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Evaluation of Crack Closure in Epoxy Resin Plates with an Embedded SMA Wire Using Digital Image Correlation

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Crack closure in epoxy resin plates with an embedded linear shape-memory alloy (SMA) wire, which are effective actuators in intelligent structure members, heated by supplying electric current under a tensile load is investigated using a digital image correlation technique. Results show that the maximum deformation of the plate surface can be obtained on both sides of a crack and increases with the duration of the current supply. Therefore, the measured deformation suggests the possibility of its application in the prediction of crack closure in epoxy resin plates with embedded SMA wires heated by supplying electric current

Key words: Intelligent Structure, Shape Memory Alloy, Epoxy Resin Plate, Crack, Digital Image Correlation

1. INTRODUCTION

Intelligent materials and structures with a self-recovery function similar to that of a living organism have recently attracted considerable attention [1]-[5]. Sensor, processor and actuator functions are microscopically embedded in the materials and macroscopically embedded in the structures.

The authors investigated the fundamental characteristics of shape-memory alloy (SMA) wires, which are effective actuators in intelligent structures, embedded in epoxy resin plates in order to develop a intelligent structure which prevents crack generation and closes cracks generated in machine parts and structure members [6]-[9]. Furthermore, the authors investigated crack closure, which is due to the recovery of the shape of shape-memory alloy (SMA) wires embedded in epoxy resin plates and heated by supplying electric current, on the basis of the stress intensity factor determined from isochromatics obtained from photoelastic experiments [6]-[12].

Results showed that the technique used for the determination of the recovery force of SMA wires is important for the development of an accurate finite-element model for crack closure. The recovery force was difficult to measure because SMA wires were embedded in epoxy resin plates. If the two-dimensional deformation of epoxy resin plates with embedded SMA wires heated by supplying electric current were to be measured, the recovery force could be estimated from this measured deformation.

In this study, the deformation of epoxy resin plates with embedded SMA wires heated by supplying electric current was measured using an image correlation technique, and the relationship between the deformation and crack closure was investigated.

2. EXPERIMENTAL PROCEDURES

Figure 1 shows specimens of epoxy resin plates with an embedded linear SMA wire. The epoxy resin plates were produced from Araldite-CY230: hardener-HY956 =100:20 weight ratio, and had Young's modulus of 2.8GPa and Poisson's ratio of 0.35. The SMA wire used was a TiNi wire with a diameter of 0.5mm, maximum recovery stress of 290MPa, shape recovery of 6% and austenite finishing temperature of 58°C [13]. The SMA wire had Young's modulus of 14.1GPa and Poisson's ratio of 0.3 at 20°C after shape-memory heat treatment. One linear SMA wire with a prestrain of approximately 6% was embedded in the epoxy resin plates.

The SMA wires were fixed during the formation of the plates to prevent recovery of the SMA shape generated at a high temperature in the initial stage of molding during which much heat is generated. A steel plate of 0.15mm thickness with silicon grease applied on the surface to a thickness of about 0.025mm was placed in the mold before adding the mixture of Araldite and hardener, in order to form a notch of about 0.2mm to simulate a crack.

Figure 2 shows the experimental setup used to measure the deformation of the specimens shown in Fig.1. An electric current of 1.5A was applied for 60s to each SMA wire in the specimens shown in Fig.1 from the wire exposed to air at the ends of the plates using power supply equipment, after which the current was switched off. The electric current was supplied under a no-load condition for specimens A and B, and under a tensile load of 313.6N for specimen C.

The images of the specimen surface were taken at intervals of 1/30s for a duration of 60s immediately after the supply of electric current to the SMA wires. The deformations of the specimen surfaces were measured from the images using a digital image correlation system (VEDDAC 2.6, Ettemeyer Co.) with a spatial resolution of 0.1 pixels. A correlation area of 15×15 pixels and a search area of 40×40 pixels were used. The digital image correlation system utilizes two images, which are called a reference or undeformed image and a deformed image, to measure the deformations by comparison of the images.

3. EXPERIMENTAL RESULTS

To measure the deformations of all of the specimens, an image taken at t=0s, which is immediately before the supply of electric current to the SMA wire, was used as the reference image and that at t=60s as the deformed image.

Figure 3 shows the displacements obtained for specimen A without a crack. Figure 4 shows the x displacements as a function of time at points a and b in specimen A. The displacement was about -10μm at point a and about +20μm at point b for a current supply duration of 60s. The minus displacement at point a and the plus one at point b implied the expansion of the plate. Figures 3 and 4 indicate that the epoxy resin plate expanded outward due to heat generated by supplying electric current to the SMA wire, and the expansion close to the SMA wire exposed to air was smaller than that at the upper periphery of the plate close to the SMA wire. These results suggest that the displacement of the plate induced by the shape recovery of the SMA wire is smaller than that by the thermal expansion of the plate.

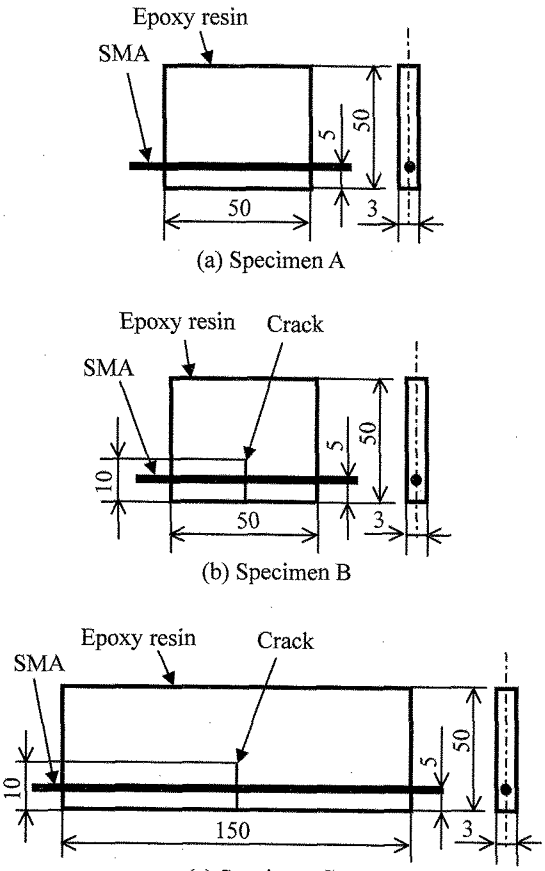


Fig.1 Shape and dimensions of specimens

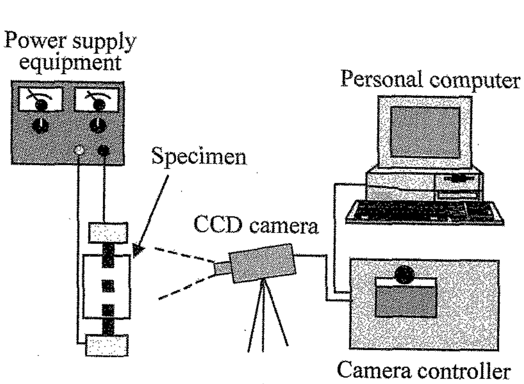


Fig.2 Experimental setup

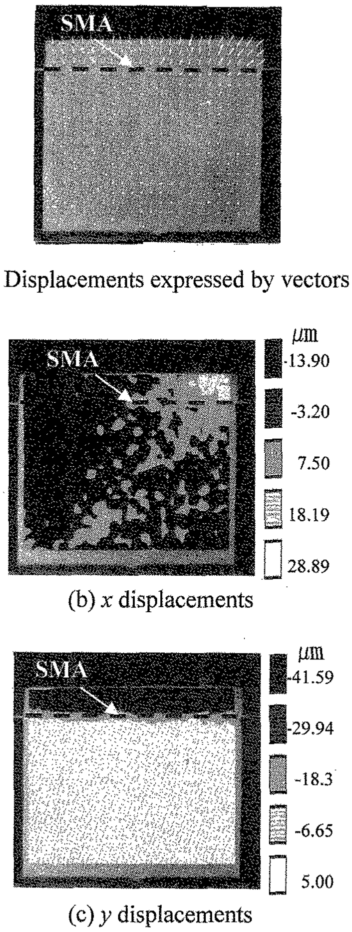


Fig.3 Displacements obtained by the digital image correlation for specimen A

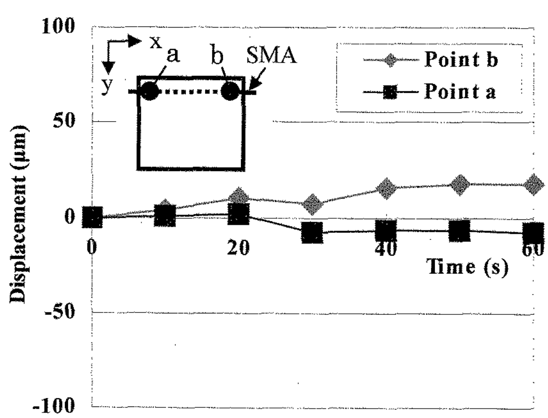
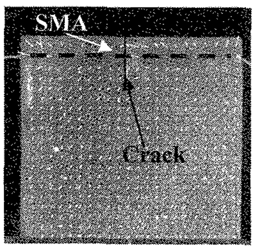


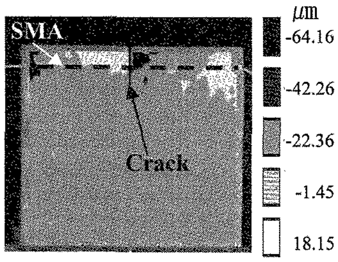
Fig.4 x displacements in time series for specimen A

Figure 5 shows the displacements obtained for specimen B with a crack. Figure 6 shows the *x* displacements as a function of time at points c, d, e and f in specimen B. The displacement was about -40μm at point c and about +5μm at point f for a current supply duration of 60s, similar to the case of points a and b for specimen A. The displacement was about +10μm at point d and about -35μm at point e. Therefore, parts of the plate around the crack located in the middle of the upper side of the plate moved toward the crack, and those close to the SMA wire exposed to air moved outward. These results suggest that the shape recovery force of the SMA wire is smaller than the thermal expansion force of the plate at the periphery of the plate and larger than the thermal expansion force around the crack.

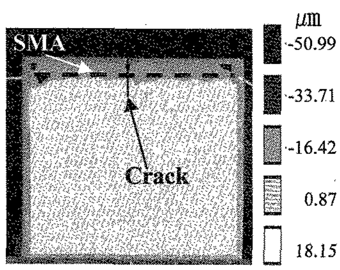
Figure 7 shows the displacements obtained for specimen C subjected to a tensile load. Figure 8 shows the *y* displacements as a function of time at points g and h. The displacement was about +45μm at point g and



(a) Displacements expressed by vectors

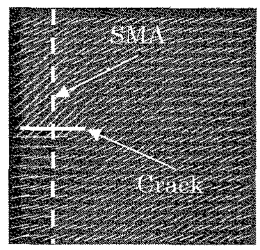


(b) *x* displacements

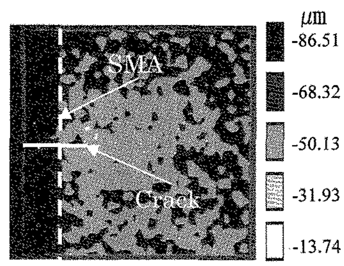


(c) *y* displacements

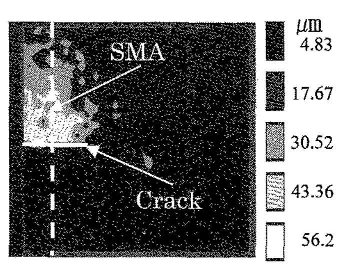
Fig.5 Displacements obtained by the digital image correlation for specimen B



(a) Displacements expressed by vectors



(b) *x* displacements



(c) *y* displacements

Fig.7 Displacements obtained by the digital image correlation for specimen C

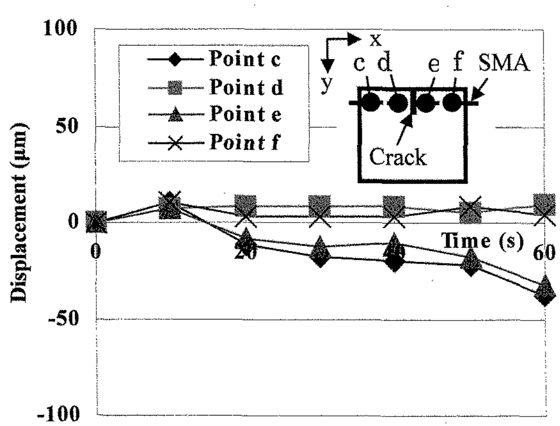


Fig.6 *x* displacements in time series for specimen B

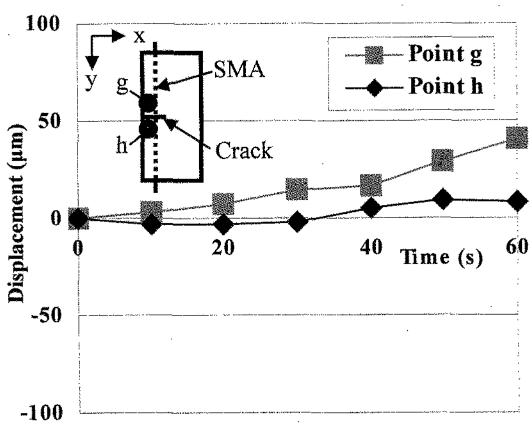


Fig. 8 *y* displacements in time series for specimen C about +10μm at point h for a current supply duration of 60s. These results suggest that the displacement generated in the plate around the crack is maximal and that the crack in the plate subjected to a tensile load is closed.

The above results show that the two-dimensional deformation of the plate surface with an embedded SMA wire heated by supplying electric current can be measured using the digital image correlation technique, which suggests the possibility of its application in the prediction of crack closure in the plates.

4. CONCLUSIONS

The two-dimensional deformation of the surface of epoxy resin plates with an embedded linear shape-memory alloy (SMA) wire was measured using a digital image correlation technique. The measured two-dimensional deformation of the plate surface suggests the possibility of its application in the prediction of crack closure in epoxy resin plates with embedded SMA wires heated by supplying electric current.

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