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SURFACE RESIDUAL STRESS IN COLD ROLLED 5083 ALUMINUM ALLOY PLATE

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ABSTRACT

Generation behaviors of the surface residual stress in the cold rolled 5083 aluminum alloy plate were investigated in view of the total reductions in area, specimen thickness, and variations of the working rolls' diameter, etc. Effects of one pass rolling on the generation of residual stress were also studied. The measurement of residual stress on the specimen surface along the rolling direction was achieved by applying a X-ray analysis method.

INTRODUCTION

It is well known that corrosion resistance and fatigue properties are affected markedly by the residual stresses retained in the specimen surface. From the viewpoint of engineering applications, there are a lot of studies dealing with the effect of residual stress on certain physical and mechanical properties. On the other hand, the systematic study on the residual stress generated by cold rolling has not been sufficiently made; so that the relations between the surface residual stresses and the cold rolling processes have not been clearly established. This paper describes a series of experimental study on the residual stress generated in the cold rolled aluminum plate. In the present study, an extent of generated surface residual stress has been experimentally studied mainly in view of working rolls' diameter, plate thickness, reduction rate per one pass, total reductions in area and so on.

EXPERIMENTAL PROCEDURE

5083 aluminum alloy was applied as the specimen, which was usable as structural parts of an airplane and LNG tankers and so on. It contains 4.5% magnesium and permits fairly high percentage reductions in area under rolling at ordinary room temperature. The rectangular specimens having 25 mm width and 250 mm length were machined from the commercial 5083 aluminum alloy plate. As shown in **Fig.1**, two kinds of specimens with different plate thickness were used. One of which had the constant initial thickness of 10 mm, while the other had the constant final thickness of 2 mm after applying various amounts of cold rolling (Hereafter, these are referred to as CIT and CFT specimen). Before cold rolling they were fully annealed at 673K for 7.2ks so as to relieve the residual stress generated in the machining process. The rolling processes in one direction were repeatedly conducted at room temperature under oil lubrication. Reduction in area per pass was selected mainly as 0.3 mm. In order to discuss the effect of the working rolls' diameter on the generation of residual stress, two kinds of rolling mills having different working rolls of 106 mm and 254 mm in diameter were used. In case of the one pass rolling, the reduction rates per one pass were selected mainly in a range of 0.2 to 0.7 mm.

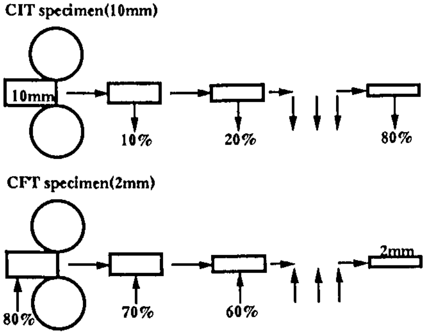

Fig.1 Specimen thickness.

The measurement of surface residual stress along the rolling direction was made by a X-ray analysis method. The residual stress was estimated from the changes in a location of the diffraction peak of the {311} crystal planes in accordance with a square $\sin\psi$ technique.

RESULTS AND DISCUSSIONS

The surface residual stresses are plotted in **Fig.2** against total reductions in area taking the plate thickness and working rolls' diameter as parameters. As shown in **Fig.2**, the absolute value of the residual stress extensively varies depending upon the specimen thickness, total area reductions, and working rolls' diameter. In the case of lower total reductions in area, the difference of residual stresses between the CIT and CFT specimens is significantly large. However, in the case of high total reductions in area at 80 %, certain differences are absent between the CIT and CFT speci-

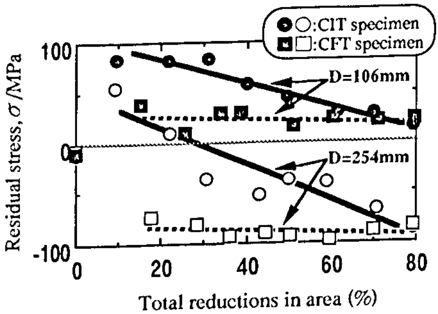

Fig.2 Changes in residual stress with total reductions in area.

mens. In addition to the above, it is characteristic that the residual stress is compressive for the larger working rolls. Generation behaviors of the residual stresses were affected mainly by the initial specimen thickness and diameter of working rolls.

Geometrical situation between the working roll and specimen is shown in **Fig.3**. From the relation shown in **Fig.3**, a roll gap ratio is estimated in accordance with equation (1).

$$\omega_n = \frac{l_n}{H_{mn}} = \frac{2R}{H_n + H_{n+1}} \cos^{-1}\left(1 - \frac{H_n - H_{n+1}}{2R}\right) \tag{1}$$

Where l_n is the contact length between the roll and specimen, H_{mn} is mean thickness of the plate ($H_{mn}=(H_n+H_{n+1})/2$).

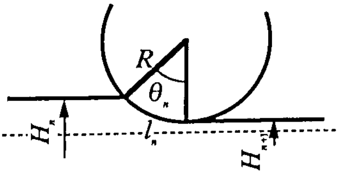

Fig.3 Geometrical situation of working roll and specimen.

In the present study, two kinds of the roll gap ratio values were applied with respect to equations (2) and (3). $\Sigma\ \omega_n$ is the value obtained from the sum of the roll gap ratio in each pass and ω_0 is calculated from the apparent thicknesses of the specimen before and after rolling. Hereafter, these are referred to as integrated roll gap ratio and apparent roll gap ratio.

$$\sum_{n=1}^{n} \omega_n = \omega_1 + \omega_2 + \cdots\cdots + \omega_n \tag{2}$$

$$\omega_0 = \frac{2R}{H_1 + H_{n+1}} \cos^{-1}\left(1 - \frac{H_1 - H_{n+1}}{2R}\right) \tag{3}$$

Fig.4 shows the relations between the residual stress and integrated roll gap ratio. As known from this figure, the variations in residual stress related to the integrated roll gap ratio are similar to the relations between residual stress and total reductions in area.

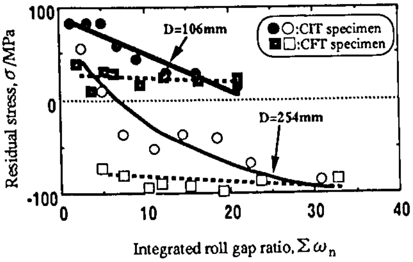

Fig.4 Plots of residual stress against integrated roll gap ratio.

Relations between the residual stress and apparent roll gap ratio are shown in **Fig.5**. Reasonable linear relations are obtained for each specimens rolled by respective working rolls and no effect of the plate thickness on the residual stress is observed. In other words, the residual stress can be expressed as a function of the apparent roll gap ratio. Consequently, the following relations (4) and (5) can be obtained basing upon the relations between residual stress and apparent roll gap ratio.

$$\sigma = 102.6 - 24.6\omega_0,\ R^2 = 0.811(D = 106mm) \qquad (4)$$

$$\sigma = \ 51.6 - 27.6\omega_0,\ R^2 = 0.826(D = 254mm) \qquad (5)$$

Here, the value of R^2 shows an extent of linearity. When R^2 equals unity, a linear relation is obtained.

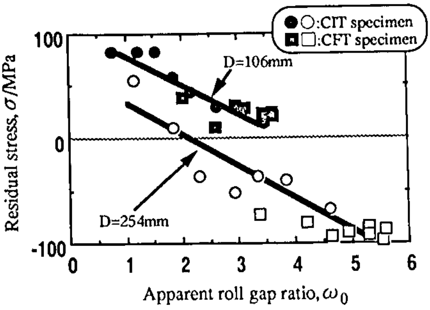

Fig.5 Plots of residual stress against apparent roll gap ratio.

According to Suzuki[1], the final pass condition in a rolling process was prominent for the residual stress generations. So, the present authors have tried to plot the measured residual stress against the roll gap ratio in the final pass process. In accordance with the relations shown in **Fig.6**, the following relations (6) and (7) can be proposed for the respective working roll sizes.

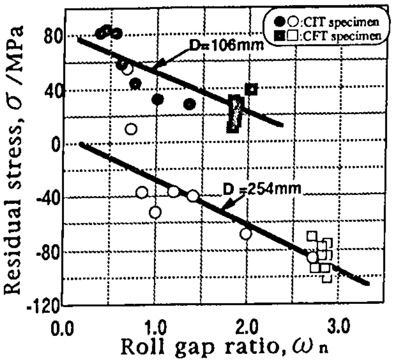

Fig.6 Relations between residual stress and final roll gap ratio.

$$\sigma = 87.4 - 35.4\omega_0,\ R^2 = 0.744(D = 106mm) \tag{6}$$

$$\sigma = 24.8 - 40.7\omega_0,\ R^2 = 0.764(D = 254mm) \tag{7}$$

As known from R^2 values in (4)-(7) relations, a fine linear relations can be obtained between the apparent roll gap ratio and residual stress measured in the present study. From the above mentioned reasons, the residual stress can be calculated basing upon the apparent roll gap ratio. According to a study[2] on the residual stress generated in the copper alloy strip in rolling processes, reasonable relations have been obtained between the residual stress and $(t/l)^2$; where t is the plate thickness after rolling and l is the chord subtended by the arc of contact between the working rolls and the plate. **Fig.7** shows the relations between σ_R/σ_y versus $(t/l)^2$. In this figure, the ordinate shows the ratio of residual stress to yield stress, σ_R/σ_y and also the result reported by Baker[2] is shown together for reference. For each of the working rolls' diameter, the value of σ_R/σ_y increases gradually with the increase in the value of $(t/l)^2$ but independent of each other. It seems that the ratio of residual stresses for the two diameters is coincidental at values of $(t/l)^2$ near unity. It can be considered that the result reported by Baker could be extrapolated from this study.

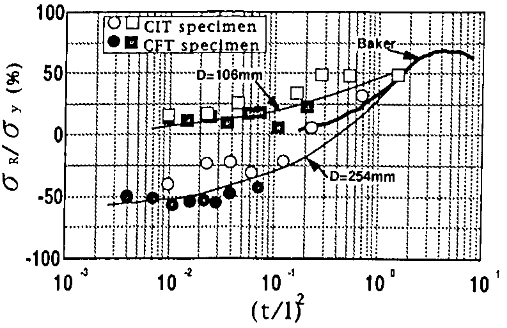

Fig.7 Plots of σ_R/σ_y against $(t/l)^2$.

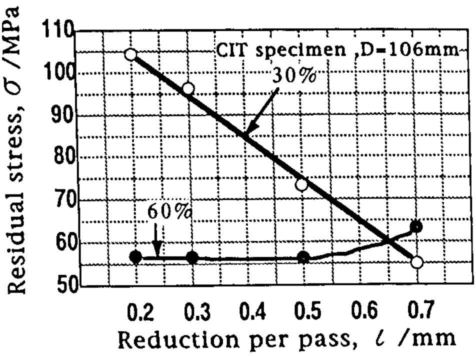

Fig.8 Relations between residual stress and reduction per pass.

The results described above are the residual stress generated in rolling process under constant reduction rate of 0.3 mm per pass. The effects, of various reduction rates aside from 0.3 mm per one pass rolling, on the generation behaviors of residual stress were also investigated. Residual stress versus reduction per one pass (l/mm) relations are shown in **Fig.8**, taking total reduction in area as a parameter. As known from this diagram, a tensile residual stress of the 30 % specimens decreases linearly as the reduction rate per pass increases. So, the reduction rate can be considered as an important factor for the generation of residual stress. This variation in residual stress related to the reduction rate per one pass rolling coincides with the results reported by Baker[2]. In contrast to the case of 30 % reductions in area, a reduction rate per pass is nearly independent of residual stress in the case of 60 % total reductions in area. As a result, in the case of reduction rates from 0.2 to 0.5 mm per one pass, the residual stresses decrease as the total reductions in area increase.

The variations in the residual stress generated by one pass rolling are plotted in **Fig.9** against the reduction per one pass, taking the working rolls' diameter and plate thickness as parameters. As shown in this figure, certain variations in the residual stress are observed for the respective CIT and CFT specimens.

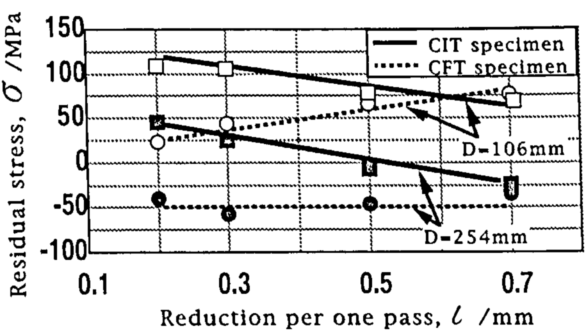

Fig.9 Relations between residual stress and reduction per one pass.

Reasons that the residual stresses were variable with relation to the change of one pass reduction rate, were discussed in view of the distribution of rolling pressure. **Fig.10** shows the representative results of rolling pressure calculated by Karman's equation[3] for the CIT and CFT specimens taking reduction rate and working rolls' diameter as parameters. In this figure, the ordinate is shown as the ratio of rolling pressure to yield stress in shear deformation and the abscissa shows the ratio of distance from the ending point of rolling to contact length between working rolls and plate. As known from these figures, the distributions of rolling pressure are fairly variable with the variations in reduction rate per one pass, specimen thickness, and working rolls' diameter. These results suggest that certain close relation exists between the rolling pressure and residual stress.

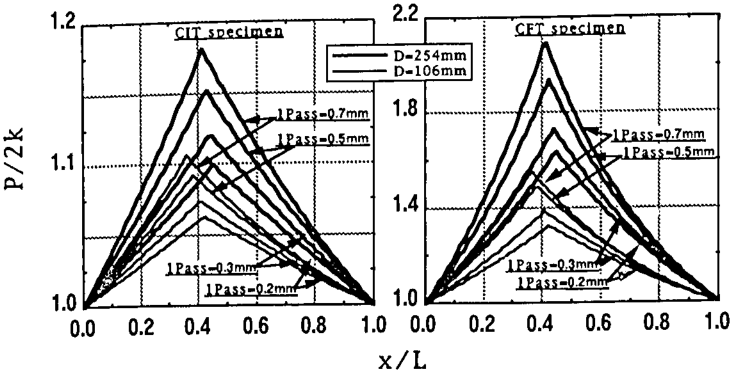

Fig.10 Rolling pressure distributions.

The residual stresses shown in **Fig.9** are plotted again in **Fig.11** against the peak value of rolling pressure. In spite of the variation in working rolls' diameter, generated residual stresses of the CIT specimen decrease almost linearly as the peak value of rolling pressure increases.

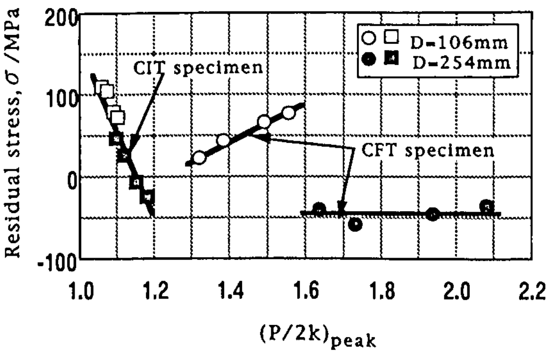

Fig.11 Plots of residual stress against $(P/2k)_{peak}$.

CONCLUSIONS

From the experimental study on the residual stress generated in the cold rolled 5083 aluminum alloy plate, the following concluding remarks were obtained. (1) The residual stresses along the rolling direction were fairly affected by the specimen thickness, working rolls' diameter, and reductions per one pass. (2) Higher tensile residual stresses were measured for the thicker specimen and for the specimens rolled by smaller working rolls. (3) The residual stresses for the specimens decreased as the total reductions in area increased. (4) Reasonable linear relations were obtained between the residual stress and the apparent roll gap ratio. (5) The reduction rate per pass had evident influence to the generation of residual stress. In case of the 30 % total reductions in area, the lighter passes gave a high level residual tensile stress. (6) The residual stresses of the CIT specimen in one pass rolling process decreased linearly as the reductions per one pass increased and the reasonable linear relation was obtained between the residual stress and the peak value of rolling pressure.

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