random intensity distribution of any sort can be considered as a speckle pattern, and it may be naturally present or artificially created. The development of speckle technique evolves from the laser optical speckle technique [6], the white light speckle technique[7], and the digital speckle technique [8,9]. The digital speckle technique maintains all the advantages of conventional speckle photography but eliminates the tedious tasks of photograph development and fringe pattern analysis. Speckle Interferometry with Electron Microscopy is a micro/nano experimental mechanics technique that is able to perform the full field displacement mapping over a region of only several microns in size. There are three basic procedures in SIEM technique: the creation of micro/nano-speckle patterns, the recording and digitization of these patterns before and after specimen deformation and the analysis of speckle images.

The displacement resolution of SIEM depends on the magnification and the number of pixels in each image. In the current system the image size is 4.5 inch × 3.5 inch. In the case where the magnification of the image is 1500× and the image consists of 2048×2048 pixels, the resulting physical size of a pixel is of 37 nm in X (horizontal) and 29 nm in Y (vertical) directions. Because SIEM usually can resolve at least 0.5 pixel displacement, the sensitivity of displacement at this magnification is about 19 nm in X and 15 nm in Y directions, respectively. Thus, by using an electron microscope, the sensitivity of speckle interferometry is increased by several orders of magnitude.

EXPERIMENTS AND RESULTS

Two polymer materials, pure binder material and binder material mixed with 6 μm aluminum particles, were tested. The binder material with microparticles was made by adding 10% by weight 6 μm aluminum particles into the pure binder material. Dog-bone shaped specimens were tested under uniaxial tension inside the vacuum chamber of a Hitachi scanning electron microscope. The cross-section of the pure binder material specimen is 10.6 mm x 2 mm and that of the binder material with

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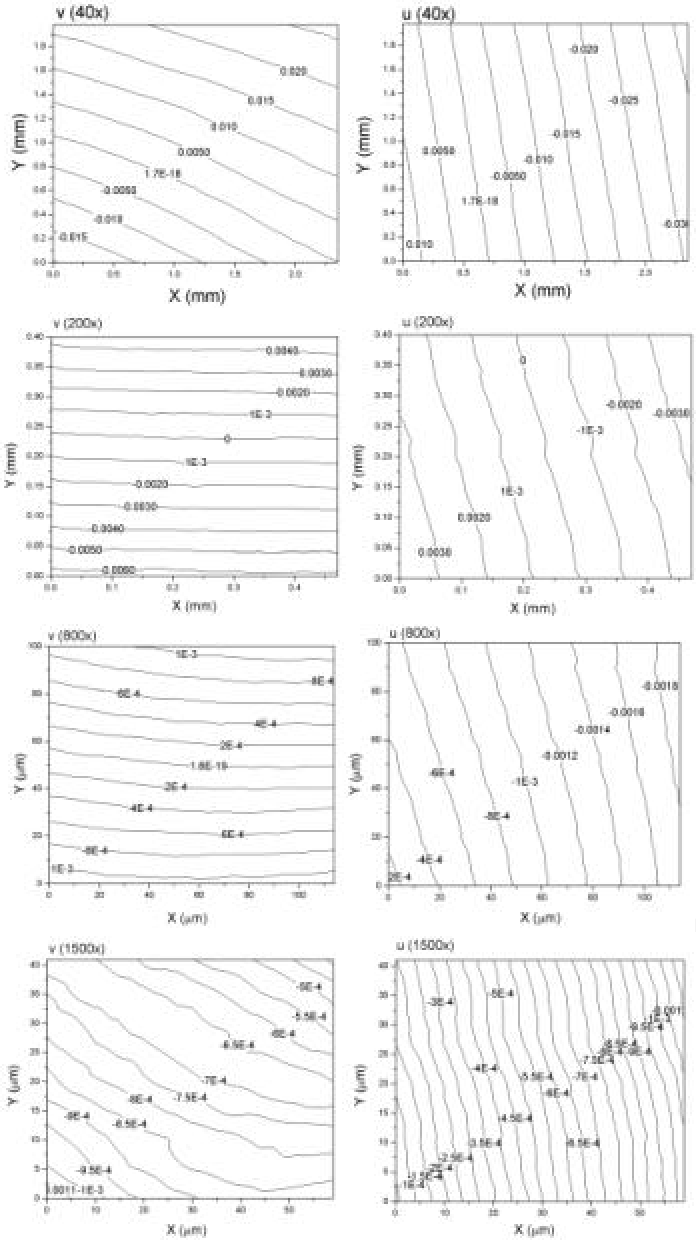
microparticles is 10.6 mm x 1.4 mm. Figure 1 shows the v and u displacement fields of pure binder material at four different magnifications, 40x, 200x, 800x, and 1500x, under slightly different loadings. Figure 2 shows the corresponding ε_{yy} and ε_{xx} normal strain distributions.



Load = 0.17N

Load = 0.13N

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Figure 1 v and u displacement fields of pure binder material at four different magnifications, 40x, 200x, 800x, and 1500x

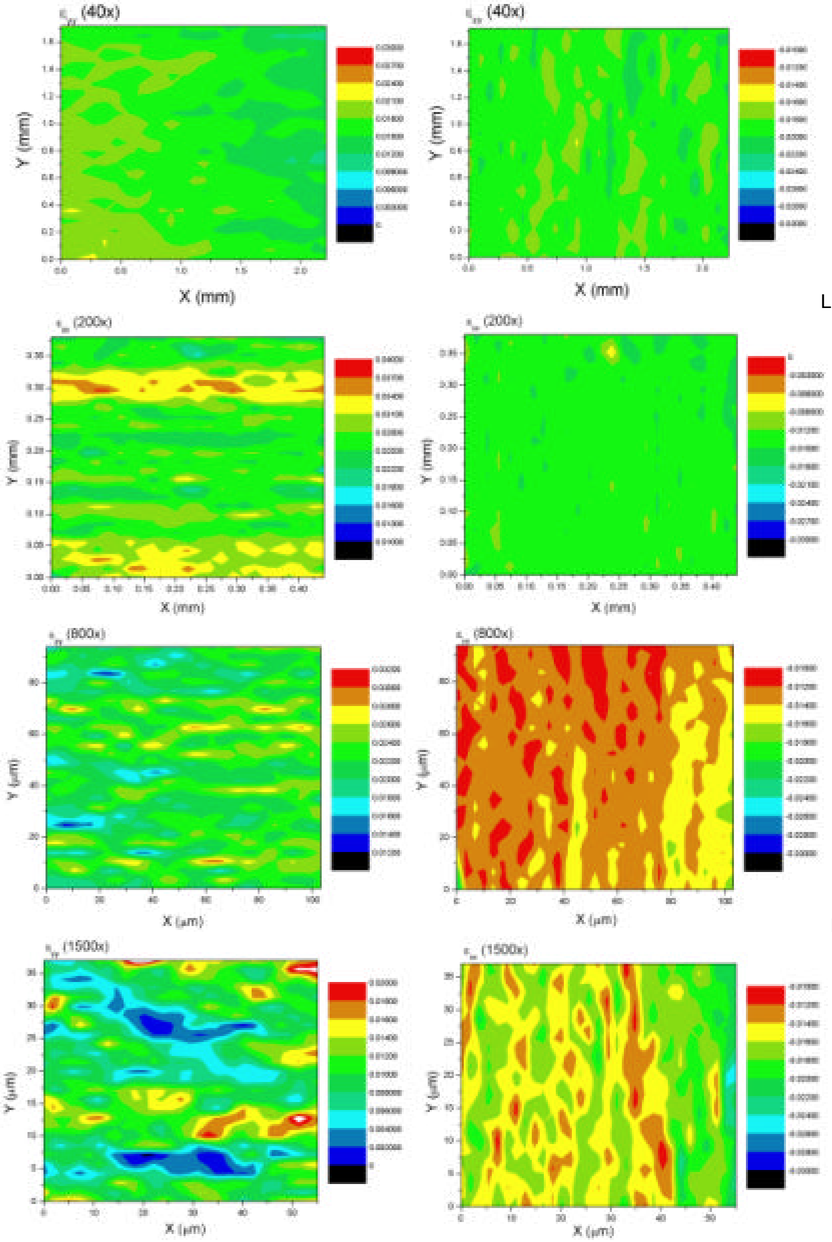

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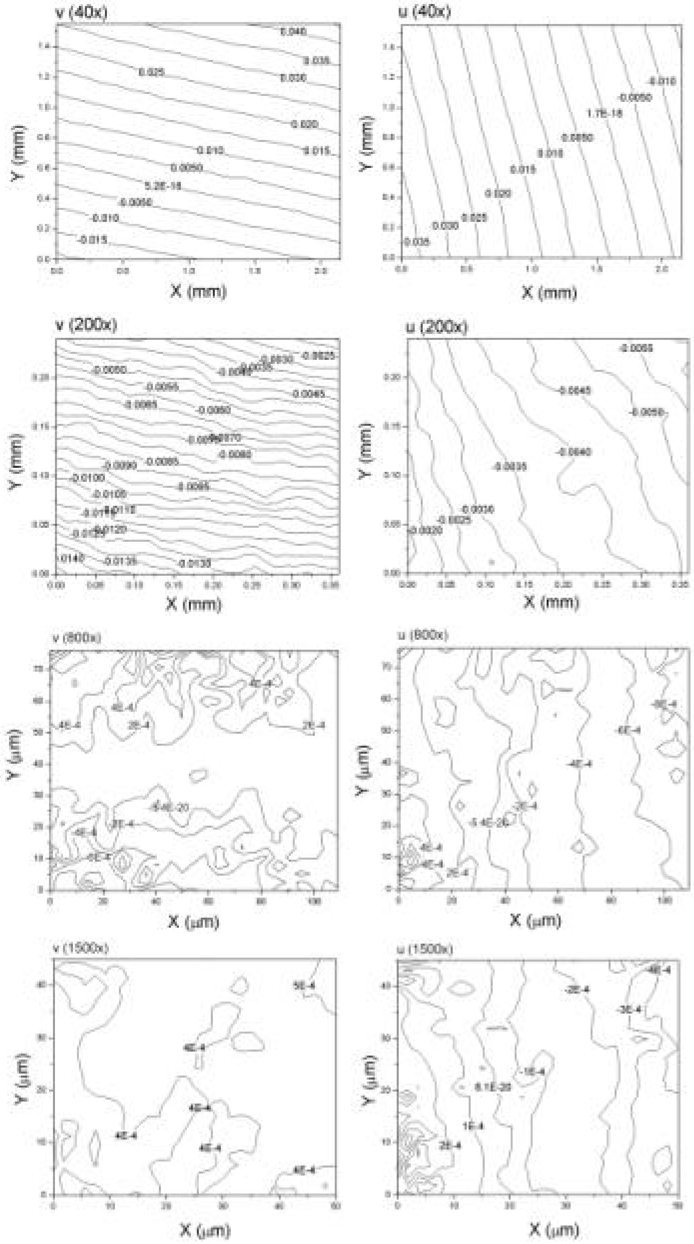
Figure 2 ε_{yy} and ε_{xx} strain distributions of pure binder material at four different magnifications, 40x, 200x, 800x, and 1500x

Figure 3 shows the v and u displacement fields of binder material with 6 μm aluminum particles at four different magnifications under slightly different loadings. Figure 4 shows their corresponding ε_{yy} and ε_{xx} normal strain distributions.



Load = 0.20N

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Load = 0.16N

Figure 3 v and u displacement fields of binder material with 6 μm aluminum particles at four different magnifications, 40x, 200x, 800x, and 1500x

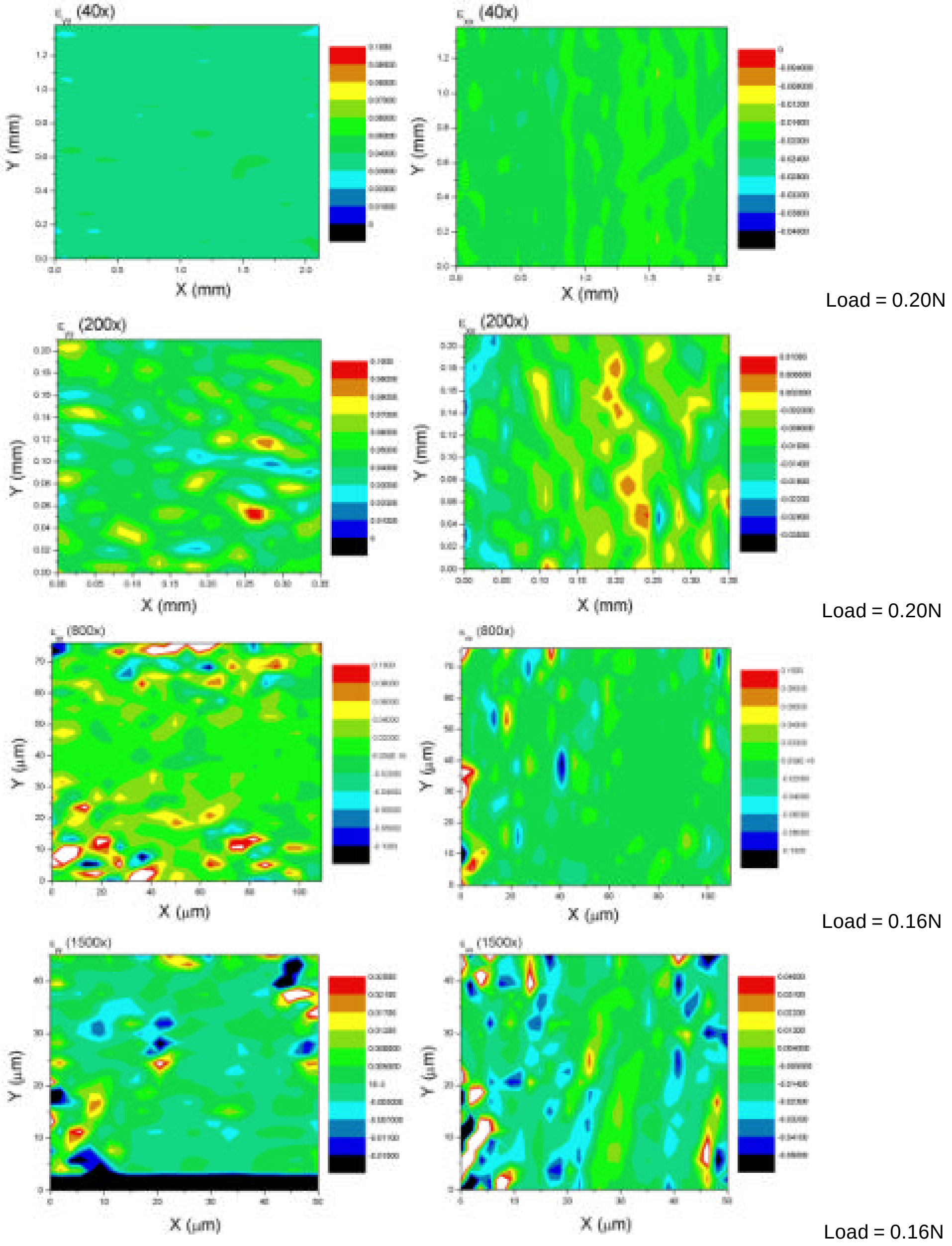

Figure 4 ε_{yy} and ε_{xx} strain distributions of binder material with 6 μm aluminum particles at four different magnifications, 40x, 200x, 800x, and 1500x

It is noted that in Figure 1 and Figure 3 some displacement contour lines in the displacement fields are tilted. This is the result of small rigid body rotation during the loading. For example, the tilted contour lines in v field at 40x in Figure 1 results from a 0.37° counterclockwise rotation. The rotation was so small that its effect on the strain calculation was negligible.

From Figure 1-4, it can be seen that the displacement and corresponding strain fields are relatively uniform at magnification 40x for both materials. This indicates that the material's microstructure has no significant effect on the strain distributions at this magnification. However, for binder material with 6 μm aluminum particles, the non-uniformity of strain distribution can be observed starting from the magnification of 200x; whereas for pure binder material, the non-uniformity cannot be detected until the magnification reaches 1500x. It is noted that for the binder material with 6 μm aluminum particles at 1500x, both tensile and compressive strains exist simultaneously in the small area. The non-uniformity as a function of observing area is further clarified in the plotting of the relationship between the coefficient of variation (standard deviation/mean) of strain distribution and the observing area, as shown in Figure 5 and Figure 6.

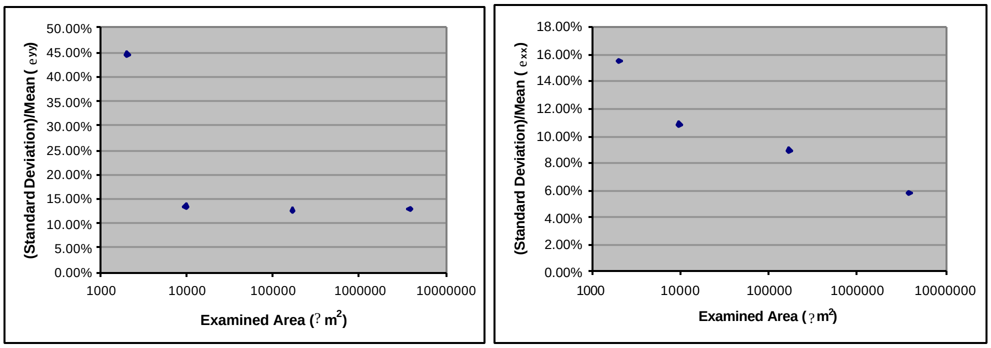

Figure 5 Relationship between the coefficient of variation (standard deviation/mean) of ε_{yy} (left), ε_{xx} (right), and the testing area for pure binder material

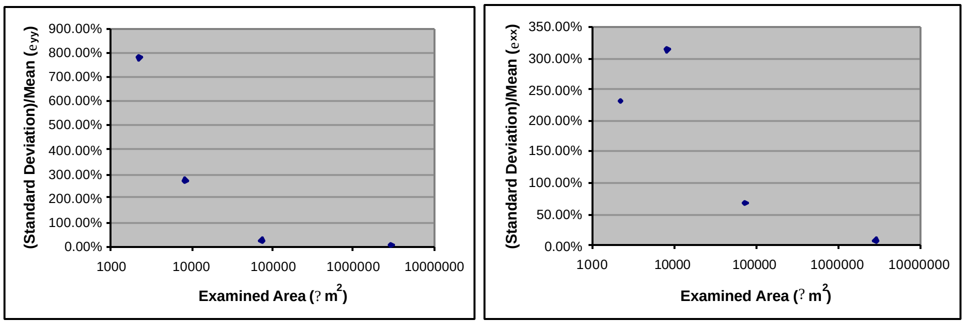

Figure 6 Relationship between the coefficient of variation (standard deviation/mean) of ε_{yy} (left), ε_{xx} (right), and the testing area for binder material with 6 μm aluminum particles

In general, as the magnification becomes larger and larger and the examining area becomes smaller and smaller, the strain distributions become more and more non-uniform. However, in Figure 6, the coefficient of variation of ε_{xx} reaches the largest number when the examined area is about 8000 μm^2, indicating that ε_{xx} has the largest level of non-uniformity at 800x for the binder material with 6 μm aluminum particles.

CONCLUSION

Strain distributions of the pure binder material and the binder material with 6 μm aluminum particles at the magnifications of 40x, 200x, 800x, and 1500x were obtained by using SIEM technique. The relationships between the coefficient of variation of ε_{yy}, ε_{xx} and the examined area were plotted for both materials. The microstructure had a significant effect on the strain distributions at 200x for the binder material with 6 μm aluminum particles; whereas, for pure binder material, the effect was not observed until at 1500x. It was found that in general, the strain distributions were more non-uniform when the examining area became smaller. An exception is that the ε_{xx} distribution has the largest level of non-uniformity at 800x for binder material with 6 μm aluminum particles.

REFERENCE

1. Kim, G.-M. and Michler, G. H., "Micromechanical deformation process in toughed and particle-filled semicrystalline polymers: Part 1: Characterization of deformation processes in dependence on phase morphology", *Polymer*, Vol. 39(23), pp. 5689-5697, 1998.
2. Kim, G.-M. and Michler, G. H., "Micromechanical deformation process in toughed and particle-filled semicrystalline polymers: Part 2: Model representation for micromechanical deformation processes", *Polymer*, Vol. 39(23), pp. 5699-5703, 1998.
3. van der Wal, A. and Gaymans, R.J., "Polypropylene-rubber blends: 5. Deformation mechanism during fracture", *Polymer*, Vol. 40, pp. 6067-6075, 1999.
4. Chapleau, N. and Ajji, A., "Micromechanical behavior of impact modified poly(ethylene terephthalate)", *Polymer Engineering and Science,* Vol. 43, pp.1197-1199, 2003.
5. F.P. Chiang, Q. Wang, and Lehman, F., "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., American Society for Testing and Materials, pp. 156-169, 1997
6. Chiang, F.P., "Speckle Metrology", *Metals Handbook*, 10th edition, Vol.17, pp. 432-437, 1989.
7. Asundi, A. and Chiang, F.P., "Theory and Applications of the White Light Speckle Method for Strain Analysis", *Optical Engineering*, Vol.21, No.4, pp. 570-580, 1982.
8. Chen, D.J. and Chiang, F.P., "Computer Aided Speckle Interferometry Using Spectral Amplitude Fringes", *Applied Optics* 3(2), 225-236, 1993.
9. Chen, D.J., Chiang, F.P., Tan, Y.S. and Don, H.S., "Digital Speckle-Displacement Measurement Using a Complex Spectrum Method", *Applied Optics*, 32(11), pp. 1839-1849, 1993.