THE THICKNESS EFFECT OF THE CCT SPECIMEN

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I. INTRODUCTION

In case of the crack propagation under the elastic-plastic condition,the plastic region created at the crack tip is very large. Therefore, it is necessary to know the stress and strain distribution within it. The plane strain condition exists at the midsection, while the plane stress condition exists at the surface of specimen. Many analytical studies [1,2] have been carried out three dimensionally. However, the experimental sturdies [3,4] have been hardly carried out. The recrystallization technique is effective to investigate the distribution of plastic strain within the intense strain region at the crack tip.

Then, in this paper, the recrystallization technique is utilized to investigate the plastic strain energy within the intense strain region at the crack tip of center cracked tension specimen. At the same time, the finite element method analysis is carried out from the theoretical aspect. The thickness effect of CCT specimen is discussed from both experimental and analytical aspects.

II. EXPERIMENTS AND ANALYSES

The test material is a rolled steel for general structure, SS41. The chemical compositions and the mechanical properties are shown in Table. 1 and 2, respectively. The specimen used for tension tests is CCT specimen as shown in Fig. 1. The specimen thickness, B, is 18, 12 and 6 mm, respectively. All specimen were precracked by fatigue at the stress intensity levels less than that recommended by ASTM STP E399-72 up to a final crack length of 2a/W=0.5. Each specimen was loaded up to the previously specified displacement with the loading rate 2mm/min and then unloaded.

The recrystallization annealing was conducted in the vaccum furnace for 3 hours at 630 °C. Then, the surface of specimen was mechanically polished and etched with the 5 % nital, the same procedure was repeated by turns to the midsection.

Fig.2 shows the mesh pattern of a quarter part of CCT specimen which is used in the following analyses. The crack front profiles as shown in Fig.3 are employed which are obtained from the observation of fracture surface of CCT specimens.

III. ESTIMATE OF THE PLASTIC STRAIN ENERGY PER UNIT THICKNESS

The distortional plastic strain energy density, Wd, within the intense strain region can be expressed in the same manner as in infinitesimal strain theory even when the plastic deformation at the crack tip is large as follows;

$$Wd = \int \bar{\sigma}\, d\bar{\varepsilon}_p \tag{1}$$

where $\bar{\sigma}$ and $d\bar{\varepsilon}_p$ are the equivalent stress and the equivalent plastic strain increment, respectively. The relation between $\bar{\sigma}$ and $\bar{\varepsilon}_p$ obtained from the round bar tension test as shown in Fig.4 could be expressed as

$$\left.\begin{array}{lll} \bar{\sigma} = 775\ (0.015 + \bar{\varepsilon}_p)^{0.26} & [\mathrm{MPa}] & \text{for } \bar{\varepsilon}_p \leqq 0.2 \\ \bar{\sigma} = 306.5\ \bar{\varepsilon}_p + 457.7 & [\mathrm{MPa}] & \text{for } \bar{\varepsilon}_p > 0.2 \end{array}\right\} \quad (2)$$

By using the relation between the equivalent plastic strain and the recrystallized grain size obtained from the round bar tension tests as shown in Fig.5, the distortional plastic strain energy density is obtained in the intense strain region. Then, the total plastic strain energy absorbed within the intense strain region per unit thickness of specimen, Wp, is obtained from a following equation;

$$W_p = \int_s Wd\ ds \tag{3}$$

where s means the area of the intense strain region.

IV. ESTIMATE OF J INTEGRAL

The J integral, J, may be regarded as the sum of the elastic part of J, J_{el}, plus the plastic part of J, J_{pl},

$$J = J_{el} + J_{pl} \qquad (4)$$

The simple equation of J for CCT specimen proposed by Rice et al. [5] is expressd as

$$J = (1-\nu^2)\frac{K^2}{E} + \frac{2A}{B(W-2a)} \qquad (5)$$

where K is the stress intensity factor, A is an area under the load displacement record as shown in Fig.6, B is the specimen thickness, W is the specimen width, ν is Poisson's ratio, E is the Young's Modulus and 2a is the total crack length.

V. RESULTS AND DISCUSSION

Fig.7 is the typical recrystallization microphotographs of the intense strain region at the crack tip. Wp can be measured from these photographs. Fig.8 shows the distribution of Wp along the thickness (δ= 0.6mm). 2Z/B=0 means the midsection of thickness. Wp is highest at the surface, decreases rapidly in the vicinity of surface and becomes nearly constant at the central part of thickness. Fig.9 shows the case of δ= 0.4mm. The same tendency is shown in this case. Fig.10 shows the distribution of COD along the thickness. Although the data are scattering a little, there is the same tendency as shown in case of Wp.

The followings are the results obtained from the finite element method analysis. Fig.11 shows the distribution of J value along the thickness. While the deformation is small, the thickness effect is not shown. However, as the deformation increases, J values at the neighborhood of surface differ largely in both cases of B= 6mm and 18mm. Fig.12 shows the distribution of Wp along the thickness. Wp is highest at the surface and decreases gradually up to the midsection in both cases. The rapid variation as shown in the experimental results is not shown. Fig.13 shows the distribution of COD along the thickness. There is the same tendency as shown in case of Wp and experimental results.

VI. CONCLUDING REMARKES

The plastic strain energy within the intense strain region at the crack tip is highest at the surface and nearly constant at the central part of thickness. As the thickness increases, the ratio of the flat part of Wp to thickness increases. The distribution of COD along the thickness shows the same tendency as shown in case of Wp. As the thickness decreases, J value varies largely along the thickness.

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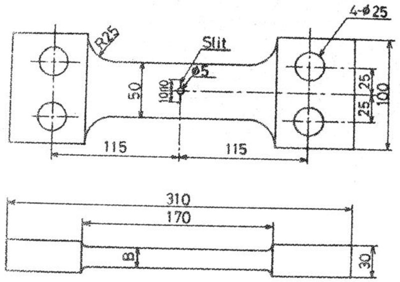


Fig.1 Specimen configuration.

Table.1 Chemical compositions(wt%).

C	Si	Mn	P	S
0.14	0.23	1.13	0.017	0.010

Table.2 Mechanical properties.

σ_{YS} (MPa)	σ_{TS} (MPa)	E (GPa)	T.E. (%)
265	422	206	44

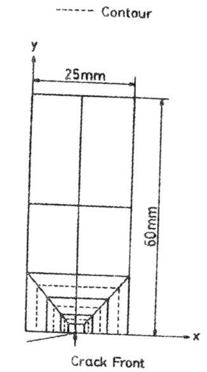


Fig.2 Mesh pattern of CCT specimen.

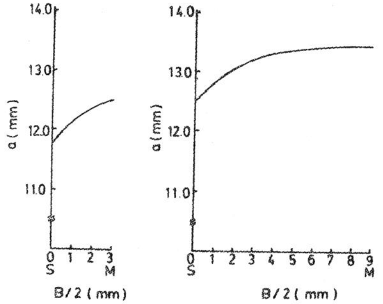


Fig.3 Crack front profiles.

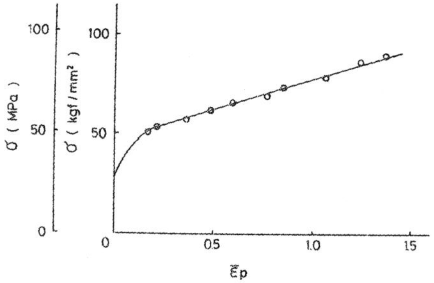


Fig.4 True stress versus true strain curve.

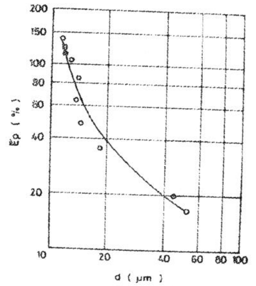


Fig.5 Relation between $\bar{\epsilon}_p$ and d.

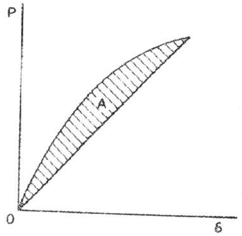
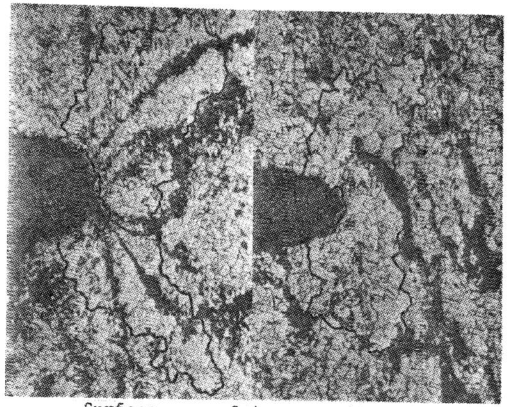


Fig.6 Schematic load displacement record.



B=6mm, J =152 kN/m

Fig.7 Typical recrystallization microphotographs of intense strain region.

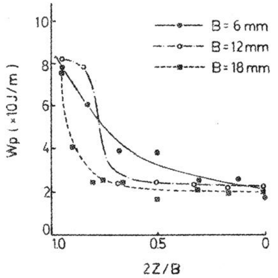


Fig.8 Distribution of Wp along the thickness (δ=0.6mm).

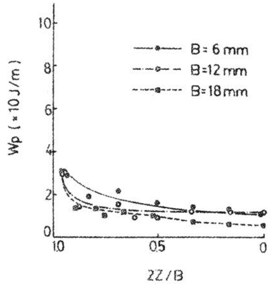


Fig.9 Distribution of Wp along the thickness (δ=0.4mm).

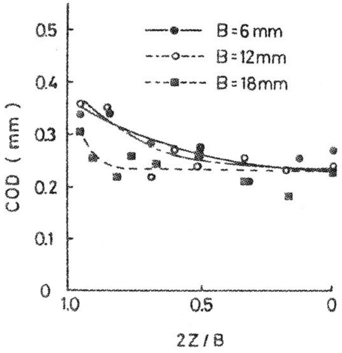


Fig.10 Distribution of COD along the theckness (δ=0.6mm).

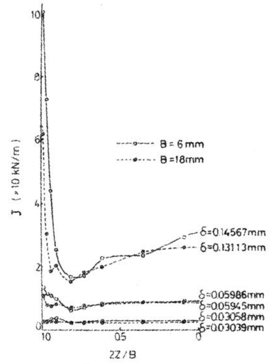


Fig.11 Distribution of J along the thickness.

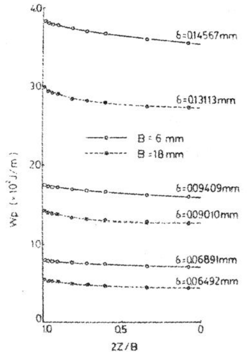


Fig.12 Distribution of Wp along the thickness.

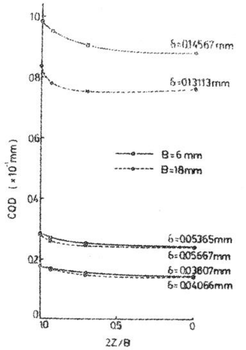


Fig.13 Distribution of COD along the thickness.