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The effects of ultrasonic vibration and temperature on in-atmosphere solid state bonding of aluminum alloy.

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Abstract

The need for aluminum joints has grown in recent years. However, as aluminum forms strong oxide layers in atmosphere, forming joints with this material is difficult. This is where we conceived of a new in-atmosphere solid phase bonding method that uses high-frequency induction heating and ultrasonic vibration. This research investigated the effects of ultrasonic vibration and bonding temperature on this new bonding method. The results thereof were able to confirm the efficacy of ultrasonic waves on bonding. Additionally, this research also made clear the relationship between the bonding temperature and joint strength.

Keywords: Aluminum Alloy, Solid State Bonding, Atmosphere, High frequency induction heating, Ultrasonic vibration.

1. Introduction

From the standpoint of improving environmental performance, the amount of aluminum being used is growing. Accompanying this is an increase in the need for aluminum joints. However, it is known that aluminum forms strong oxide layers in atmosphere, making it a difficult material to bond. In recent years, new bonding methods have been attempted, but these require specialized environments such as vacuum or are limited by the high price of the equipment involved. [1][2] This is where we conceived of a method for bonding aluminum in atmosphere over a short time using ultrasonic vibration and high-frequency induction heating. The present research investigated the effects of ultrasonic vibration and the bonding temperature on this new bonding method.

2. Experimental Method

2.1 Test Materials

This experiment used the aluminum A1070-112H (JIS designation), which has the chemical structure shown in Table 1. The length of the side of the test piece contacting the ultrasonic horn was 68mm, the length of the fixed side was 73mm and the bonding surface was turned so that it had a diameter of 5mm. The shape of the bonding surface is shown in Figure 1. After being worked, the bonding surface was delipidation washed in 0.1 mol/L sodium hydroxide.

Table1 Chemical composition of aluminum

[mass%]

Materials	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	V
A1070	0.06	0.10	0.00	0.00	0.00	-	0.00	0.01	0.01

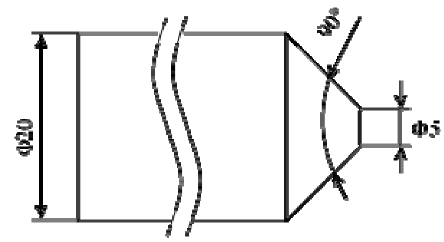

Fig.1 dimensions of specimen

2.2 Experimental Equipment and Bonding Process

The equipment used in the experiment is shown in the schematics in Figure 2. The bonding section was heated using a high frequency induction heater with an oscillator output of 10 kW and a frequency of 30 kHz. The heating rate was 16.7 K/sec, the temperature was monitored with an infrared thermometer and maintained at a constant level via a temperature control. The mechanism applying pressure to the test pieces was a 5 kN servo press. An internal load cell and controller made it so that a constant load was applied to the joint surfaces. Additionally, the ultrasonic oscillator output was 1200 W, the frequency was 20 kHz and the amplitude at the horn with no load was 6 μm (peak to peak). The oscillation amplitude was maintained at a constant level.

Figure 3 shows the pressure, temperature and the ultrasonic oscillator load cycle . The aluminum was placed such that the turned surfaces faced each other and after prepressure P1 was applied, the servo press added the 1000 N load P2 at the same time that the joint section was heated using the high frequency induction heater. Once the joint section reached the predetermined temperature T1 when t1=390s, ultrasonic waves were applied while the heat and pressure were maintained (input IP to the oscillator). After 390s had elapsed, the addition of oscillation and pressure were halted and load P3 of 3000 N was applied for t2=10s, followed by radiant cooling in atmosphere. The joint strength was evaluated with a tensile test. Additionally, observations with a scanning electron microscope were performed at an acceleration voltage of 15 kV.

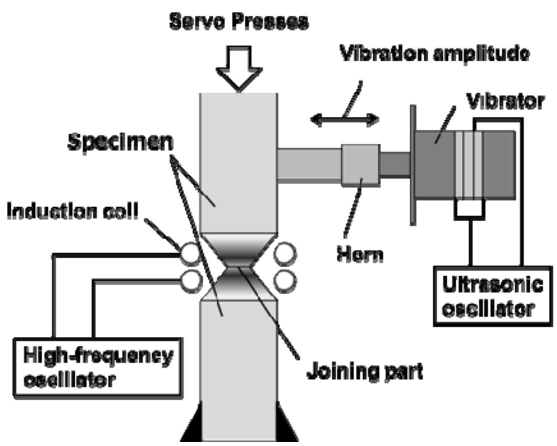

Fig.2 Schematic diagram of testing apparatus

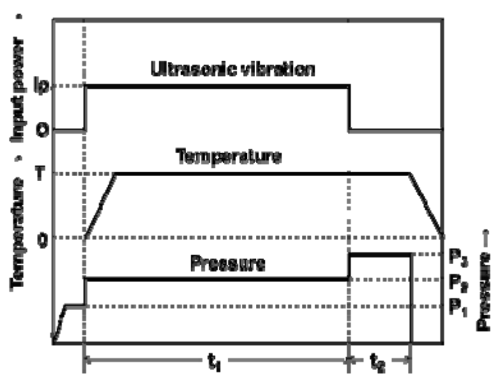

Fig.3 Temperature, pressure and input power to the transducer as a function of time during the application of ultrasonic vibration

3. Experimental Results

The effects of the temperature and the presence or absence of ultrasonic waves during bonding on tensile strength are shown in Figure 4. Bonding temperature T1 is in 50K increments between 473K and 723K and in addition to that, the experiment was performed with P1=500N, P2=1000N, P3=3000N, t1=390 s, t2=10 s and with the presence and absence of ultrasonic waves. Here, the tensile strength when a joint was not formed is 0MPa. According to Figure 4, in cases where ultrasonic waves were applied, tensile strength increased alongside the bonding temperature. The bonding temperature which exhibited the highest strength was 673K, at which the resulting tensile strength was 35MPa. This is roughly 46% of the strength of the base material. There were no cases of the base material fracturing under any conditions, but fracturing did occur at the joint interface. However, when ultrasonic waves were not applied, joints could not be formed, regardless of the bonding temperature. As such, it can be understood that the application of ultrasonic waves increases joint strength. In order to investigate the origin of the difference in joint strength depending on the presence or absence of ultrasonic waves, the fracture surfaces following the tensile strength test were observed with an SEM. The results of these observations are shown in Figure 5. In comparison to (a) in which T1=523K, the area which has taken on a torn dimpled form can be seen to be larger in the photograph of (b) in which T1=673K. The area that has taken this dimpled state is the joint area and increases alongside the bonding temperature. [3] Conversely, areas taking on this dimpled state were not observed on the joint surfaces at any temperature in cases where ultrasonic vibration was not applied and joints were not formed.

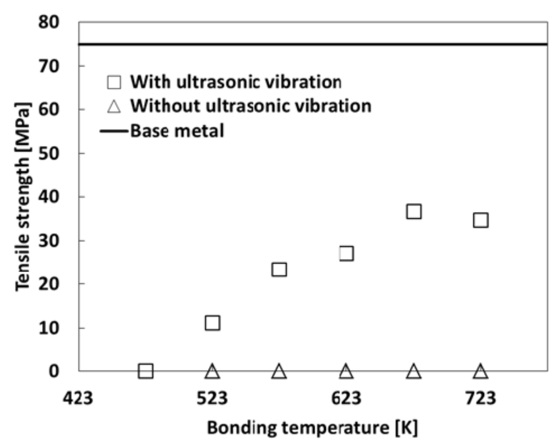

Fig.4 Relationship between tensile strength and bonding temperature

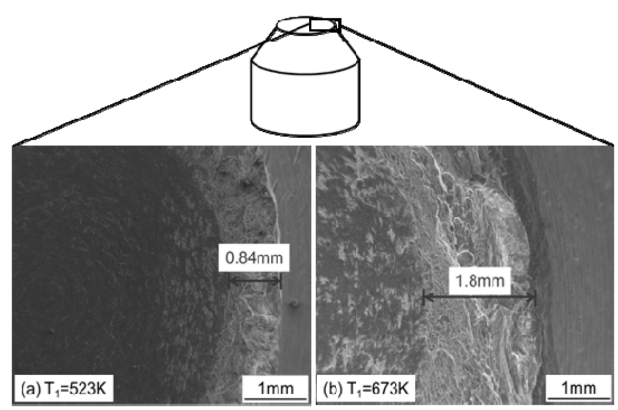

Fig.5 Effect of ultrasonic vibration on the morphology of fractured surfaces of joints

4. Joint mechanism

4.1 Metal surface

General metal surface is covered with various material films which is different from the internal structure. Figure 6 shows a schematic view of the metal surfaces.

There is a base metal layer; on top of that, there is a work-affected layer that was deformed by cutting or plastic working. Work-affected layer is harder than the internal metal. There is an oxide layer made when exposed to the air on top of the work-affected layer; adsorbed molecule layer, oil or dust, and dirt film exists on it.

Though the thickness is very thin at several hundred Å (angstrom: 10^{-10}m), friction phenomenon or friction force by the nature of these surface film is greatly affected.

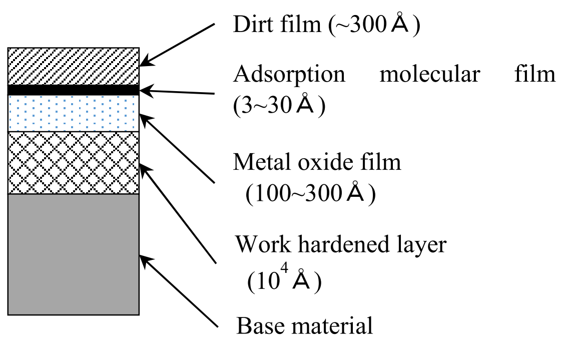

Fig.6 Surface of the metal

4.2 Jointing force

The adhesive force acts on the contact part if it is brought into contact with two metals. The adhesive force, there are short-range force and long-range force. There is a metal binding as the short-range force. A clean metal has a very high surface energy, immediately a metal binding is produced there If brought into contact with such metal to each other. Binding force will be on the strength of the same degree with the binding of internal metal. On the other hand, the long-range forces is the intermolecular attractive forces, called as van der Waals forces. Binding force is much smaller than that of the short-range force [4].

4.3 Jointing mechanism

The actual metal surface is covered with dirt film or oxide film, only a weak long range forces due to van der Waals forces of the dirt film together act as an adhesion. Therefore, by increasing the surface pressure on the contact surface and exerting a force of sliding the two surfaces, a large plastic deformation occurs in the convex portions which are committed contact, dirt layer is partially broken. As a result, clean metal (called the new surface) appeared at the position that dirt film broken, locally adhesion occurs (A: occurrence of adhesion nucleus). Then, further by applying ultrasonic vibration to the bonding surface, plastic flow occurs in the tissue near the joint portion , the smoothing of the bonding surface advances and destruction of the oxide layer (B: generating the bonding surface). Moreover, a new surface is expanding and becomes a strong metal binding (C: Enlargement of the junction). A schematic diagram of this joint mechanism is shown in Figure-10 [5].

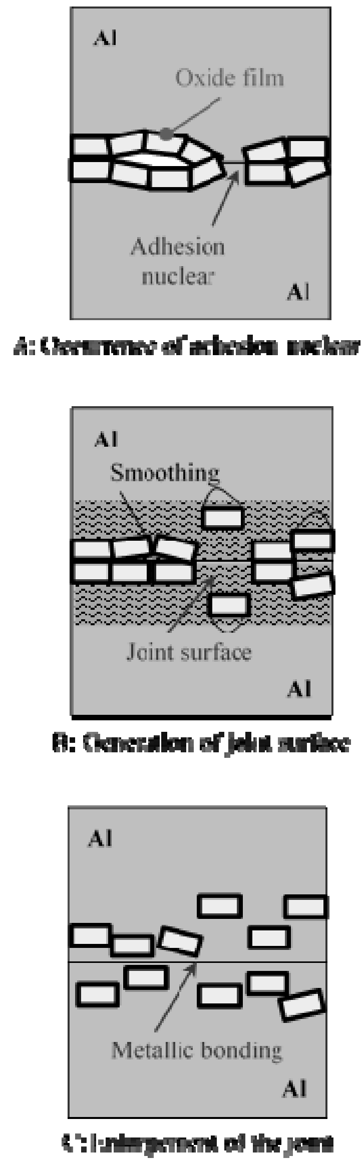

Fig.7 Schematic diagram of a bonding mechanism

5. Conclusion

The present research had the aim of bonding aluminum in atmosphere and investigated the effects of the application of ultrasonic waves and of bonding temperature on joint strength. The results obtained thereby are as follows.

AMM0003

(1) In cases where ultrasonic vibration was applied to joint surfaces, it was possible to form joints. Conversely, in cases where it was not applied, it was impossible to form joints.
(2) In cases where ultrasonic vibration was applied and joints formed, joint strength increased alongside the bonding temperature.
(3) In cases where ultrasonic vibration was applied and joints formed, the area of fracture surfaces after bonding that was in a dimpled state increased alongside the bonding temperature.

6. References

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