Ultimate strength of aluminum alloy plates in compression considering joining locations†

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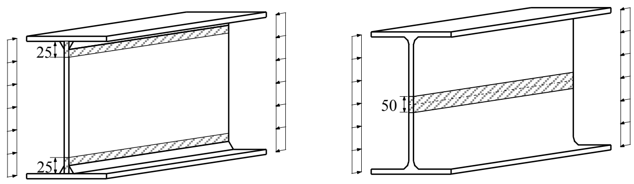
1. Introduction

The ultimate strength of aluminum alloy plates in compression is investigated considering joining locations by the elastic-plastic large deflection analysis with FEM. The aluminum alloys dealt with in this research are heat-treated A6061-T6 and non-heat-treated A5083-O. The softening of material and the residual stress caused by FSW and MIG welding are introduced in the analysis. It is shown that the joining locations and the width of plate have a great influence on the ultimate strength in A6061-T6 alloy plates.

2. Joining Locations

The joining locations are different between MIG welding and FSW. As shown in **Fig. 1**, for the columns of I-shaped section in compression, in MIG welding, both the edges of a web are joined to flanges by fillet welding, but in FSW, the edges of the extrusions of T-shaped section are connected in the middle of a web by butt joining.



(a) MIG welding (b) FSW

Fig. 1 Joining locations

3. FEM Analysis

The ultimate strength of the edge- and middle-joined plates in compression is investigated by the elastic-plastic large deflection analysis with FEM. The analyzed model is a square plate which is simply supported around the edges.

In A6061-T6 alloy, the strength at the joint is reduced to the half of that of the parent material. The softening region is 25 mm on each side of the center of the joint, as shown by the shaped parts in Fig. 1 [1].

The relationship between stress and strain is given by the following [1]:

For the parent material,

$$\begin{cases} \varepsilon = \dfrac{\sigma}{E} + 0.002\left(\dfrac{\sigma}{\sigma_{0.2}}\right)^{n} & (\sigma \le \sigma_{0.2}) \\ \sigma = \sigma_{0.2} & (\sigma > \sigma_{0.2}) \end{cases} \tag{1}$$

For the joints,

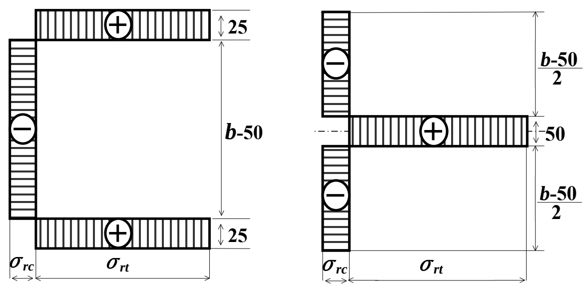
$$\begin{cases} \varepsilon = \dfrac{\sigma}{E} + 0.002\left(\dfrac{\sigma}{\sigma_{j0.2}}\right)^{n_j} & (\sigma \le \sigma_{j0.2}) \\ \sigma = \sigma_{j0.2} & (\sigma > \sigma_{j0.2}) \end{cases} \tag{2}$$

where σ and ε are the stress and strain, respectively, $\sigma_{0.2}$ and $\sigma_{j0.2}$ the 0.2 % proof stresses for the parent material and the joints, respectively, E the Young's modulus (= 70 GPa), and n and n_j the parameters for stain hardening for the parent material and the joints, respectively. The values for $\sigma_{0.2}$, $\sigma_{j0.2}$, n and n_j are listed in **Table 1** [1].

Table 1 Values for 0.2 % proof stresses and parameters for strain hardening

Alloys	Parent material		Joints			
			MIG		FSW	
	$\sigma_{0.2}$ (MPa)	n	$\sigma_{j0.2}$ (MPa)	n_j	$\sigma_{j0.2}$ (MPa)	n_j
A6061-T6	245	29.1	108	5.3	108	10
A5083-O	127	5.3	127	5.3	127	5.3

The distributions of the residual stress are given in **Fig. 2** [1]. For the edge-joined plate, the tensile residual stress of $\sigma_{rt} = \sigma_{j0.2}$ is created in the region of 25 mm from each edge, and the compressive one of $\sigma_{rc} = 50\sigma_{j0.2}/(b-50)$ in the inside. Here b is the width of the plate in mm. On the other hand, for the middle-joined plate, the tensile



(a) Edge-joined plate (b) Middle-joined plate

Fig. 2 Distributions of residual stress

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residual stress of $\sigma_{rt} = \sigma_{j0.2}$ is created in the region of 50 mm in the middle, and the compressive one of $\sigma_{rc} = 50\sigma_{j0.2}/(b-50)$ in the rest of the plate.

For the initial deflection of the plate, the following equation is assumed, which is the same as the buckling shape:

$$w_0 = (b/150)\sin(\pi x/a)\sin(\pi y/b) \tag{3}$$

where a is the length of the plate in the direction of the compression.

4. Ultimate Strength of A6061-T6 Alloy Plates

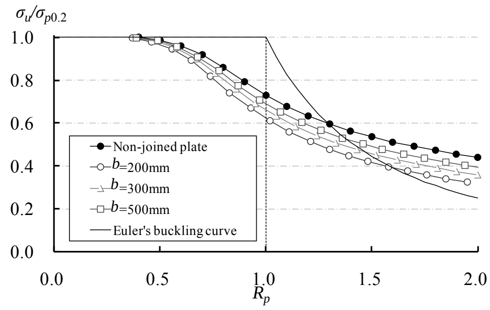
The relation between $\sigma_u/\sigma_{p0.2}$ and R_p for the A6061-T6 alloy plates is shown in **Fig. 3**, in which the residual stress is not introduced. σ_u is the ultimate strength in terms of the mean compressive stress. $\sigma_{p0.2}$ and R_p are defined as follows:

$$\sigma_{p0.2} = \{(b-50)/b\}\sigma_{0.2} + (50/b)\sigma_{j0.2} \tag{4}$$

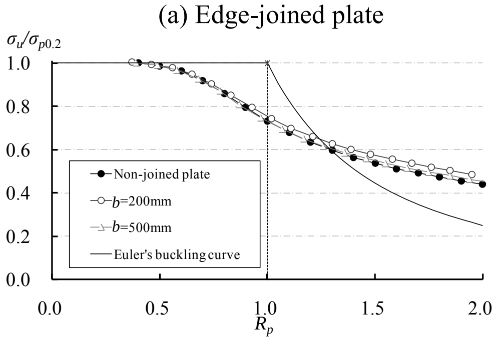
$$R_p = \frac{1}{\pi}\sqrt{\frac{12(1-\mu^2)}{4}\frac{\sigma_{p0.2}}{E}}\beta \tag{5}$$

where b is in mm, μ the Poisson's ratio, $\beta(=b/t)$ the width-to-thickness ratio, and t the plate thickness.

As shown in Fig. 3(a), in the edge-joined plate, $\sigma_u/\sigma_{p0.2}$ decreases as the width is smaller. On the other hand, as shown in Fig. 3(b), in the middle-joined plate, $\sigma_u/\sigma_{p0.2}$ is almost the same in the different width of plate. The relation between $\sigma_u/\sigma_{p0.2}$ and R_p considering the residual stress is shown in **Fig. 4**. The influence of the residual stress on the ultimate strength is small for both the edge- and middle-joined plates.



(a) Edge-joined plate

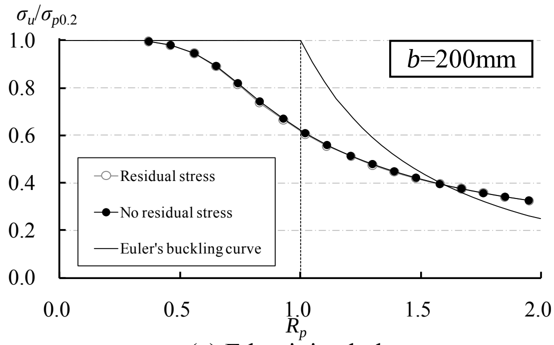


(b) Middle-joined plate

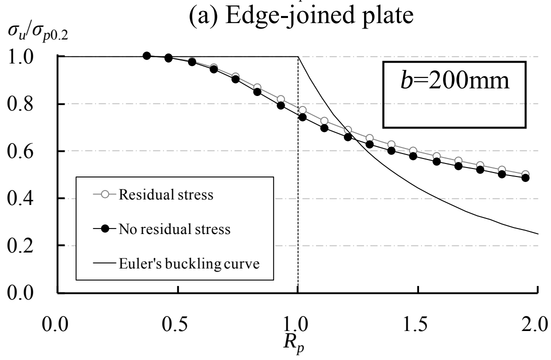
Fig. 3 Influence of joining locations

5. Ultimate Strength of A5083-O Alloy Plates

The relation between $\sigma_u/\sigma_{p0.2}$ and R_p for the A5083-O alloy plates is shown in **Fig. 5**. Here, $\sigma_{p0.2} = \sigma_{0.2}$. In this analysis, the residual stress is taken into account. The influence of the width of plate on the ultimate strength is small for both the edge- and middle-joined plates.

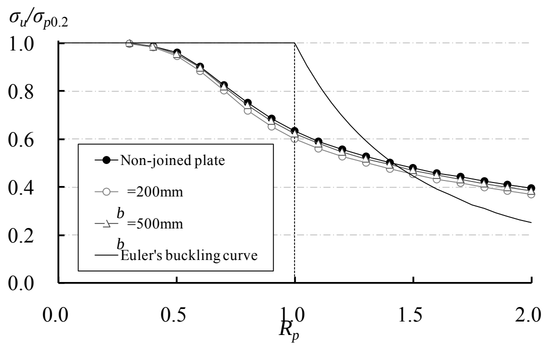


(a) Edge-joined plate

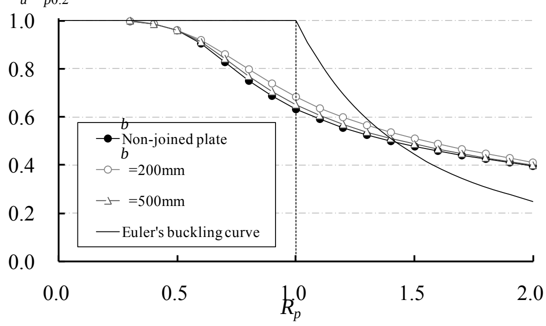


(b) Middle-joined plate

Fig. 4 Influence of residual stress



(a) Edge-joined plate



(b) Middle-joined plate

Fig. 5 Influence of plate width

References

[1] I. Okura, T. Nagao, T. Ishikawa, N. Hagisawa and S. Osumi: J. of Structural and Earthquake Engineering, JSCE, 64 (2008), pp.789-805.