THE INFLUENCE OF THE SURFACE ROUGHNESS ON THE ROLL BONDING INTERFACE OF 6061 ALUMINUM ALLOY PLATES

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ABSTRACT

Roll Bonding process is applied to clad the core plate (U_3O_8+Al), with high strength aluminum alloys during fabrication of plate type nuclear fuel elements for research reactors, or to produce many new constructions which have special uses in industrial applications. In the present work the effect of the surface roughness of 6061 aluminum alloy plates on roll bonding interface was studied using both microscopic examination and mechanical testing. It was found that the bond strength reached a maximum value at surface roughness of about 5.2 µm. The bond strength decreases rapidly with both decreasing or increasing the surface roughness than 5.2 µm. The increase of the surface roughness resulted in the blistering area increase.

KEY WORDS

Nuclear Fuel -Research Reactors - Roll Bonding - Solid State Welding - Metal Cladding - 6061 Aluminum Alloy

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1 INTRODUCTION

The roll bonding process is an important application of the solid state welding. In principle, two or more slabs of the materials to be bonded are placed in contact and welded around the edges or otherwise treated to exclude air. Then, they are heated and rolled until the required thickness is obtained[1]. This process is applied during fabrication of nuclear fuel. Also this process is used to produce many new constructions which have special use in industrial applications. Previous studies on the solid state bonding of metals[2,3,4] suggest that under combined action of pressure and heat over short period, the reaction between the metal laminates involve a three stages process; (i) development of physical contact, (ii)activation of the surfaces in contact, and (iii) interaction within the material being joined.

The nuclear fuel used in the second Egyptian research reactor(ETRR-2) is plate type (MTR-type) fuel elements. The fabrication of this type of fuel plates is carried out by using picture-frame technique, Fig.1. This method is used to produce the preplate (sandwich). The sandwich plate consists of a core plate (the picture) made from a mixture of uranium compound (U_3O_8) and aluminum powder, which is surrounded by a frame and two cover plates, made from 6061 aluminum alloy (the cladding). The three-layer assembly is welded and rolled in several passes at about 500 °C. During hot rolling passes, roll bonding takes place between all the sandwich component. Then, the final plate thickness is obtained by a cold rolling pass[5].

This application and the diversity of other possible applications of this method of bonding, as well as the scientific and technological interest, were the motives to carry out the present investigation to study the effect of the surface roughness of 6061 aluminum alloy plate on roll bonding interface. The results can be used in determinations the required surface roughness of the fuel plate components.
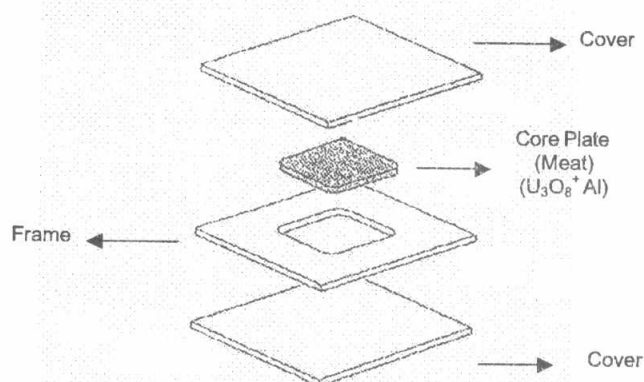

Fig. 1 Components of fuel plate

Studies[6-9] have been carried out to examine the relationship between the surface condition of roll-bonded specimens and bond strength of the interface. However more work is still needed to fully understand this effect.

2 EQUIPMENT AND EXPERIMENTAL PROCEDURES

Figure 2 shows the sequence of the experimental work, which has been done in order to study the process of roll bonding of 6061 aluminum alloy plates.
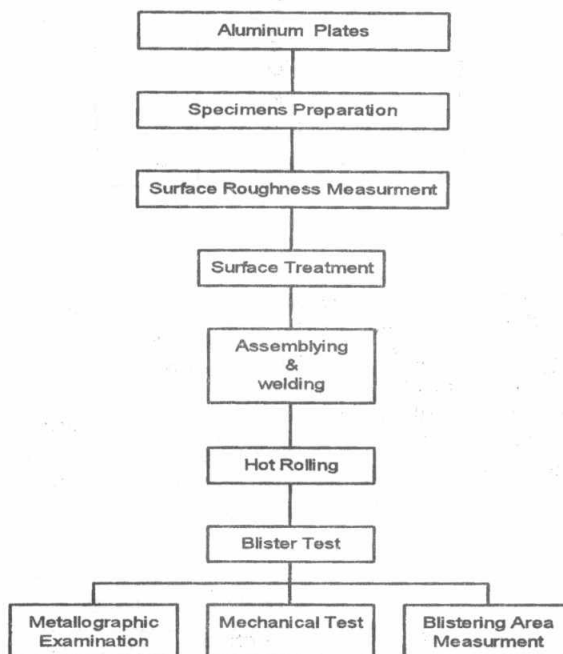
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│      Specimens Preparation      │
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│  Surface Roughness Measurment   │
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Fig. 2 The sequence of the experimental work

2.1   Preparation of The Specimens

A nuclear grade 6061 Aluminum alloy was obtained form Cressona Aluminum Company, United States of America (USA). Two types of specimens used. The first one is composed of 3 plates (2 cover + 1 frame). The thickness of the cover = 4.85 mm, where the thickness of frame 8.5 mm. The second specimen is composed of two plates with thickness 9.1mm. The first type of specimens was used in the metallographic examination and blister test, while the second type was used for the mechanical test, namely single lap shear test. Different surface roughness degrees were obtained using different grade grinding emery papers. This step was done by using belt grinding machine. Then the surface roughness was determined using roughness measuring equipment type Mahr model, PST-MSH, Germany. Table 1

shows the surface roughness values used in the present work. These plates were subjected to surface treatment process by pickling the plates in NaOH (10%) at 70 °C and neutralizing with HNO_3(40%) Then, the specimens were assembled and welded around the edges as applied in fabrication of fuel plates, using TIG welding process.

Table 1 Specimens surface roughness

Emery Paper Used	Surface Roughness (μm)
230	23.875
400	12.275
600	9.233
800	7.158
1000	4.122
1200	1.844
As-machined surface	5.197

2.2   Hot Rolling

The preplates were heated in an air recirculation furnace for one hour at 500 ±10 °C to soften these preplates before hot rolling. Then, the preplates were subjected to hot rolling according to the sequence given in Table 2. This sequence is the one used in MTR-type fuel plates fabrication. After that, the plates were subjected to the blister test and annealing step. In this step these plates are held at 500 °C for one hour. After that the plates are cooled in the furnace from 500°C to 250°C at the cooling rate of 30 °C per hour. The plates are taken out of the furnace after being cooled to room temperature. The blistering area is measured by using profile projector.

Table 2 The sequence of the hot rolling of fuel plate as applied in fabrication of MTR-type fuel plates

Pass N$^{\circ}$.	Reduction of Thickness (mm)	Reheating time in minutes	Thickness in (mm)
-----	Initial	-----	18.2
1 st	1.82	15	16.38
2 nd	2.46	15	13.92
3 rd	2.78	15	11.14
4 th	2.79	10	8.35
5 th	2.09	10	6.26
6 th	1.88	10	4.38
7 th	1.53	5	2.85
8 th	0.85	5	2.00
9 th	0.375	----	1.63

2.3 Mechanical Testing

Mechanical testing plays a vital part in the assessment of roll-bonded joints. Tensile tests are normally used to evaluate joints in thick sections, but in our case, thin sections are obtained. Lap shear tests are the most common test to evaluate such joints. To measure the strength of roll-bonded aluminum joints, it is essential that failure occurs at the bond interface. Failure in the base metal away from the bond may provide information on joint design, but does not help in the evaluation of the bonding process[10].

Single lap shear test specimens, as shown in Fig. 3, are used to determine joint shear strength. To obtain reproducible shear strength values and to ensure failure at the bond interface, short overlap length (< 0.5 T, Fig. 3) have been recommended[11]. The shear strength values for these single lap joints are still dependent on constraints imposed by the testing jig. It is therefore difficult to make comparisons between test results obtained by different researchers, unless similar test piece dimensions and testing techniques are used. In addition, control tests should be carried out on the base metal under identical conditions[12].

Tests were carried out using a 100 KN Instron machine. The shear strength is calculated from measurement of the failure load and the overlap area of each tested specimens using the following Eq.[1];

$$Bond \quad Strength \quad (MPa) = \frac{Failure \quad load \quad (KN)}{Overlap \quad Area \quad (mm^2)} \times 1000 \qquad [1]$$
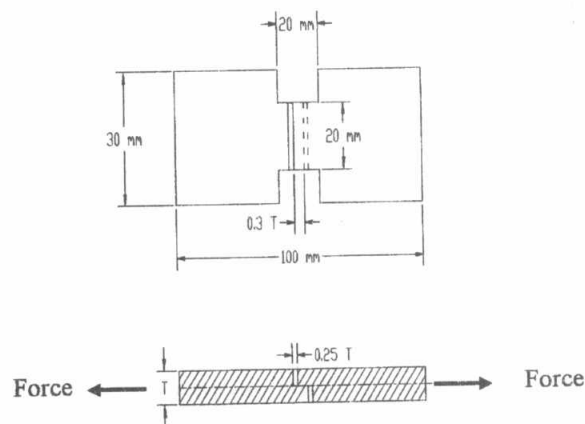

Fig. 3   Lap shear test specimen

2.4   Metallographic Examinations

The specimens were cross sectioned in the rolling direction. These cross sections were used to prepare specimens of 20 mm length for metallographic examinations after being carefully mounted. The polished specimens were etched using solution 10 % H_2SO_4 + 5% HF for 30 to 60 seconds at room temperature. The etched specimens were examined using optical microscope.

3 RESULTS

Single lap shear test was carried out on the roll bonded specimens. The results are given in Fig. 4. The curve shows that, at the beginning the bond strength increases rapidly with the increase in the surface roughness until it reaches a maximum value at about 5.2 μm. However, further increase in the surface roughness leads to rapid decrease in the bond strength up to surface roughness of about 10 μm, thereafter the rate of decreasing in the bond strength is very slow.
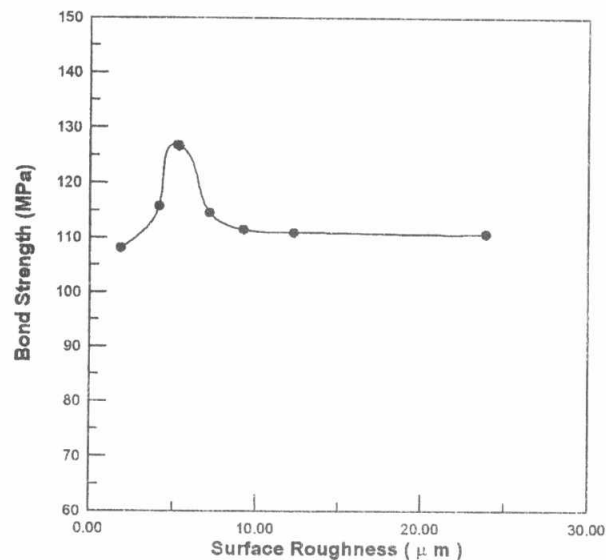

Fig. 4 The influence of the surface roughness on the bond strength of roll bonded specimens

The blistering area on the surface of the roll bonded plate was observed after the blister test. This area is formed due to accumulation of trapped gases between the layers of the roll bonded plate. This appear as blister on the plate surface. Examples of the blistering area are shown in Fig. 5. The results showed that the blistering area formed increases as surface roughness increases, Fig. 6.
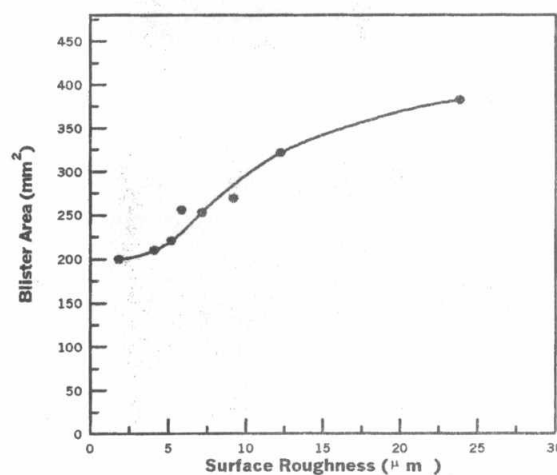
Fig. 5 The blistering in roll bonded plates

Fig. 6 The relationship between surface roughness and blistering area in roll bonded specimens
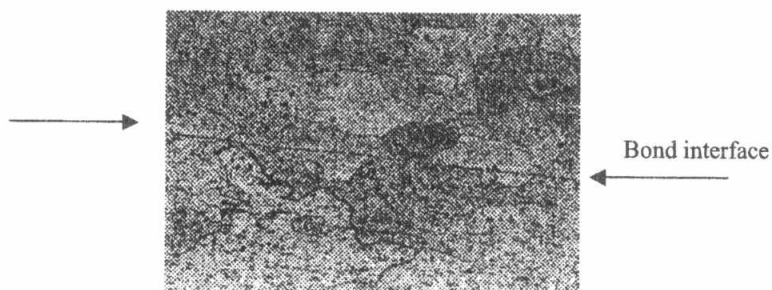
Fig. 7 shows the microstructure of roll bonded specimens with different surface roughness, after approximately 90% reduction in thickness. It is noted that, the appearance of grain boundaries at the bond interfaces is not as clear as those far from the interface. These microstructures indicate that, many grains are shared on both sides of the bond interface. These grains grown across the bond interface during blister test and annealing step.

Another important observation to be mentioned form the optical microscopy examination, is that the bond line have been found inside the grown grains in all roll bonded specimens even in the case of complete grain growth across the bond interface. This bond line could be seen easily in the examined microstructures. The recrystallisation and grain growth steps did not eliminate the bond line. It seems that the grain growth was not affected by the variation in surface roughness.
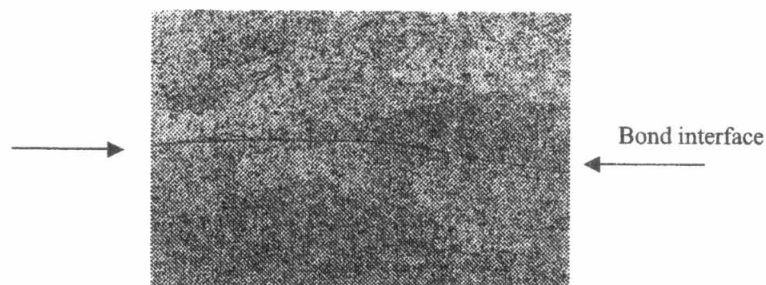
The microstructure examination shows that the bond line was almost linear at low surface roughness values. However, somewhat wavey appearance was observed with increasing in the surface roughness.
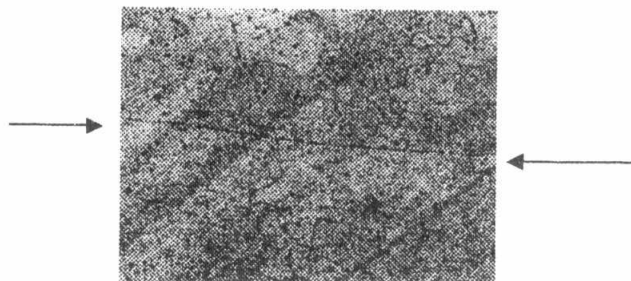
A)Surface roughness is 1.844µm , 400X

B) Surface roughness is 5.19µm, 400X

C)Surface roughness is23.875 µm, 400X

Fig. 7   The microstructure of roll bonding specimens

4 DISCUSSION

In the present work, the effect of the surface roughness on bond strength was studied. The present results, Fig. 4, shows that the bond strength of roll bonded plate increases with increasing the surface roughness up to certain value (about 5.2 μm). Then it decreases with surface roughness increase. This is in agreement with results of H. A. Mohamed and J. Washburn[13]. They stated the fact that initially rough surface is required for welding. They suggested that bringing oxide free metals into contact does not result in welding unless there is also some shear displacement as the two surfaces come into contact. This was confirmed by butt welding of gold with different methods of surface preparation. It was found that, at the pressures where welding did occur in wire brushed specimens, highly polished specimens degreased in acetone did not weld.

The observed decrease of the bond strength for surface roughness higher than 5.2 μm could be due to the fact that increasing the surface roughness is expected to lead to increase of the trapped gases, which leads to decrease in the bond strength . The increase of the trapped gases due to increasing the surface roughness explains the increase in blistering area as shown in Fig. 6. Therefore, the surface roughness plays an important role in the manufacturing of fuel plates. The blistering area and their position control the quality of fuel plates. Any blister in a fuel plate would lead to the rejection of this plate.

An important observation is that a highly smooth surface is not required for the 6061 aluminum alloy plates used for the cladding of nuclear fuel core. The surface produced by normal machining tools resulted in the best bond strength.

5 CONCLUSIONS

The effect of the surface roughness of the 6061 aluminum alloy plates on the roll bonding process was studied. The results indicate that the surface roughness could affect the quality of the produced fuel plates. It was found that the bond strength reached a maximum value at surface roughness of about 5.2 μm. The bond strength decreases rapidly with both decreasing or increasing the surface roughness, than 5.2 μm. Furthermore, the increase of the surface roughness resulted in increasing the blistering area .

6. ACKNOWLEDGMENT

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