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Analysis of heat generation under plastic deformation, crack initiation and propagation

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Abstract

In order to evaluate the plastic deformation of mechanical members, we pay attention to surface temperature that is generated by plastic deformation. Most of the plastic energy exhausted by plastic deforming is converted into heat. The distributions of the heat generation represent the microscopic plastic deformed intensity. In the present study, the tensile tests were performed on stainless steel (SUS304) plate with a center crack. We measured the distributions of surface temperature by using the thermocouple and thermograpy (TVS: Thermal Video System) under the plastic deformation and crack propagation. Furthermore FEM elasto-plastic analysis coupled with transient heat condition analysis was performed. The analytical results were good agree with the experimental ones and the propriety of this non-contact measurement system of plastic deformation and fracture process by theromgraphy system was shown.

1 Introduction

Thermogaphy is one of the most effective devices to detect the heat distribution of two dimensional material's surface with non-contact. This device is used as the detection of the delimitation of composite materials, the analysis of fracture mechanics, the non-contact inspection and so on. [1]-[2]

Recently, authors paid attention to heat generation under plastic deformation and the establishment of visualized evaluation system of the plastic deformation by sensing the material's surface is examined [3]-[7].

In this study, the tensile tests were performed on stainless steel plate with a center crack. We measured the distributions of surface temperature in the plastic deformation and the fracture by using the thermocouple and thermograpy. Furthermore, FEM elasto-plastic and crack propagating analysis coupled with transient heat condition analysis was performed. The analytical results were compared with experimental ones and the propriety of this non-contact measurement system of plastic deformation and fracture process by theromgraphy system was discussed.

2 Experiments

2.1 Thermal image detecting system

Figure 1 shows the outline of the thermal image detecting 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 personal computer and image data processing was carried out

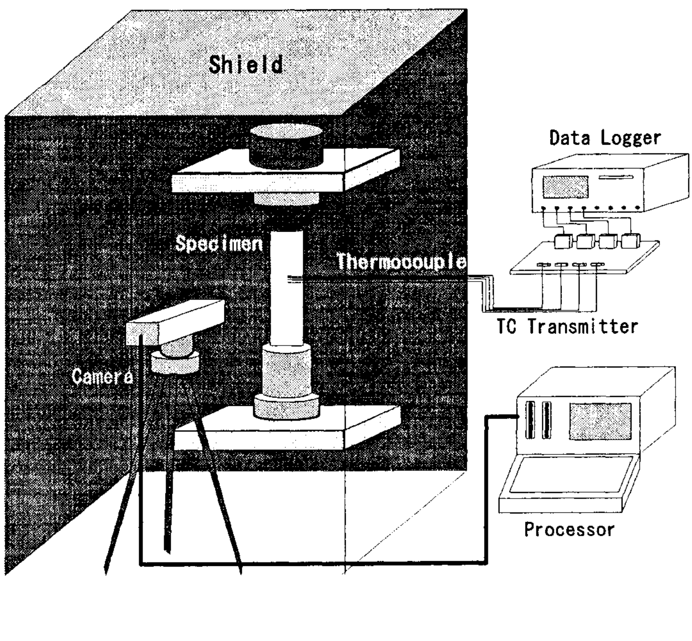

Fig.1 Thermal image detection system (TVS8200)

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Table 1 Specification of TVS-8200

Range of measurement temperature	-40～1200℃
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 μ m

2.2 Material and specimen

The material used is stainless steel, SUS304 in JIS. The geometry and dimensions was shown in Fig.2. The center pre-crack was made by electrospark machine with 0.3mm diameter as stress concentration parts. After machining, the strain relief anneal was done in these specimen. The shadow part in Fig.2 shows the simulation region used by FE analysis

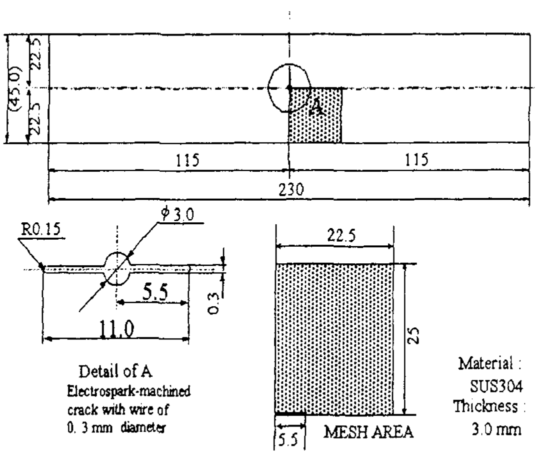

Fig.2 geometry and dimensions of specimen

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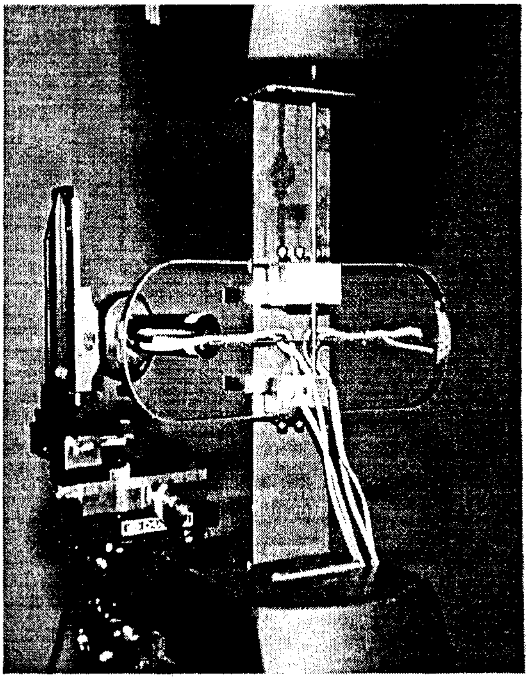
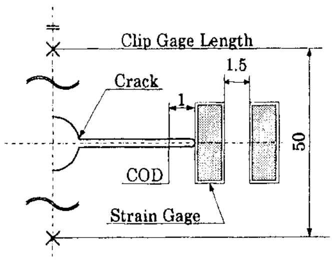
2.3 Experimental method

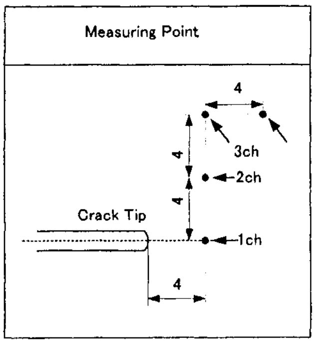
The tensile tests were carried out by Instron type universal testing machine at cross head speed 25mm/min. The appearance of deformation in the vicinity of crack tip was observed by CCD camera in Fig.3(a). The displacement was measured by using clip gage (gage length: 50mm) in Figs.3(a)(b) in order to obtain the input data of displacement control in FE analysis. The strains and the temperatures around the crack tip were detected by the strain gages and the thermocouples shown in Fig.3(b) and Fig3(c), respectively.



(a) Clip gage and CCD unit



(b) Clip gage length and strain gage positions



(c) Temperature measuring positions (thermocouple)

Fig.3 Appearance of the deformation measurement unit and the measuring points

Simultaneously, the heat distributions on the specimen's surface were measured continuously and recorded by the thermography. .The thermal images obtained by the thrmography, were converted into the distribution of temperature rise on specimen surface by a thermal image processing. The distribution of temperature rise per unit time was obtained as the differential thermal image of current one and referent one.

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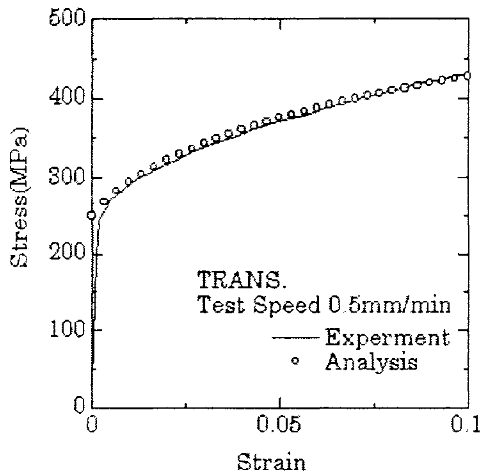
3 Simulation of heat generation in plastic deformation and crack propagation

In order to study the relation between the temperature rise measured by TVS and the plastic deformation and crack propagation, elasto-plastic FE analysis coupled with transient heat conduction analysis was performed. In elastic region, thermoelastic effect was considered. It was assumed that plastic strain energy was perfectly converted into heat. The condition of time integration of Crank-Nicolson in transient heat conduction was used and displacement-control method was adopted.

In this analysis, plane stress condition was assumed and strain hardening is expressed by the Swift's equation shown in Fig.4. In the crack propagation analysis, the nod's constrain at crack tip was released according to experimental result.

Analytical constants in elasto-plasticity were calculated from the stress-strain relation in this figure and the displacement-time curve obtained by this experiment was used. The open mark in this figure represent the simulation results of the experimental stress-strain curve and both curves are agreeing well.



$$\sigma = c(\alpha + \varepsilon^{p})^{n}$$

α	C	n
0.0083	680.000	0.209

Fig.4 Stress-strain curve and analytical constants

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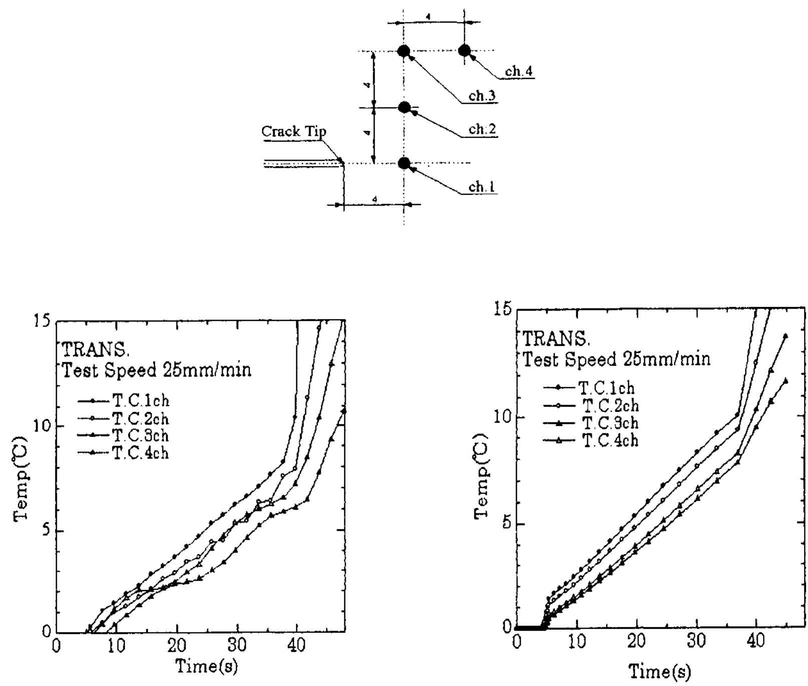
4 Results and discussion

Figs.5(a),(b) show the temperature rise on the specimen's surface measured by the thermocouples and the FE analysis around the crack tip during the plastic deformation and crack propagation, respectively. Both temperature rise curves agree well. Paying attention to the temperature-rise at each position, the temperatures are going up in order of ch.1, ch.2, ch.4, and ch.3 and rise suddenly when the crack propagation starts. These temperature distributions coincide with plastic strain distributions obtained by FE analysis.



(a) Thermocouple (b) Analysis

Fig.5 Temperature rise on specimen's surface during plastic deformation and crack propagation

Fig.6 shows an example of the thermal image measured by thermography and the one calculated by FE analysis in the crack propagation region to examine the surface temperature distribution. In this FE analysis, as we assume that the boundary is in adiabatic and the strain energy is perfectly converted into heat, the analytical temperature distribution become a little higher than the experimental one.

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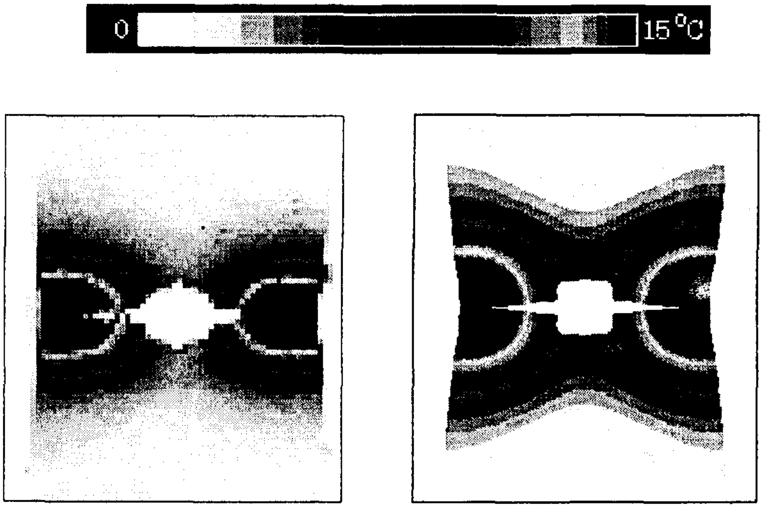
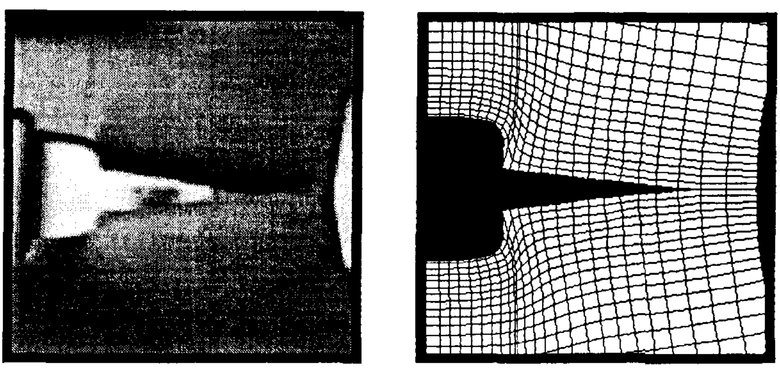


(a) Thermography (b) FE analysis

Fig.6 Comparison between experiment thermal image and analytical thermal image

Next, the comparison between the configurations observed by CCD camera and the corresponding analytical one was shown in Fig.7. From the picture of CCD camera, it is found that the surface roughness at the vicinity of crack increase with opening the crack and development of the plastic deformation. The deforming shape of the FE analysis good agree with the experimental one.

From Fig.6 and Fig.7, the plastic strain distribution correspond well to the temperature distribution during the plastic deformation and the crack propagation.



(a) CCD camera (b) FE analysis

Fig.7 Deformed configuration around the crack tip

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Conclusions

The results obtained are summarized as follows:
(1)The temperature distribution by obtained FEM analysis good agree with the one measured by TVS , quantitatively.
(2)The plastic strain distribution corresponds well to the temperature distribution, but it is not easy to estimate directly the size of plastic deformation and the plastic stress/strain distribution from temperature, because the temperature distribution in elasto-plastic body are influenced by the heat condition and radiation.
(3)The stress and strain distribution during the plastic deformation and the crack propagation are determined by elasto-plastic analysis coupled with transient heat conduction through the thermal image obtained by thermography.

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