Estimation of plastic deformation in strain rate dependence materials by infrared video system

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Abstract

A method of detecting the plastic region from thermal image generated by plastic deformation is proposed. The heat distribution on specimen surface with a center crack was measured by using infrared thermo video system (TVS-8200) under uni-axial tensile test, and the relation between the distribution of temperature rise and the region of plastic deformation was examined. Furthermore, elasto/visco-plastic FE analysis coupled with transient heat conduction analysis was performed. The experimental thermal image was good agreement with analytical one and the applicability of evaluating the plastic deformation behavior by thermography was demonstrated.

1 Introduction

The strength, deformation and fracture of strain rate dependence materials closely depend on deformation rate, because the strain rate affect on the plastic zone size. As a detecting technique of this plastic zone size undergoing deformation, authors paid attention to thermal energy of material which is generated by plastic deformation, a infrared thermography method was adopted. This device have some characteristics such as two dimensional data acquisition, non-contact, dynamic measurement and wide area measurement etc.

The aim of the study is development a simpler and more convenient detecting system of plastic deformation. The distribution of temperature rise undergoing deformation was measured continuously and the effect of deformation rate on thermal image by thermography was examined through the FE simulation and the propriety of this non-contact quantitative evaluation of macroscopic plastic deformation was shown.
2 Experiment

2.1 Thermal image detecting system

Figure 1 shows outline of thermal image measuring system. The specification of infrared thermal video system (TVS-8200) is shown in Table 1. The TVS-8200 system consists of infrared camera and image processing unit. The camera has two dimensional array infrared sensors (horizontal 320 x vertical 240) and the 256 colors or gradient thermal image can be continuously obtained every 1/50 second and recorded in the frame memory. These recorded thermal images were transferred to personal computer and image data processing was carried out.

The experiment was executed under light shield condition in order to avoid the reflection noise such as the inside reflection in thermo camera and surface reflection etc.

Fig.1 Construction of the surface temperature distribution detecting system under deformation

<table>
<thead>
<tr>
<th>Table 1 Specification of TVS-8200</th>
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<tr>
<td>Measurable temperature range</td>
</tr>
<tr>
<td>Resolution of temperature</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Number of scanning frames</td>
</tr>
<tr>
<td>Display elements</td>
</tr>
<tr>
<td>Detector</td>
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<td>Detecting wave range</td>
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2.2 Material and specimen

The material used is 99.5% pure titanium. The geometry and dimensions of specimen are shown in Fig.2. The center pre-crack was made by electrospark machine with wire of 0.3 mm diameter as stress concentration parts. The crack configuration, clip gage length and the positions of thermocouple and strain gages are shown in the detail A and B of this figure, respectively. After machining, strain relief annealing was done in all specimens.

Fig.2 Geometry and dimensions of specimen and measuring positions of temperature, strain and displacement

In order to obtain the strain rate dependence of the material, uni axial tensile tests under various strain rates \((1.70\times10^{-5} \sim 1.67\times10^{-1})\) were carried out. Figure 3 shows the stress-strain curves obtained by these tests. It is found that stress level increased with higher strain rate in plastic region.

Fig.3 Stress-strain curves
2.3 Measurement of thermal image by thermography under deformation

The tensile tests were carried out by using Instron type universal testing machine at crosshead speeds at 10 mm/min and 50 mm/min. The thermocouple was welded on specimen surface by electro spark as calibration with temperature measured by thermography system. The displacement was measured by the clip gage (gage length : 40 mm) in order to obtain the input data of displacement control in FE analysis. The strain gages pasted on specimen surface were used to compare with analytical results. Heat distributions on the specimen surface by infrared camera were measured at real time and recorded by VTR and frame memory continuously. The thermal image obtained by thermography is converted into the distribution of temperature rise on specimen surface by the thermal energy of plastic deformation as shown in Fig.4.

![Thermal image by plastic deformation](image)

Fig.4 Thermal image by plastic deformation

Figures 5 and 6 show the temperature distribution of specimens' surface around crack tip in the case of crosshead speed 10 mm/min and 50 mm/min at clip gage displacement 0.9mm, respectively. High temperature region occurred near the crack tip in the case of crosshead speed, 50 mm/min, while in the case of 10 mm/min, the heat which was generated by plastic deformation, widely spread over the specimen and peak temperature become low.
3 Analysis of heat generation and thermal conduction by FEM

In order to study the relation between temperature rise measured by TVS-8200 and plastic deformation, elasto/visco-plastic FE analysis coupled with transient heat conduction analysis was used. In elastic region, thermoelastic effect was considered. In plastic region, for purpose of introducing strain rate dependence, the visco-plastic theory of Perzyna was employed. It is assumed that plastic strain energy was perfectly convert into heat in this analysis. The condition of time integration of Crank-Nicolson in transient heat conduction was used. In this analysis, displacement-control method was adopted.

Analytical constants in visco-plasticity were calculated from the stress-strain relations shown in Fig.3. The dotted lines in Fig.3 show the calculated stress-strain curves. In displacement control, the displacement-time curve in clip gage obtained by experiment was used.

4 Results and discussion

Figures 7 and 8 show the relations between temperature rise and stress ratio at the point of 3 mm distance from crack tip (Fig.2) obtained by thermocouple and analysis. From these figures, it is found that these analytical results good simulated the experimental temperature behaviors in both elastic and plastic regions.

Figures 9 and 10 show the temperature distributions by analysis at clip gage displacement 0.9 mm. In Fig.9, the temperature rise occurred around crack tip and the heated region spread over the specimen with increasing time. In Fig.10, the region of temperature rise concentrate near the crack tip and the spread of heat is small.

Figures 11 and 12 show the distribution of equivalent plastic strain by analysis at clip gage displacement 0.9 mm. The strain distribution depend on displacement speed, i.e. the high strain region in the case of low displacement velocity become a little wider than that in the case of high displacement velocity and total deformation at 10 mm/min also become than that at 50 mm/min.

In the case of high deformation ratio, the thermal image by thermography correspond to plastic strain distribution, but in the case of low one, the thermal image is different from plastic strain distribution because of heat conduction and radiation.

Comparing the thermal image by experimental and analysis, these distributions of the temperature rise calculated by FE analysis were good agree with the ones by measured TVS-8200, quantitatively. This suggests the possibility of inference of local plastic deformation and local plastic damage region from thermal image by coupling with computer simulation.
Fig. 5 Distribution of temperature rise by thermography
(10 mm/min)

Fig. 6 Distribution of temperature rise by thermography
(50 mm/min)
Fig. 7 Relation between temperature rise and stress ratio (10mm/min)

Fig. 8 Relation between temperature rise and stress ratio (50 mm/min)
Fig. 9 Temperature distribution by analysis (10 mm/min)

Fig. 10 Temperature distribution by analysis (50 mm/min)
Fig. 11 Distribution of equivalent plastic strain by analysis (10 mm/min)

Fig. 12 Distribution of equivalent plastic strain by analysis (50 mm/min)
5 Conclusions

The results obtained are summarized as follows;

(1) The plastic strain distribution around crack tip is influenced considerably by loading velocity. in the case of high displacement speed, the small plastic strain was obtained at same displacement.

(2) The variation of surface temperature in metal generated by deformation can be measured by using infrared thermography in elastic region and plastic region.

(3) The temperature distribution calculated by Elasto/visco-plastic FE analysis coupled with transient heat conduction analysis good agree with the ones by measured thermography quantitatively, therefore, the local plastic deformation and local plastic region are able to evaluate from thermal image through computer simulation.

(4) In the case of high deformation ratio, the thermal image by thermography correspond well to plastic strain distribution.

References


