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Finite Element Analysis for Internal Stress of Room Temperature Cured Adhesives

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abstract

An internal stress (residual stress) of room temperature cured adhesive generated during curing process causes the damage, such as detachment and/or deformation and/or cracking, in the bonded structures. However, a numerical analysis method for the internal stress of room temperature cured adhesive has not been established. In this study, the numerical analysis using the finite element method (FEM) for the internal stress was examined. Good results were obtained in a comparison between calculated and experimental deformation.

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terms

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1. INTRODUCTION

The internal stress, called also residual stress, generated by curing shrinkage of room temperature cured adhesives causes the damage, such as detachment and/or deformation and/or cracking, in the bonded structures/1-8/. But a numerical analysis method for the internal stress of room temperature cured adhesives has not been established. The numerical analysis method using finite element method (FEM) for the internal stress was studied. Room temperature cured epoxy adhesive was used. The dilatometer and the rheometer were used to measure the change of shrinkage ratio and elastic modulus, respectively. The piecewise linear analysis theory was applied to FEM to consider the change of mechanical properties/9/. The deformation of specimen was measured by an optical interferometer during curing process. Good agreement was found in a comparison between calculated and experimental deformation.

2. EXPERIMENTAL RESULTS

2.1 Deformation of Specimen

Figure 1 shows specimen configuration. Glass mirror was bonded to stainless support using two-part epoxy adhesive (Eccobond 45/#15(100/100), Grace Japan Corp.). Teflon plate with a hole was placed between mirror and stainless support to control the shape of adhesive layer. Mixed adhesive was put into the Teflon hole and cured at room temperature (25 C). Figure 2 shows the schematic diagram of a measurement system. Deformation of mirror surface during curing process was measured by an optical interferometer Zygo Mark II (Zygo Corp.). Interferometers measure the difference in optical paths in units of the wavelength, λ (=632.8nm), of the light used. Figure 3 shows the relationship between an

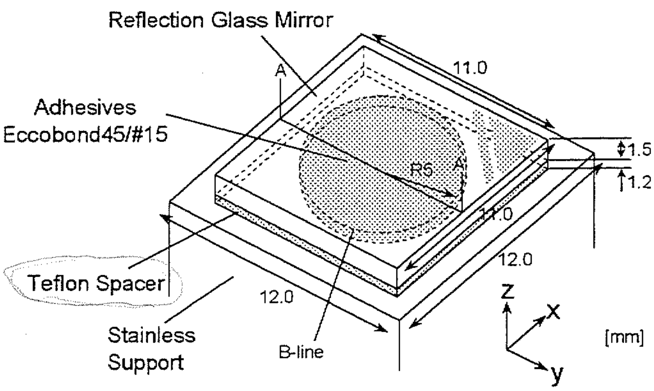

Figure 1 Specimen configuration.

aberration of a mirror and curing time. Deformation started to increase from about 100 minutes and reached to saturate at 1600 minutes. Figure 4 shows displacement distribution on mirror surface after adhesive hardens. Mirror deformed in the z-direction and bending deformation was generated. In this study, an analysis method using FEM was examined to calculate this deformation on mirror surface.

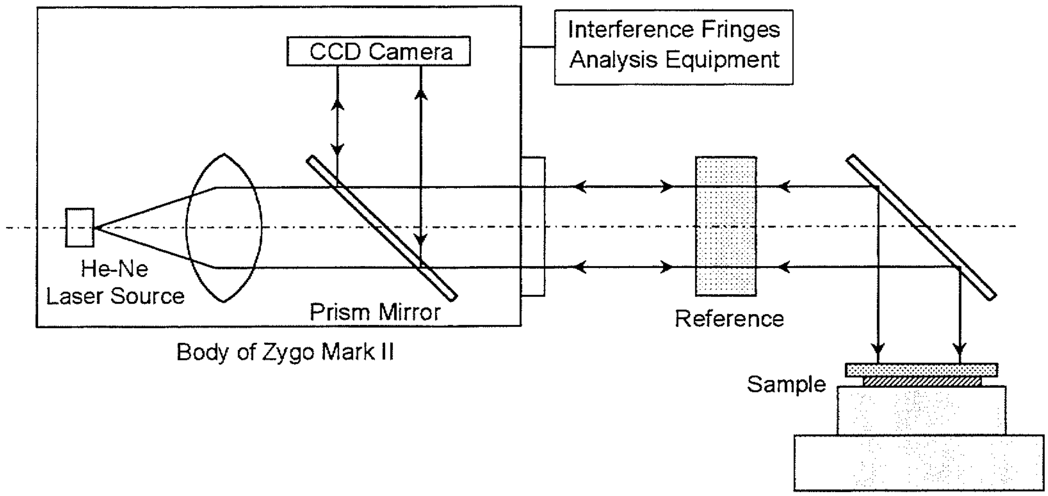

Figure 2. Schematic diagram of the measurement system.

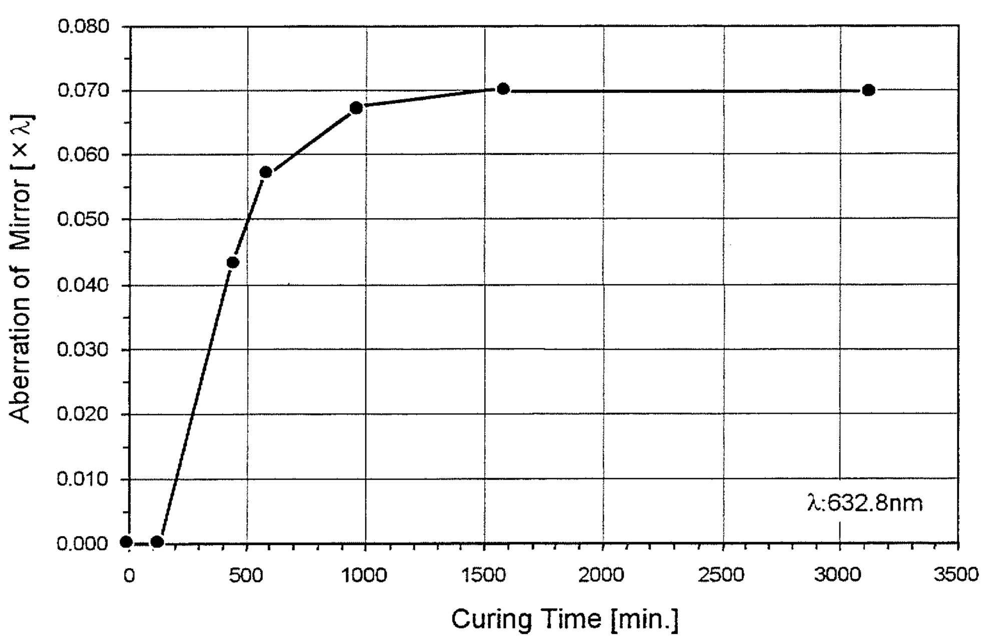

Figure 3. An aberration of mirror surface as a function of curing time that was measured by an optical interferometer.

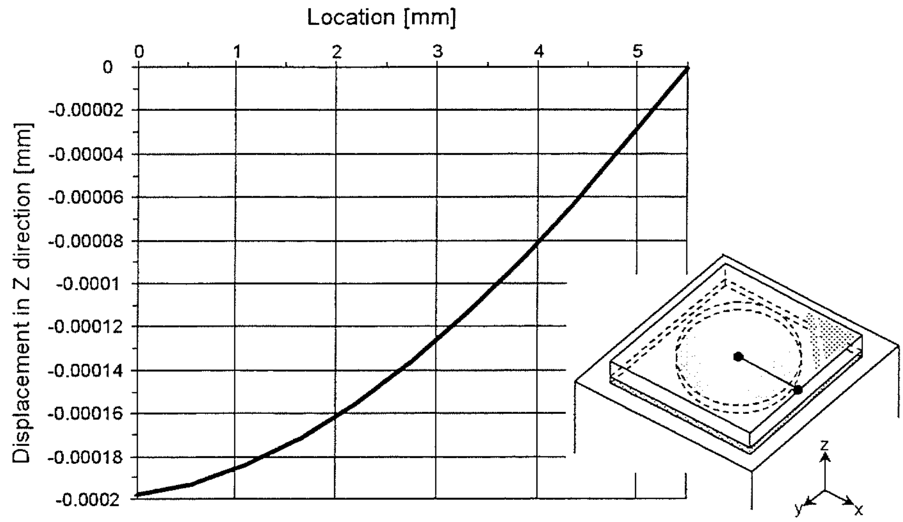

Figure 4. Displacement distribution of mirror surface after adhesive hardens.

2.2 Material Properties of Adhesive

Shrinkage ratio and elastic modulus during curing process were measured by the dilatometer and the rotating rheometer, respectively. In the rheometer, the viscoelastic response has two components, the in-phase and out-of-phase components, which are the storage modulus (G') and the loss modulus (G"). In this study, G' was transformed to tensile modulus E by equation (1). Poisson's ratio of bulk resin was used. Figure 5 shows the variation of linear-shrinkage ratio (αcure) and tensile modulus (E) during curing process. αcure increased after adhesives were mixed, while E increased after about 200 minutes.

$$E = G' \cdot (1+\upsilon) \quad \cdots\cdots (1)$$

E : Tensile modulus   G' : Shear storage modulus υ : Poisson's ratio(=0.4)

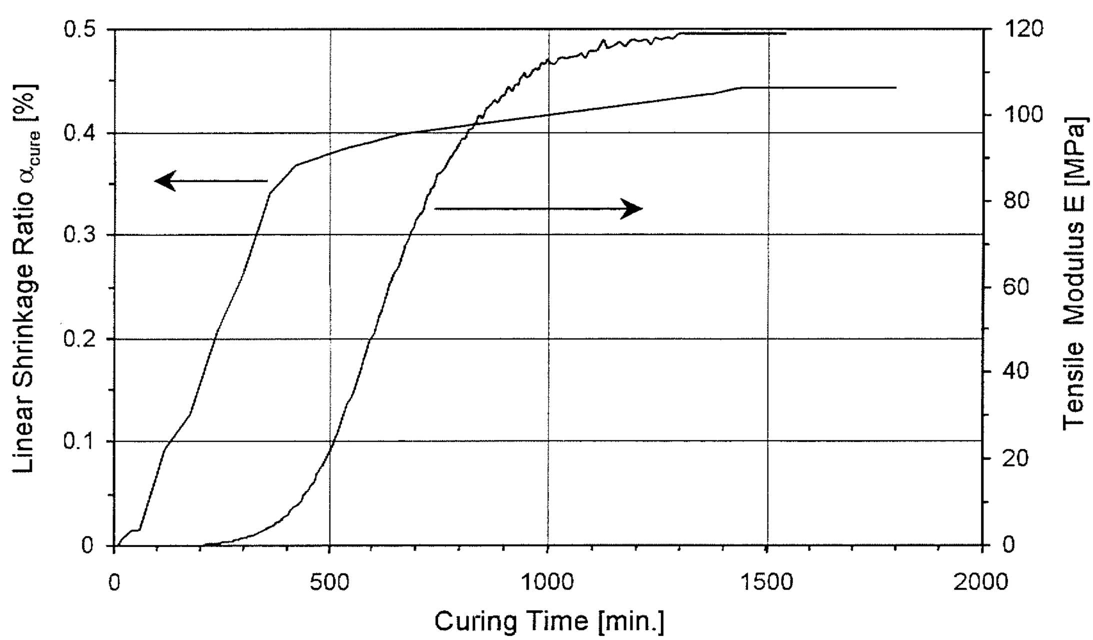

Figure 5. Variation of linear-shrinkage ratio (αcure) and tensile modulus (E) during curing process.

3. FINITE ELEMENT ANALYSIS

3. 1 Analysis Procedure

In this study, the thermal analysis cord of MSC/NASTRAN was diverted. Zero was applied to coefficient of thermal expansion of mirror and stainless support. The internal stress of room cured adhesive can be calculated since volume shrinkage generates in only adhesive layer. The piecewise linear analysis theory was applied to consider the change of shrinkage ratio and elastic modulus. An area during curing process was divided into some stages as shown in Figure 6. Linear analysis using material properties in each stage ($\Delta\alpha i$, Ei) was performed in each stage and added up an analysis results in each stage .

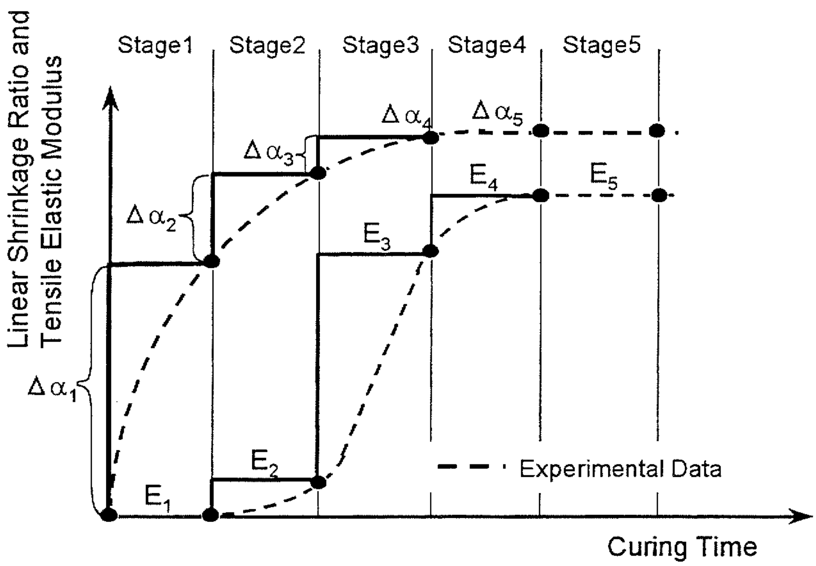

Figure 6. Algorithm of the piecewise linear analysis.

Figure 7 shows an initial mesh division for the FE analysis. Solid element with 8 nodes was used. Degree of freedom in z-direction was fixed on B line ,which was shown in Figure 1. Figure 8 shows a flow of actual analysis. An area during curing process was divided into 5 steps. Nodal load obtained by 1st analysis and thermal load (-1 Celsius) were applied to FE model from 2nd step. An internal stress in previous stage was applied to present stage by nodal load. An internal stress in present stage was generated by thermal load. This analysis was repeated to final step.

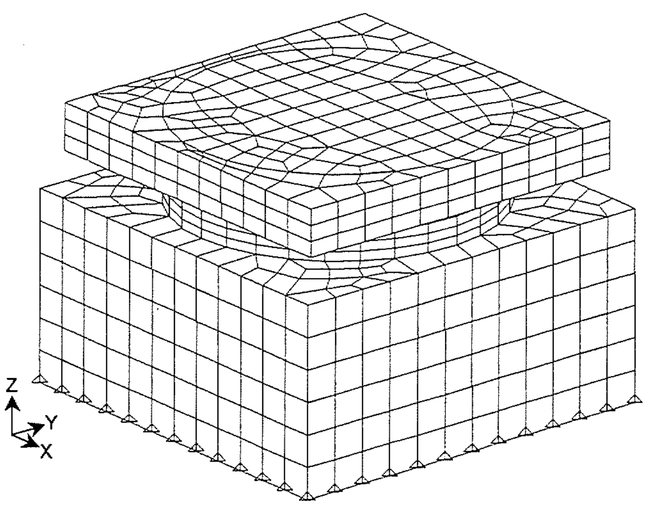

Figure 7. Initial mesh division for FEA.

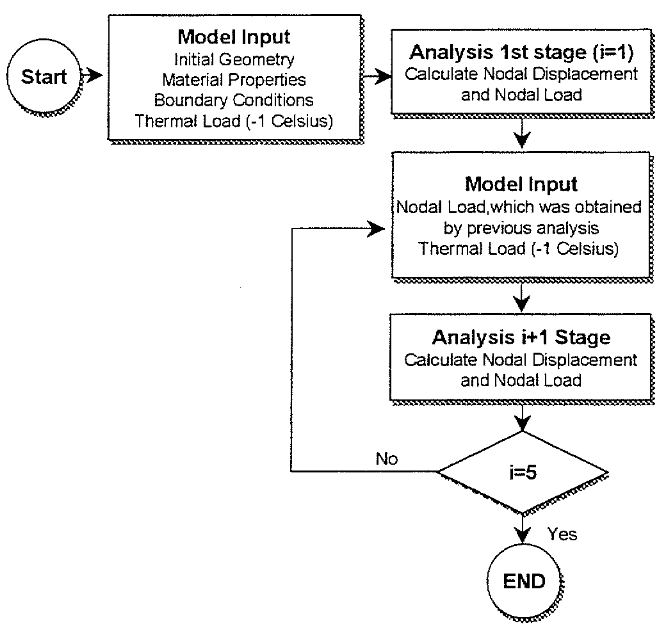

Figure 8. Flow of actual analysis.

3.2 Analysis Results

Figure 9 shows an example of deformation. Mirror was deformed in -z direction by volume shrinkage in adhesive layer. Figure 10 shows a variation of deformation distribution on A-A line (which was shown in Figure 1). Deformation of mirror surface starts to generate from 200 minutes and saturates at 1000 minutes. Figure 11 shows a comparison between experimental and calculated displacement distribution at the end of curing process. Good agreement was obtained. So the internal stress can be calculated by the piecewise linear analysis. And the stress analysis of adhesively bonded joints in consideration of the internal stresses can be performed since the internal stress can be applied as the nodal load in FE analysis.

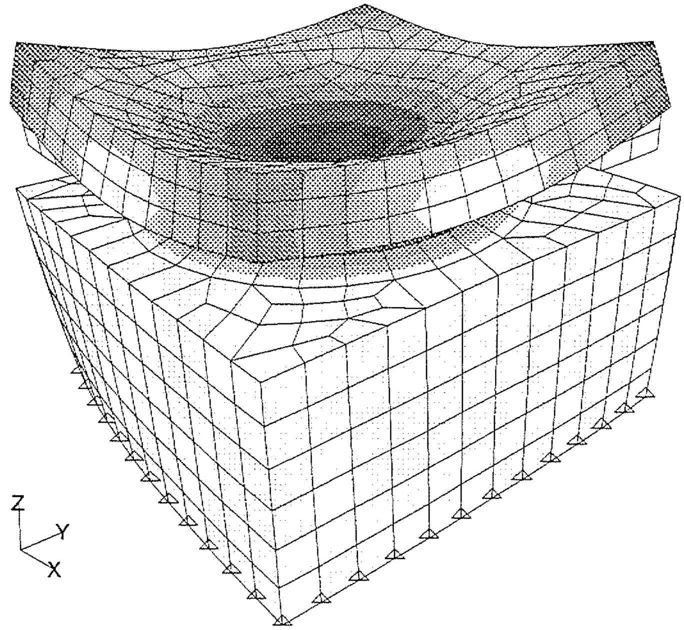

Figure 9. Example of deformation state.

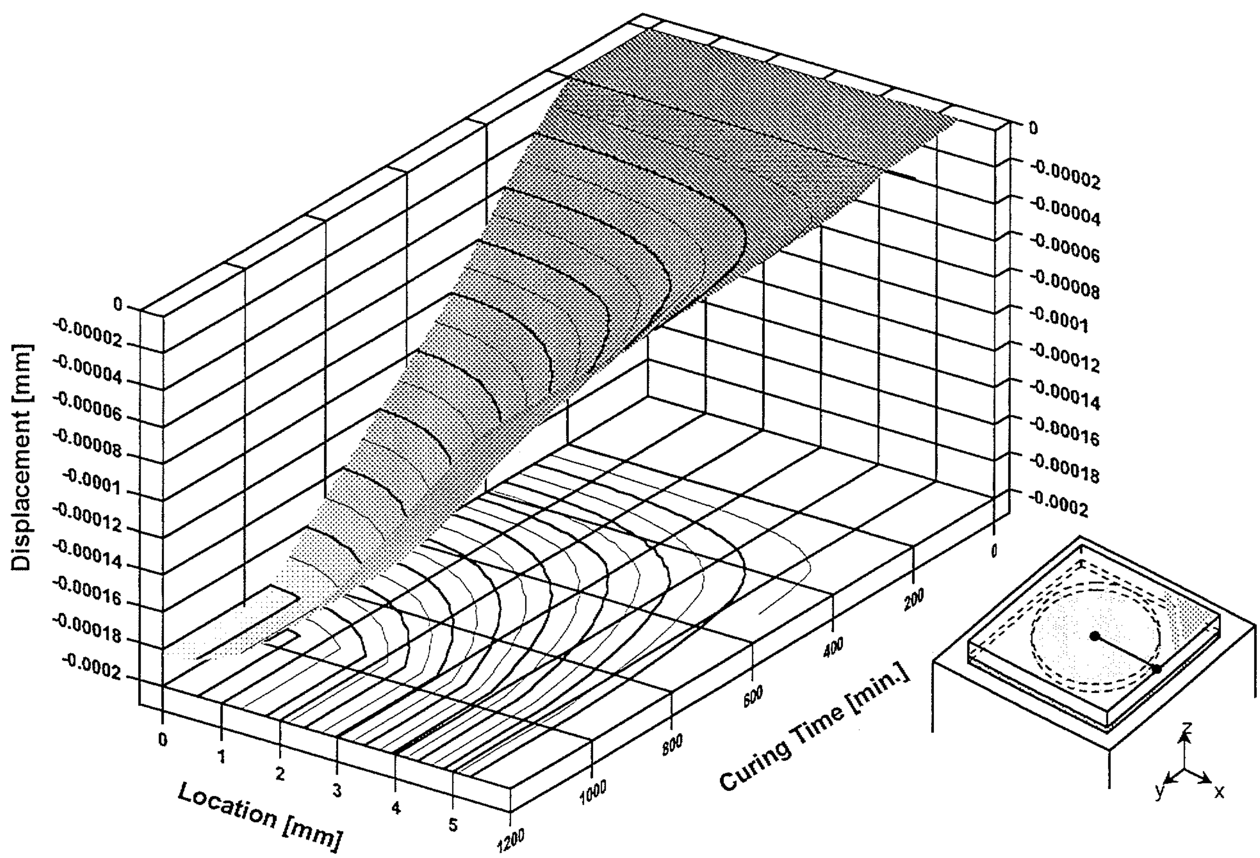

Figure 10. Calculated displacement distribution on mirror surface as a function of curing time.

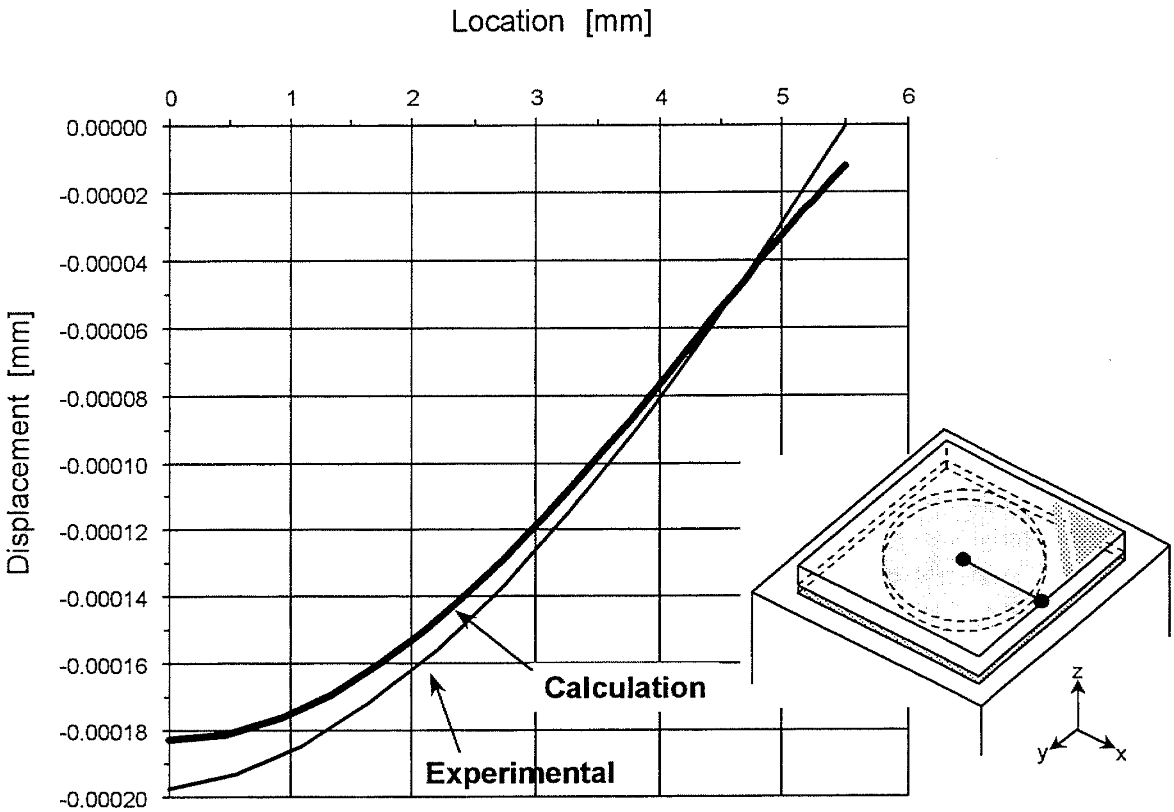

Figure 11. Comparison between experimental and calculated displacement distribution on mirror surface at the end of curing process.

4. CONCLUSIONS

In this study, the internal stress generated by curing shrinkage of room temperature cured epoxy adhesive was measure by an optical interferometer and numerical analysis method for the internal stress was examined. The dilatometer and the rheometer measured the change of shrinkage ratio and elastic modulus during curing process, respectively. The piecewise linear analysis theory was applied to consider the change of material property during curing process. As a result, a good agreement was obtained between experimental and calculated displacement on mirror surface. Moreover, a stress analysis of adhesively bonded joints considering an effect of the internal stress can be performed by proposed method since the nodal force in FE model can apply the internal stress.

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