Macroscopic Evaluation of Localized Damage in Metal by Infrared Thermography

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ABSTRACT

Infrared thermography is a device for conducting thermal radiation pattern from an object into a visible image. We pay attention to heat generation by plastic deformation and discussed the possibility of applying this device to detecting local plastic deformation by infrared thermal video system. In measuring surface temperature distribution by this device, the effective radiation rate is a very important factor of measuring the surface temperature distribution and this largely depend upon the surface roughness. In this study, the relation between the effective radiation rates and the surface roughness was examined. Furthermore, computer simulation of the deformation and the heat generation and transfer accompanied with it was performed. In the simulation, elasto-plastic FE analysis coupled with transient heat conduction analysis was used. From the comparison between experimental results and analytical ones, the validity of this non-contact measurement of local plastic deformation by infrared thermography was shown.

KEY WORDS

Plastic deformation, infrared thermography, FEM, non-contact measurement, thermal image

INTRODUCTION

Infrared thermal video system has become of major interest lately as non-contact measuring and detecting device of dynamic localized damage in metal because of these advantages such as

(1) two dimensional thermal data acquisition and wide area measurement
(2) wide measurable temperature range
(3) real time and dynamic measurement(McLaughlin et al., 1987; Shiratori et al.,1990; Kageyama et al., 1990; Osakada et al.,1993)

Authors (1992, 1994a, 1994b) paid attention to heat distribution of material surface which is generated by local plastic deformation in order to evaluate the behaviors of stress concentration parts in metal. As detection of heat in a deforming material, infrared thermal video system (TVS) was employed. In measuring surface temperature correctly by use this device, it is necessary to decide the suitable effective radiation rate. This rate was closely related into reflection rate. Consequently, this was largely depended upon the state of specimen surface. The relation between the effective radiation rate and the surface roughness was made clear. Next, the correspondence of plastic deformation and temperature rise around a crack tip under constant loading rate was discussed. The propriety of this non-contact qualitative evaluation of macroscopic plastic deformation was examined in comparison with the results of FE analysis.

THERMAL IMAGE SENSING SYSTEM

Figure 1 shows outline of measurement system. The specification of infrared thermal video system (TVS-8200) is shown in Table 1. This device 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 1/60 second and recorded in the frame memory. These recorded thermal images were transferred to computer and image data processing was carried out.

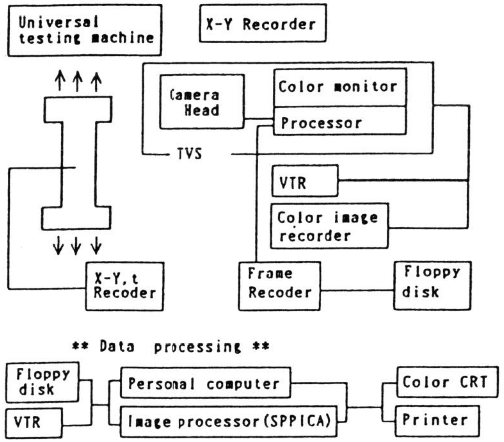

Fig.1 Measurement system

Table 1 Specification of TVS-8200

Range of measurement temperature−40	~ 1200 °C
Resolution of temperature	0.4%(full scale)
Number of scanning frames	60 frames/sec
Display elements	76,800 pixels
Detector	InSb (H 160 x V 120 elements)
Detecting wave range	4 ~ 4.6 μm

EXPERIMENT

The material used is stainless steel, SUS304 in JIS. The relation between effective radiation rate and surface roughness is shown in fig.2. Grinding papers (#80~#1500) were used for finishing of the specimen's surface. From this figure, it is found that the radiation rate increase with surface roughness increase. But, in #1500 specimen, the rise of radiation rate is observed though the surface was nearly mirror finished one. This is owing to effect of surface reflections.

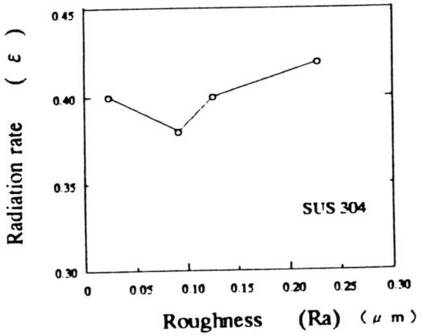

Fig.2 The relation between effective radiation rate and surface roughness

After strain-relief thermal treatment, uni-axial tensile tests under various loading rates (0.5~500 mm/min) were carried out. The relations between the stress and strain were shown in fig.3. It is found that difference of stress level did not change largely in spite of tensile speeds.

Next, surface temperature in center crack specimen subjected constant displacement ratio was measured by infrared thermography. The geometry and dimensions of specimen are shown in Fig.4. The center pre-crack was made by electrospark machine with wire of 0.3 mm diameter as stress concentration parts. After machining, strain-relief anneal was done in these specimens.

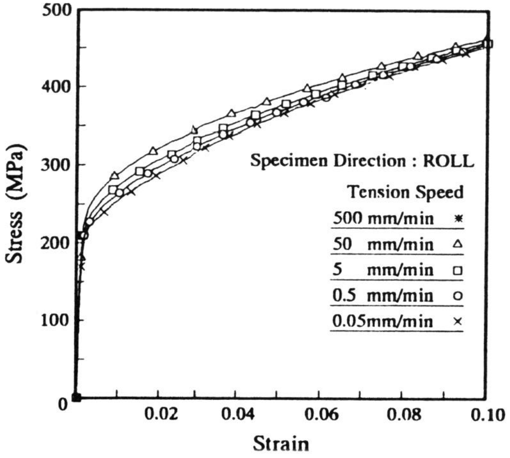

Fig.3 Stress–strain relations

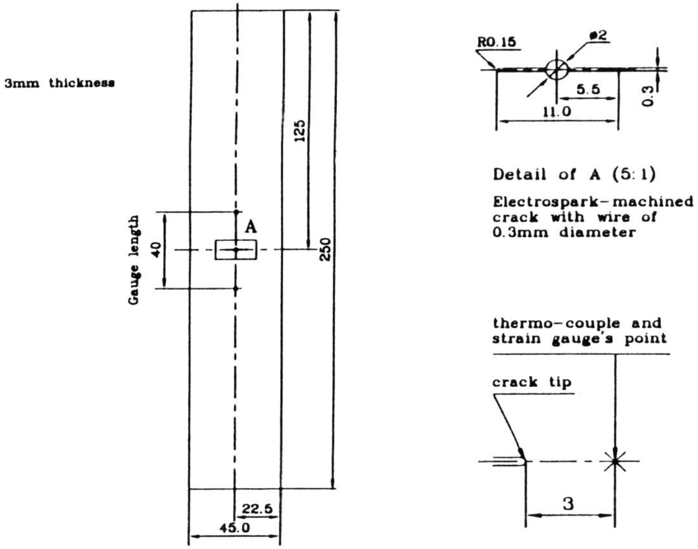

Fig.4 Geometry and dimensions of specimen

The tensile test was carried out by using Instron type universal testing machine at crosshead speeds at 25 mm/min. The displacement was measured by using clip gage (gage length ; 40 mm). Heat distributions on the specimen surface by infrared camera were measured at real time and recorded by VTR and frame memory continuously.

Figures 5 and 6 are the thermal image measured by TVS–8200. These figures show the temperature distribution of specimens' surface around crack tip at 12 second and 18 second respectively. It is observed that the temperature rises near the crack tip and the high temperature region with increasing plastic deformation spread over the specimen.

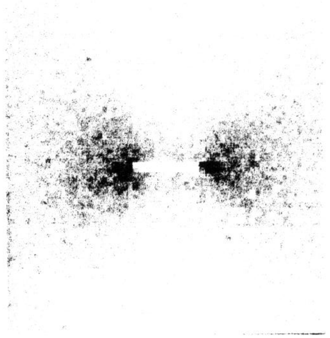

Fig.5 Distribution of temperature (12 second)

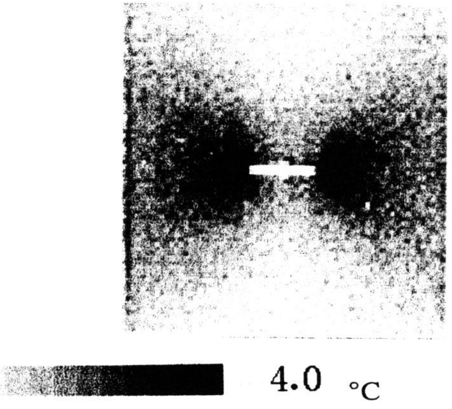

Fig.6 Distribution of temperature (18 second)

ANALYSIS

In order to study the relation between temperature rise measured by TVS and plastic deformation, elasto–plastic FE analysis coupled with transient heat conduction analysis was used. In elastic region, thermoelastic effect was considered. It was 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 elasto–plasticity were calculated from the stress–strain relations shown in Fig.3 and displacement–time curve obtained by experiment was used.

RESULTS AND DISCUSSION

Figure 7 shows the relations between temperature rise and time at the point of 3 mm distance from crack tip (Fig.4) obtained by thermocouple and analysis. From this figure, it is found that analytical result good simulated the experimental temperature behavior.

Figure 8 and Figure 9 show the distribution of equivalent plastic strain in the case at 12 second and 18 second by analysis. Figures 10 and 11 show the temperature distributions at 12 second and 18 second. In Figs.10 and 11, the temperature rise occurred around crack tip and the heated region spread over whole specimen with increasing time.

These results by calculated FE analysis good agree with the ones by measured TVS, quantitatively. Each plastic strain distributions correspond well to the temperature distributions. This suggests the possibility of inference of local plastic deformation and local plastic damage region from thermal image by coupling with computer analysis.

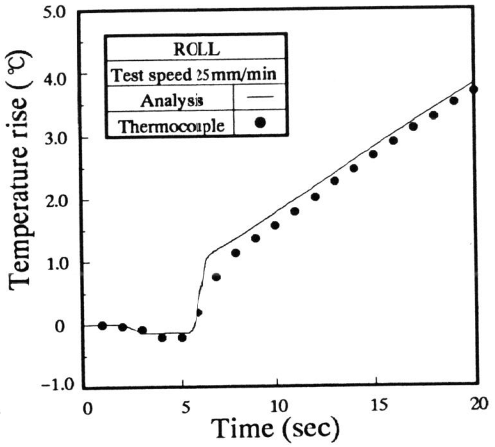

Fig.7 Relation between temperature rise and time

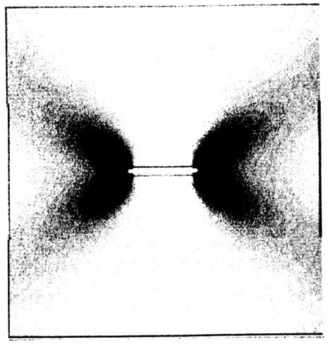

Fig.8 Distribution of equivalent plastic strain (12 second)

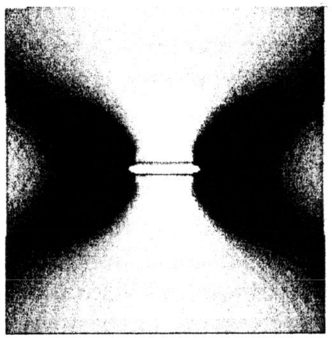

Fig.9 Distribution of equivalent plastic strain (18 second)

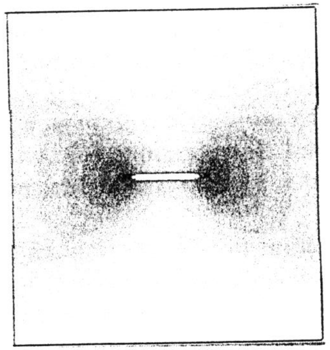

Fig.10 Temperature distribution (12 second)

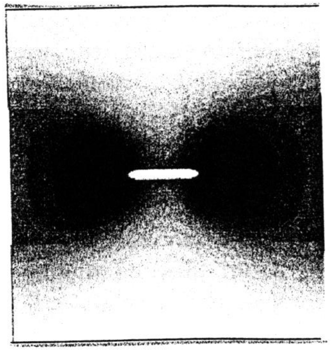

Fig.11 Temperature distribution (18 second)

CONCLUSIONS

The results obtained are summarized as follows;

(1) Effective radiation rate in thermography increase with increasing surface roughness.

(2) The surface temperature distribution occurred by local plastic deformation can be measured by infrared thermography.

(3) The temperature distribution calculated by Elasto-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 damage region are able to evaluate from thermal image through computer simulation.

REFERENCES

McLaughlin, Jr. P.V.(1987). Infrared thermographic flaw detection in composite laminates, ASME. J. Engng. Mat. and Tech., 109,146–150.

Shiratori, M.(1990). Detection of cracks and measurement of stress intensity factors by infrared video system. JSME. J., 400–408.

Sakamoto, H.,(1992). Contactless evaluation of plastic deformation under residual stress field. In: Advances in Engineering Plasticity and its Applications(W.B. Lee, ed.), 943–948, Elsevier, Amsterdam.

Osakada, K.,(1993). Measurement of plastic strain distribution by infrared thermography. In: Advanced Technology of Plasticity(Z.R. Wang, ed.), 257–262, International Academic Pubulisher, Beijing.

Sakamoto, H.,(1994a). Evaluation system of plastic deformation in elasto–visco–plastic body with crack by infrared thermography. In: Localized Damage Ⅲ(M.H. Aliabadi, ed.),453–459. Computational Mechanics Publications, Southampton.

Oda, I.,(1994b). Inference of plastic deformation in welding residual stress field from infrared thermography. In: Recent Advances in Experimental Mechanics(S. Gomes, ed.), 817–822. Balkema, Rotterdam.