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Research Article

EFFECT OF ULTRASONIC VIBRATION IN THE SOLID STATE BONDING OF THE ALUMINUM ALLOY USING INSERT METAL

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ABSTRACT:
Consumption of aluminum alloys is increasing in order to improve the environmental performance. The aim of this research is to develop a technique to bond aluminum within an atmosphere in a short amount of time and with minimal deformations. In order to accomplish this, the bonding was carried out via use of induction heating and ultrasonic vibration. As a result, by adding the high-frequency induction heating and ultrasonic vibration to the bonding surface of the aluminum material, the oxide film is destroyed and the aluminum material was joined in a short time by the plastic deformation. Then we discussed examined the bonding mechanism.

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

1. INTRODUCTION

The need for lighter materials has grown due to the demand for improved fuel economy and energy efficiency, resulting in greater use of aluminum alloys. This has led to increased needs for aluminum alloy bonding. However, due to the fact that they develop strong oxide layers in atmosphere and aluminum's specific mechanical and thermophysical properties, aluminum alloys are widely regarded as difficult materials to work with [1]. Friction-churning bond technology has seen widespread implementation in recent years, but this method and its requirements and limitations mean that it is difficult to employ with parts with precise dimensions and/or complicated designs [2]. For parts such as these, solid-phase welding via vacuum diffusion is employed. The drawbacks of this welding technique are the large size of the required equipment and the long amount of time it requires [3]. Hence the goal of this research: to bond difficulty to work with aluminum alloys in atmosphere in a short amount of time with minimal defects. To achieve this, bonding was carried out by using a metal insert and ultrasonic vibration.

2. TEST MATERIAL AND TEST EQUIPMENT

2.1 Test material

The specific aluminum alloys used were A1070-H112, a diameter 20 mm and a length of 100 mm (temper designations are omitted hereafter). The chemical composition of A1070 is shown in Table 1. The end faces were designated as the bonding surface and underwent plane grinding with emery paper up to grade #2000, followed by polishing to a mirror finish using 9 µm diamonds and colloidal silica. This was followed with dilapidations and cleaning with 4% aqueous sodium hydroxide (NaOH).

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Furthermore, insert metal was used a titanium foil. Titanium foil was used for the purpose of adsorbing the oxygen in the oxide film. [4] The chemical composition and the thickness of the insert is shown in Table 2. Before bonding, the insert was dilapidated and cleaned using acetone (C_3H_6O).

Table 1: Chemical composition of aluminum [mass %]

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

Table 2: Properties of Intermediate materials used

Materials	Property	Component
Ti	t=0.050 mm	Ti: 99.5%

2.2 Test equipment

An outline of the bonding equipment used in the experiment is provided in Figure 1. A high-frequency oscillator with 10 kW output and a frequency of 30 kHz was used. It heats up at a rate of 16.7 K/sec and the temperature of the joint was monitored with an infrared radiation thermometer and stabilized with a digital indicating controller. A servo press with a 5 kN capacity was used to compress the test piece. The load cell and controller were set up to apply a constant load to the joint surfaces. Furthermore, the ultrasonic oscillator used in the bonding process had a 1200 W output, a frequency of 20 kHz and 40μm peak to peak amplitude. The oscillation amplitude was also maintained at a fixed value.

A test cycle (temperature, pressure, and ultrasonic application timing) is shown in Figure 2. The aluminum alloys are positioned with the polished surfaces facing each other and the insert placed between the two. After a 500 N preload force (P1) is applied by the servo press to the joint surfaces, the bonding begins. At the same time that the joint is heated to the specified temperature (T1; 723K, 773K, 823K) by the high-frequency oscillator, the servo press subjects the combination to a 1099 N load (P2). Once the specified temperature is achieved, the temperature and pressure are maintained for 390 seconds, after which the materials are air-cooled.

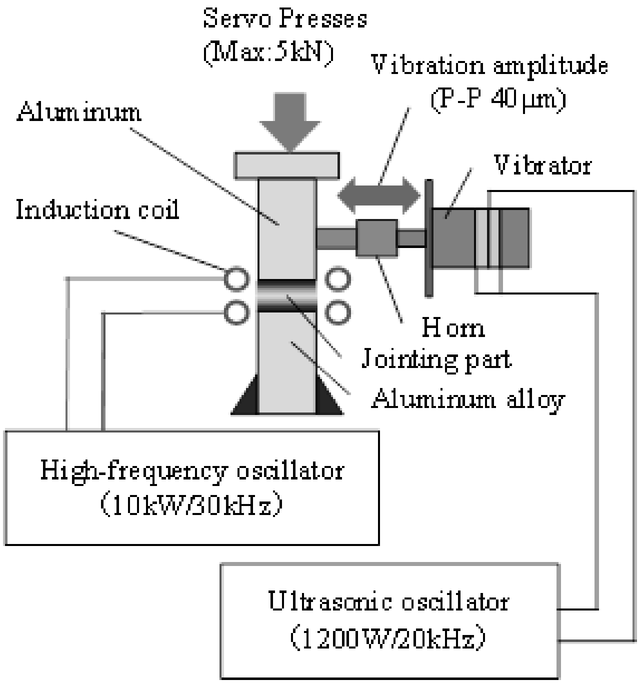

Fig. 1. Schematic of test equipment.

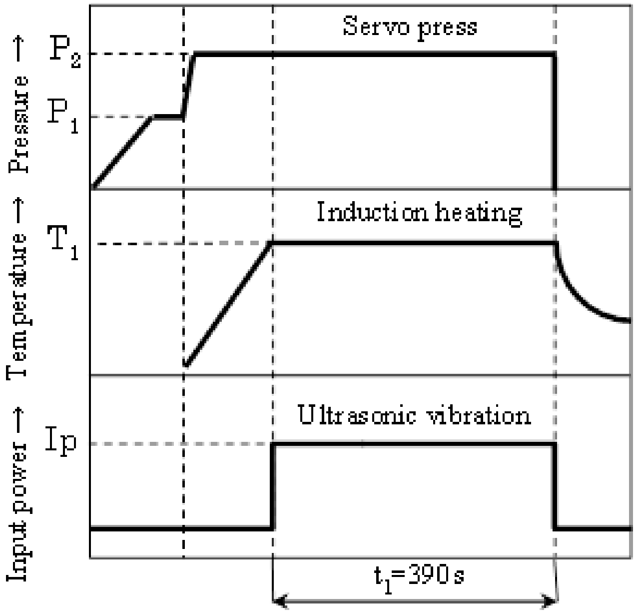

Fig. 2. Temperature, pressure and input power to the transducer as a function of time during the application of ultrasonic vibration.

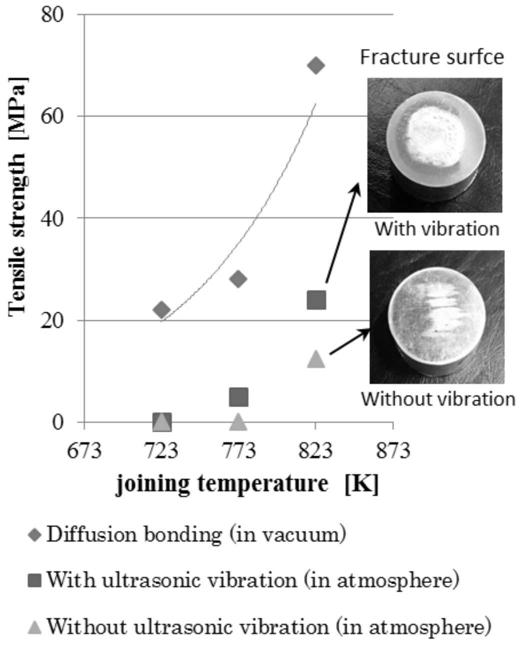

Fig. 3. Relationship of tensile strength and temperature.

2.3 Measuring the bonding strength and analyzing the joint

The strength of the bond was measured via a tension test. This test was carried out with the same specifications three times and the strength of the bond was defined as the mean value of the three results. The fracture surface after tensile test was observed by SEM. Furthermore, it was observed metal structure of near the junction by using a test piece that was cut in a plane perpendicular to the joint surface. Metal structure observation was using an optical microscope. The specimen for metal structure observation was surface grinding with emery paper up to grade 2000, and were polished with 9 μm diamond and colloidal silica. Following exposure to aqueous sodium hydroxide (NaOH) for 20 seconds, the physical structure of the joint was observed with a metallographic microscope. The distribution of elements within the materials was determined using an electron probe micro analyzer and materials subjected to the above process.

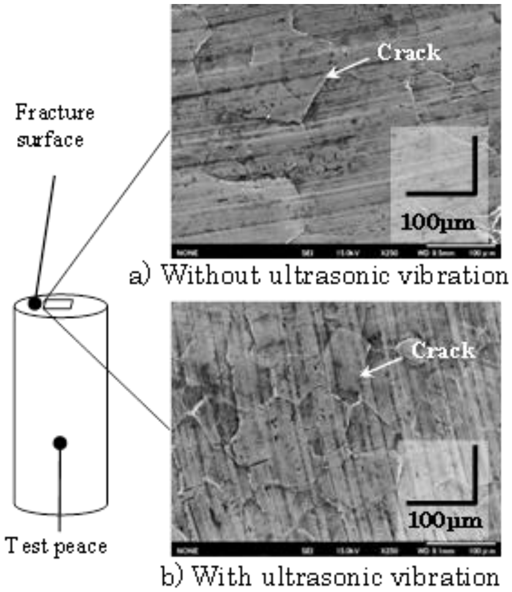

Fig. 4. SEM image of the fracture surface.

3. Experimental Results

3.1 Effects of ultrasonic vibration on the joint strength

The effects of ultrasonic vibration on joint strength are shown in Figure 3. The bond was formed at temperatures of 723K, 773K and 823K and used titanium insert metals. For comparison purposes, the strength of a diffusion bond carried out in vacuum at 3.5 MPa of pressure for one hour using a 0.02 mm thick titanium insert was also plotted [5]. Figure 3 shows that the bond strength increases as temperature does. Additionally, it is clear that the introduction of ultrasonic vibration to aluminum alloys results in bond strength greater than that of bonds formed without such vibration.

3.2 Effects of ultrasonic vibration on metal structures near the junction

Images of the fracture face from an aluminum alloy bond executed at a temperature of 823K are shown in Figure 4. Figure 4a) shows the surface that resulted when ultrasonic vibration was not used, while Figure 4b) shows the surface that resulted when it was. The cracks on the fracture face were formed by the destruction of oxides on the surface of the aluminum. The lengths of the cracks shown in the photographs are provided in Figure 5. The cracks that result when ultrasonic vibration is used are 1.8 times longer than those that result when vibration is not applied.

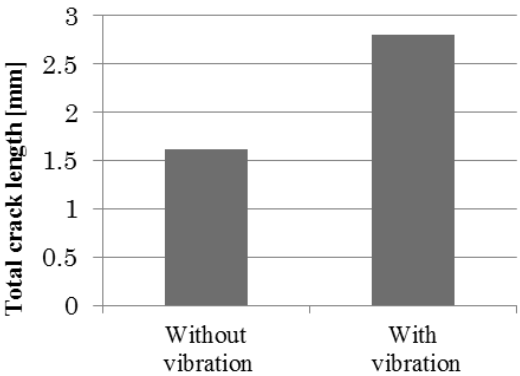

Fig. 5. Total crack length on the fractured surface.

Figure 6a) is a cross section photo of a bond in which ultrasonic vibration was not used, while Figure 6b) is a cross section photo of a bond in which ultrasonic vibration was used. The deep grey in the center of the photo is the titanium sheet and the lighter grey on either side is the aluminum alloy. Furthermore, the results of measurements taken of the hardness of the aluminum alloy structure at the bond are shown in Figure 7. Based on these results, it can be understood that the black structures deposited on the titanium sheet are harder than the structures located on the periphery, as Figure 6a) illustrates. This is evidence that the addition of ultrasonic vibration resulted in the generation of plastic flow in the aluminum alloy structure.

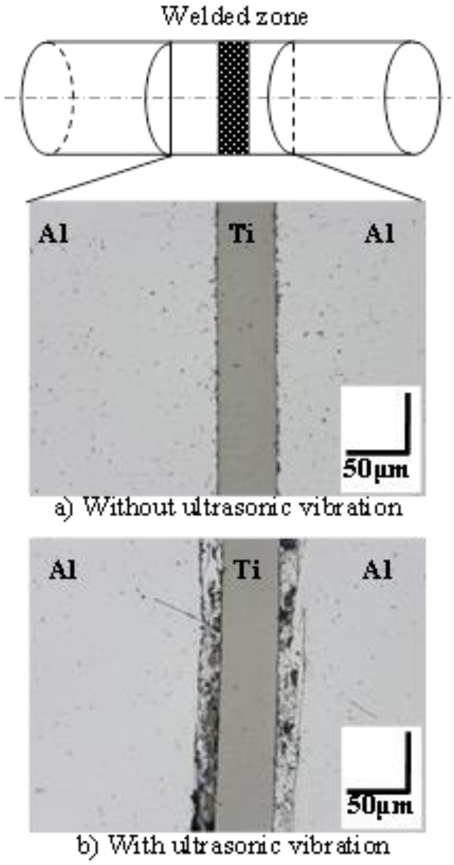

Fig. 6. Microscope image of the cross section.

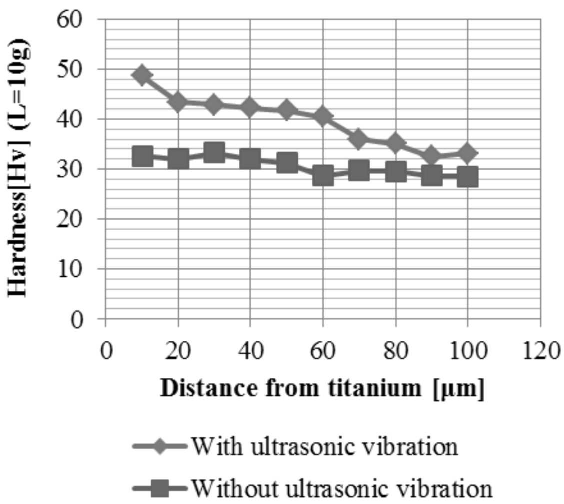

Fig. 7. The hardness distribution near welded zone.

Next, the results of electron probe microanalysis of the cross section of the bond will be discussed. Figure 8 and Figure 10 show the EPMA results for surface analysis of a bond formed by diffusion bonding in vacuum and a line graph by element. Figures 9 and 11 show the same, but for a bond formed by bonding in atmosphere with the addition of ultrasonic vibration. A larger amount of the element oxygen (O) is distributed throughout the surfaces of the bond formed in atmosphere using ultrasonic vibration than throughout the surfaces of the bond formed in vacuum. Further, the bond formed in vacuum exhibits greater titanium diffusion than the bond formed in atmosphere using ultrasonic vibration. Note that there is a correlation between element diffusion and bond strength. In short, the reason that bonds formed in atmosphere using ultrasonic vibration have weaker bond strength compared to bonds formed in vacuum is due to the high number of oxidation layers and the low level of element diffusion.

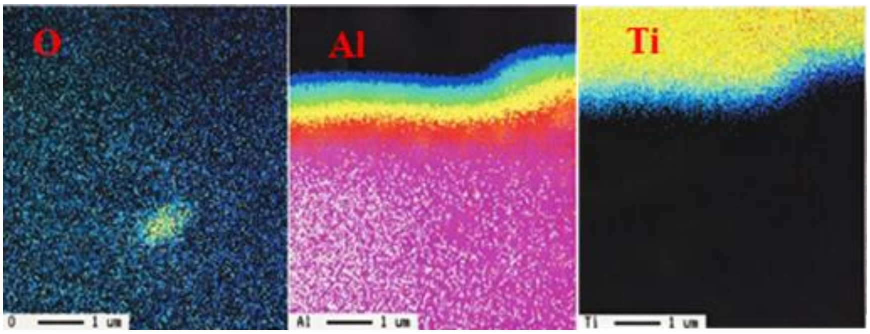

Fig. 8. EPMA image (Map) in welded zone (Diffusion bonding in vacuum).

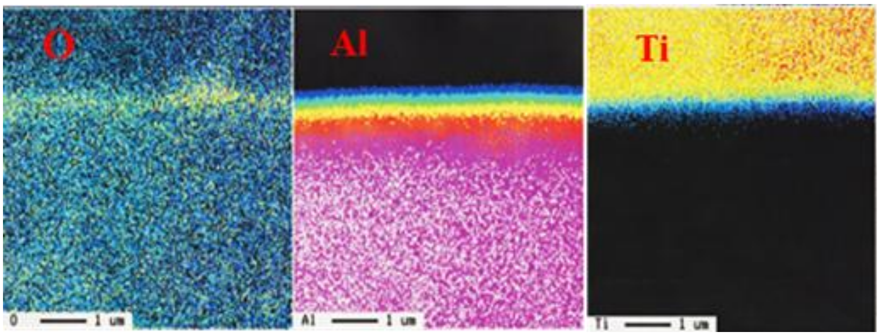

Fig. 9. EPMA image (Map) in welded zone (Ultrasonic bonding in atmosphere).

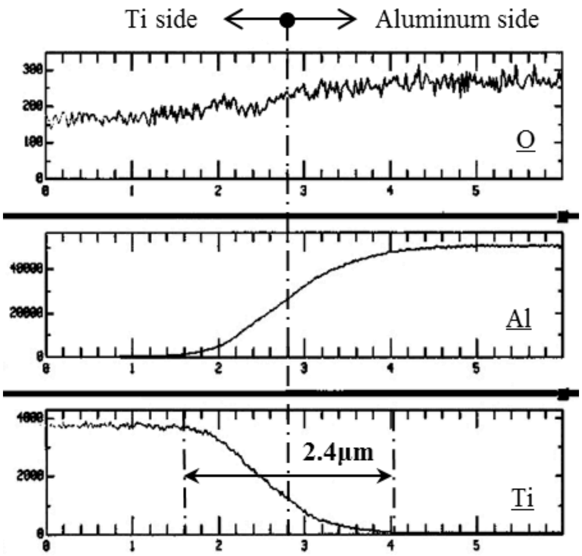

Fig. 10. EPMA image (Line) (Diffusion bonding in vacuum).

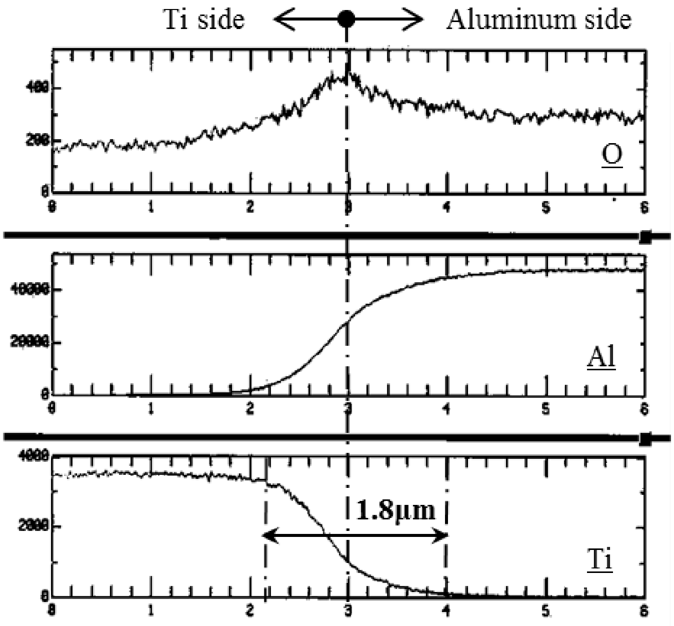

Fig. 11. EPMA image (Line) (Ultrasonic bonding in atmosphere).

3.3 Joining mechanism in atmosphere

In general, metal surfaces are covered by a variety of films, as shown in Figure 12, the surface of the metal. Work hardened layer sits upon the base metal material. The Work hardened layer undergoes plastic deformation by the cutting or plastic working. Upon the Work hardened layer is the metal oxide film that forms due to exposure to the atmosphere. Upon that are the adsorption molecular film, made from oil, dirt, and the like, and the dirt film. These surface layers are extremely thin. The thickness is few tens angstroms. (Å, 10^{-10}m). The bonding strength of aluminum is dependent by these surface film. And particularly, strongly dependent on the oxide film. Usually, aluminum bonding in atmosphere is adsorbed the dirty film each other at the top. Thus, the bonding strength is very weak. In this experiment, the dirt film in bonding surfaces were disappeared by vibration and heat. The oxide film in bonding surfaces was destroyed by vibration. Considering the bonding mechanism, pure metal appears where the dirt layer was broken (called fresh surfaces) and localized adhesion occurs (① appearance of adhesion nuclei). Following this, if yet further ultrasonic vibration is supplied to the joint surfaces, plastic flows are induced in the internal structure of the metals and the oxidation layers are broken down (② generation of joint surfaces). Then, the fresh surfaces grow and form strong metallic bonds (③ enlargement of the joint).These joint mechanisms are shown in the schematic diagrams of Figure 13[7].

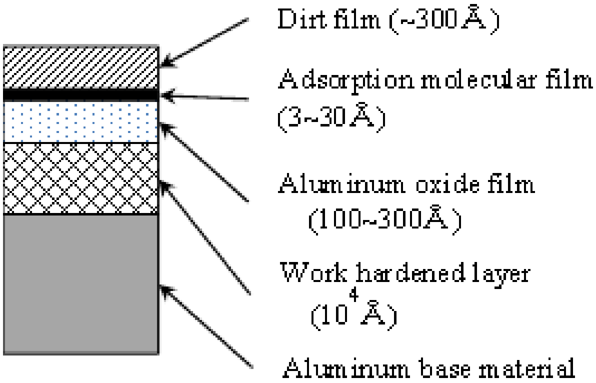

Fig. 12. Surface layer of the aluminum.

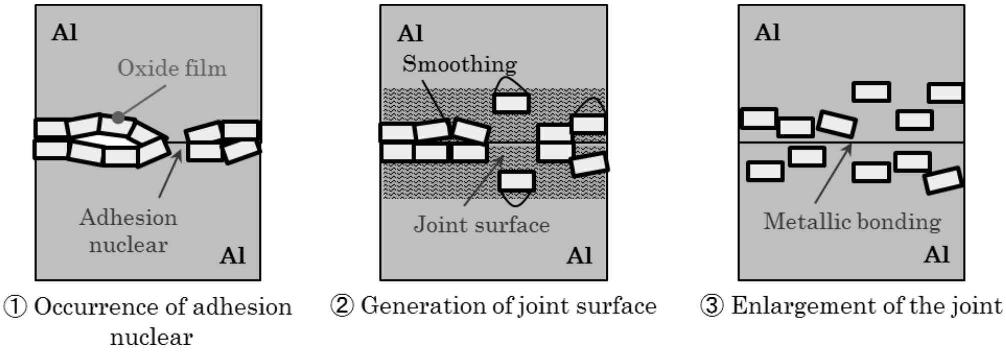

Fig. 13. Schematic diagram of an aluminum state bonding mechanism at high temperature.

4. CONCLUSIONS

This research had the goal of developing a new method for bonding aluminum alloy in atmosphere without introducing large deformations and that can be carried out in a short amount of time. It investigated the relationship of insert metals to joint strength, the effects of ultrasonic vibration on joint strength and the effects of ultrasonic vibration on metallic structures neighboring the joint. Furthermore, it was considered joining mechanism in aluminum in the atmosphere. This experiment arrived at the following conclusions.

(1) Effect of ultrasonic vibration on the joint strength

At bonding temperature 823 K, the bonding strength than when the application of a ultrasonic vibration at the time of the aluminum bonding without applying ultrasonic vibration is increased. Incidentally, the bonding strength of the aluminum at the time of applying ultrasonic vibration in the atmosphere was lower than those diffusion bonding in vacuum.

(2) Effects of ultrasonic vibration on metal structures near the junction

Near the junction of the organization is to plastic deformation and applying ultrasonic vibration while heating. Thus, oxide film on the aluminum surface is destroyed by applying ultrasonic vibration while heating.

(3) Joining mechanism in atmosphere

In the bonding of aluminum in atmosphere, adhesion nuclei are generated in the joining initial stage, then, it progresses to metal bonding. Furthermore, when applying ultrasonic vibration, near the junction of the organization is to expand the joint surface destruction proceeded of plastic flow and oxide film.

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