# EFFECT OF HEAT INPUT ON FRICTION WELDED JOINT PERFORMANCE OF 6061 ALUMINUM ALLOY

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**ABSTRACT** The effects of friction heat input and its fluctuation on the joint performance (tensile strength) in the friction welding of JIS A6061 aluminum alloy similar materials were investigated. From the traces of friction speed and friction torque detected and recorded during welding, the mean value of heat input and its fluctuation were obtained. The joint performance was evaluated with tensile test and the relation between joint performance and heat input and its fluctuation was examined.

As the results, it was made clear that increasing the friction pressure and decreasing the rotation speed caused an increase in the heat input and the area of adhesive friction surface, and a decrease in the fluctuation of heat input. Also, increasing the heat input caused an increase in tensile strength, and decreasing the fluctuation of heat input caused decrease in tensile strength. Moreover, the tensile strength of welded joints was related to the heat input ratio, that is, increasing the heat input ratio had the effect of narrowing the softened area by friction heating in the weld zone.

**Keywords:** *Friction welding, 6061 aluminum alloy, Joint performance, Tensile strength, Heat input, Friction torque*

## 1. INTRODUCTION

Friction welding has been found to be an effective welding method for dissimilar materials with high joint efficiency compared with offer welding methods. Therefore, the method is used widely in various industrial fields as a joining method of mechanical parts, electrical parts, and so on. Specially, joints of aluminum alloy are used widely with the purposes of lightening and cost down. However the optimum setting of welding condition is not easy. thus, for selecting an optimum welding condition easily, it is necessary to consider something nice to do. In this study as a way to make clear above object, heat input and its fluctuation were introduced in friction welding of 6061 aluminum alloy similar materials.

## 2. A CONCEPT ON RELATION BETWEEN HEAT INPUT AND JOINT STRENGTH

Figure 1(a),(b) shows an idealized friction interface consisting of both adhesive and sli friction surfaces in friction welding. When friction pressure $P_1$ is low (a), the area of adh friction surface is small, but at an increase of the friction pressure, the area of adhesive fri surface increases gradually (friction speed is kept constant).

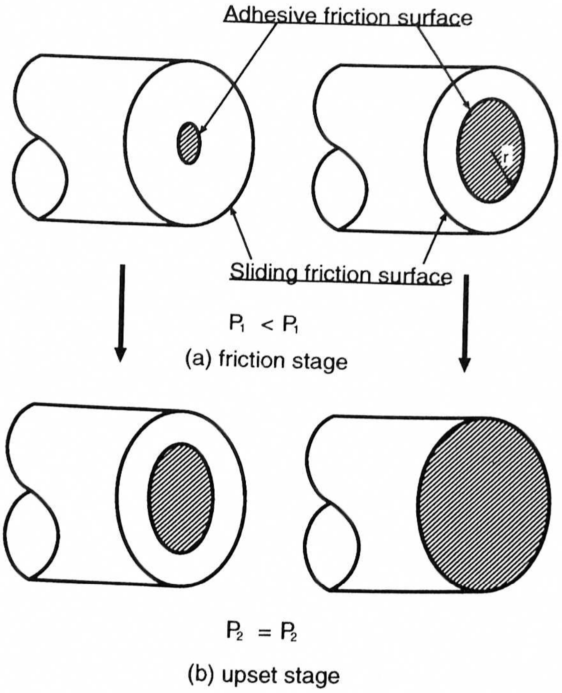


Fig. 1 Idealized friction surface

At upset stage, the adhesive fric surface increases largely by an actio high upset pressure (b). Also, as the hesive friction surface increases with friction torque or the heat input, if area of adhesive friction surface is a tual bonding portion at the end of w ing, it is possible that the strength welded joint can be related to the a sive friction area or the heat input.

Now, supposing that the sh stress $\tau$ of adhesive friction surfac constant, heat input $Q$ is expressed the following equation (1), thus the h input is in proportion to the adhe friction area.

$$Q = \frac{2\pi\tau}{3} \cdot r^3 = \frac{2r\tau}{3} \cdot A$$

where, $r$ is radius of adhesive fric surface, A is area of adhesive friction surface.

Also, supposing that the area of adhesive friction surface is an actual bonding area the tensile stress $\sigma_B$ in the bonding area is constant, the tensile load $W$ is in proportion to heat input as shown in the equation (2).

$$A = \frac{W}{\sigma_B}, \qquad Q = \frac{2r\tau}{3} \cdot \frac{W}{\sigma_B}$$

$$W = \frac{3\sigma_B}{2r\tau} \cdot Q \qquad (2)$$

That is, increasing the heat input causes an increase in the tensile load (nominal ten strength).

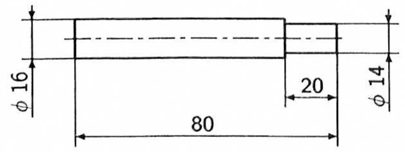


Fig. 2 Shape and dimensions of base material

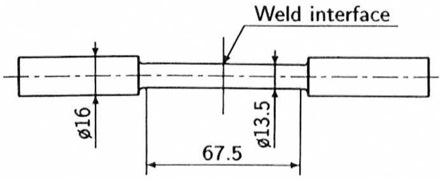


Fig. 3 Shape and dimensions of tensile test specimen

## 3. EXPERIMENTAL PROCEDURE

Mating materials used in this study are 6061 aluminum alloy (JIS A6061), this chemical compositions and static mechanical properties are shown in Table 1 and Table 2 respectively.

Table 1 Chemical compositions of base material (mass %)

| Material | Si | Mn | Cu | Cr | Fe | Mg | Zn | Ti | Al |
|---|---|---|---|---|---|---|---|---|---|
| A6061 | 0.60 | 0.02 | 0.19 | 0.07 | 0.15 | 0.97 | 0.01 | 0.01 | Re |

Table 2 Mechanical properties of base material

| Material | Tensile strength $\sigma_B$ (MPa) | Elongation $\delta$ (%) | Reduction of area $\phi$ (%) | Hardness $HV$(micro) |
|---|---|---|---|---|
| A6061 | 287 | 13.6 | 66.8 | 118 |

The material was supplied as drawn bars of 16mm in diameter, and machined to the base material presented in Fig. 2 without any heat treatment. Before welding the end faces of the mating materials were decreased with acetone.

Friction welding was carried out under a brake type welding process using an exploratory friction welding machine. The main factors used as the welding conditions are as shown in Table 3.

Table 3 Friction welding factors

| | |
|---|---|
| Friction pressure $P_1$ (MPa) | 5 ~ 60 |
| Upset pressure $P_2$ (MPa) | 15 ~ 180 |
| Friction time $t_1$ (s) | 2 |
| Stopping time $t_B$(s) | 0.3 |
| Friction speed $N$ (rpm) | 1000 ~ 4000 |

In order to examine the relation between heat input and joint performance, tensile test of welded joint was carried out using a 30ton universal testing machine. The tensile test specimen was machined to the shape and dimensions as shown in Fig. 3. The diameter of specimen was 13.5mm and the weld interface was situated at the center of specimen.

During the friction welding, the friction torque and the friction speed were detected and recorded. The heat input was calculated using the equation (3) on the data recorded, and the fluctuation of heat input was obtained by the mean of ten points height (JIS B0601).

$$Q = 1.047 \times 10^{-4} \cdot N \cdot T \quad (\mathrm{kJ/s}) \qquad (3)$$

## 4. EXPERIMENTAL RESULTS AND DISCUSSIONS

### 4.1 Appearance of friction surface and tensile fracture

Figure 4 shows the appearances of typical friction surfaces which were suddenly pulled apart during the friction (top), of tensile fractures of joints welded under the welding conditions of even upset pressure to the friction pressure $P_2 = P_1$ (middle) and of three times the upset pressure of friction pressure $P_2 = 3P_1$ (bottom). In the tensile fracture, the dark part is good bonding area. It is observed from Fig. 4 that both the adhesive friction surface and the heat

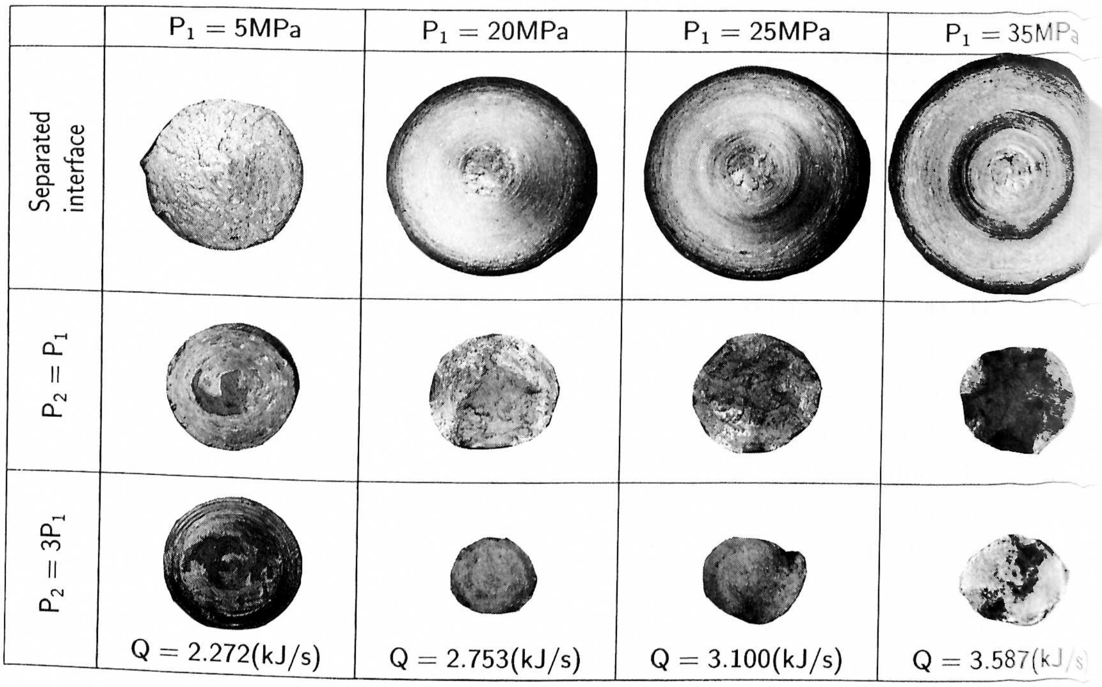


Fig. 4 Appearance of welding interface

input increase with the friction pressure, moreover an applying of higher upset pressure th the friction pressure increases an adhesive friction area, thus an increase in the area of adhes friction surface creates good welded joints.

### 4.2 Relation between heat input and tensile strength

Figure 5 shows the variation of the tensile strength of welded joints with heat input the upset stage. The plot points involve all friction speeds of 1000, 2000, 3000 and 4000 rp Although the applying of four friction speeds, the tensile strength tends to increase with heat input, and is nearly kept a certain constant value showing somewhat fluctuation of dat On the other hand, the relation between the tensile strength of welded joints and the fluctuati of heat input is shown in Fig. 6. The tensile strength of welded joints tends to decrease w the fluctuation of heat input, but the data largely scattered. So, taking the heat input ra which is expressed by the means of heat input / fluctuation of heat input ($Q_{UR} = Q_u/R_{zQ}$ reasonable relation between the tensile strength and the heat input ratio is obtained as sho in Fig. 7. The white circles in Fig. 7 are the joints which are strongly welded in manner of c welding at the junctions having partially unwelded parts.

### 4.3 Relation between heat input and softened are in the weld zone

As the heat input ratio is much related to the tensile strength of welded joints, then, so joints were friction welded with the increase in heat input ratio. Figure 8 shows the hardn distribution of the weld zone with the increase of heat input ratio. The softened ares decre

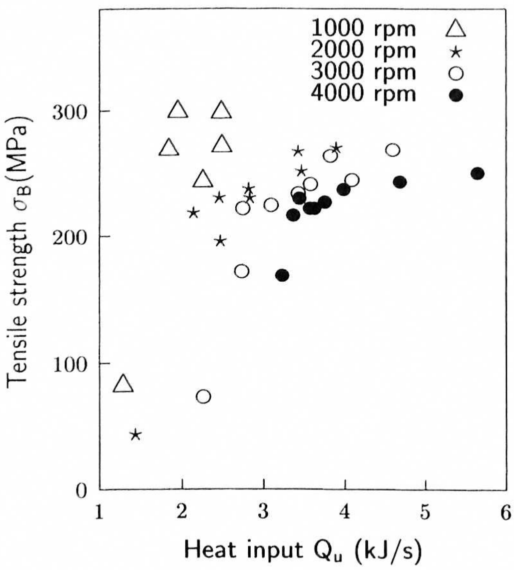


Fig. 5 Relation between tensile strength and heat input

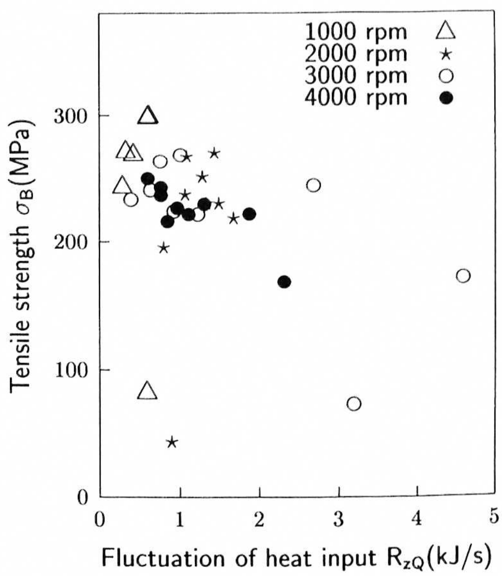


Fig. 6 Relation between tensile strength and fluctuation of heat input

with the heat input ratio. Therefore, as mentioned above, it is seemed that an increase of tensile strength of welded joints is due to an action of high welding pressure with the decrease of the softened area by an applying of high heat input ratio.

## 5. CONCLUSIONS

The main results obtained in this study are as follows.

(1) The adhesive friction surface and the heat input increased with welding pressure and increasing the area of adhesive friction surface created good welded joints.

(2) Increasing the heat input caused an increase in tensile strength of welded joints, on the other hand, increasing the fluctuation of the heat input caused a decrease in tensile strength of welded joints. However, with these types of factors the fair-sized scatter was shown in the plotted data.

(3) Heat input ratio which is expressed by the means of heat input divided by fluctuation of heat input had a reasonable relation to the tensile strength of welded joints.

(4) Increasing the heat input ratio caused a decrease in the softened area of the weld zone.

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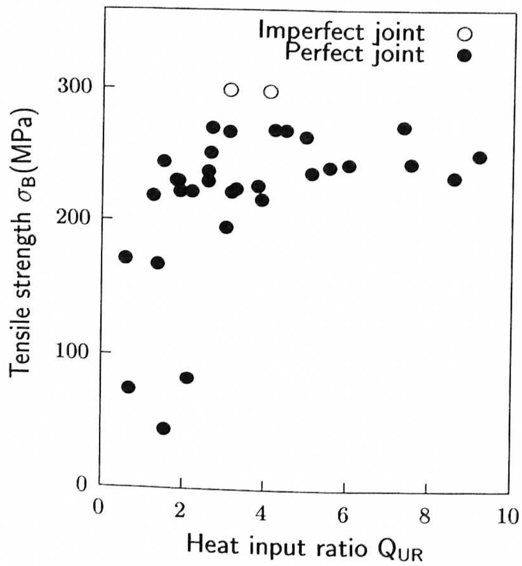


Fig. 7 Relation between tensile strength and heat input ratio

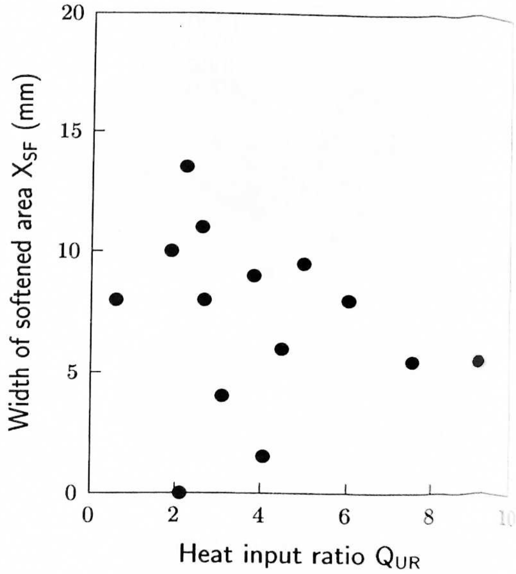


Fig. 8 Relation between width of softened area and heat input ratio


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