EVALUATION OF ULTRASONIC DISSIMILAR WELDS BY ULTRASONIC TESTING IMMERSION METHOD C-SCOPE MODE

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ABSTRACT: Ultrasonic bonding is relatively new and very useful technique for bonding dissimilar metals in which brittle intermetallic compounds are easily developed in conventional fusion welding processes The possibility of evaluations of ultrasonic bonds by ultrasonic testing was discussed in detail. In order to evaluate the quality of bonds it is necessary to obtain the correlation between the results by ultrasonic testing as non destructive test and mechanical properties, tensile shear strength in this work as a destructive test. It was confirmed that ultrasonic testing (C-scope mode) was useful to evaluate the bonding situations of the bonds by ultrasonic bonding when the appropriate threshold level was selected. In this study it was found that the threshold level of 200 had a good correlation between the result of ultrasonic testing and a tensile shear test.

KEY WORDS: ultrasonic, testing, microstructures, bonds, properties.

1 INTRODUCTION

Nowadays it is difficult to find any fields without ultrasonic techniques. It has many applications in material science, chemical science, medical fields and many industries. By using ultrasonic, we can get some useful information, which are difficult to get by other measuring techniques such as electromagnetic waves, X-rays and electron beam, etc. So recently ultrasonic is essential techniques in the modern industries (Balkin, 1991), (Katoh, 1997), (Japan Electronic, 1995). Ultrasonic bonding is a low temperature welding process. Frictional heat generated by the process only raises the temperature of the parts beyond approximately one-third of their melting temperatures. Fusion welding generates intermetallic compounds that reduce the ductility of dissimilar bonds as in the case of the aluminium/copper, aluminium/stainless steel and aluminium/steel joining.

This work is mainly concerned with the bonding of dissimilar metals by ultrasonic bonding and their materials evaluation. Many researchers have made valuable contributions for understanding of dissimilar ultrasonic bonds (Watanabe, 1996), (Hiromichi, 2016), (Wanger, 1998), (Materials Science Society of Japan, 1992), (Villafuerate, 2003), (Katoh, 2002), (Adams, 1985). They focused their studies on the influence of bonding conditions on the properties of ultrasonic bonds, observing the existence of intermetallic compounds, and the evaluation the of bonds quality by different mechanical tests and microscopic observations near bond interfaces. However, evaluations of ultrasonic bonds by non-destructive methods were not emphasized in their studies (Katoh, 2002), (Adams, 1985), (Flood, 1997), (Greitmann, 1997), (Morita, 1999), (Flood, 1999).

The authors tried to evaluate ultrasonic bonds quantitatively by ultrasonic testing (C-scope mode). More over a correlation between the result of ultrasonic testing and a tensile shear test as mechanical test was evaluated.

2 EXPERIMENTAL PROCEDURES

In this study both similar and dissimilar metals bonded combinations were used. 1050W/1050N with artificial flaw was investigated as similar combination while the other two combinations 5052/ SUS304 and 5052/SPCC are dissimilar ones. Symbol “N” is used to represent a specimen without anodically-oxidized film that is a sheet as received, while a symbol “W” is used to represent the specimen with an anodically-oxidized film. The thickness of the oxide film was changed to t0 = 4, 15 and 30 μm with an anodizing method by changing the anodizing time. Table 1 shows the chemical composition of the material used in this study. Lap joints were produced using an ultrasonic welding machine. In case of 1050N/1050W combination, aluminum sheets with the anodically-oxidized films were set in the upper side, which contacted a horn of the machine, while aluminum sheets without the anodically-oxidized films were set in the lower side, which was contacted an anvil. While in case of two other combinations

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Table 1. Chemical composition of the materials, wt%

5052	**Si**	**Fe**	**Cu**	**Mn**	**Mg**	**Zn**	**Cr**	**Ti**	**Al**
	0.09	0.270	0.027	0.049	2.19	0.005	0.19	0.015	Bal.
SPCC	C	Si	Mn	P	S	Ni	Cr	Ti	Fe
	0.05	0.004	0.18	0.01	0.01	-	-	-	Bal.
SUS304	C	Si	Mn	P	S	Ni	Cr	Ti	Fe
	0.06	0.85	1.25	0.035	0.020	8.00	18.00	-	Bal.

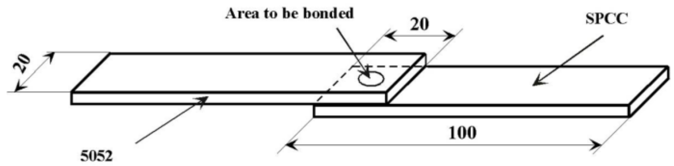

Figure 1. An example of Shape and dimensions of a specimen to be bonded (5052/SPCC)

5052/SUS304 and 5052/SPCC, steel sheets were set in upper side (horn) and aluminium 5052 sheets to lower side (anvil). Figure 1 shows an example of bond shape and dimensions of a specimen to be bonded.

Table 2 shows conditions of the ultrasonic bonding. For each combination, bonding pressure and amplitude were kept constant. The vibration direction was parallel to the specimen surface. Input energy (Ei) for the bonding was changed by 4 steps for the 1050W/1050N and by 5 steps for 5052/SUS304 and 5052/SPCC combinations, respectively. When the value of input energy (Ei) is input into the machine, it is automatically controlled by the area surrounded by a power vs. bonding time curve during the bonding. First, macrostructures of the specimens were observed as bonded. After that, the cross-sections of the bonds were microscopically observed using an optical microscope. The distributions of constituent elements and the existence of intermetallic compounds near the bonding interface were analyzed by EPMA. Moreover, the bonding situation was evaluated by ultrasonic testing (immersion method, C-scope mode) using ultrasonic imaging equipment (AT 7000 fabricated by Hitachi Construction Machine Co., Ltd). For each combination mechanical properties of the bonds were evaluated by performing tensile shear test.

3 RESULTS AND DISCUSSIONS

3.1 Features of bonds and their cross sections

Knurling marks are observed on the top of the bonded specimens due to the horn of the ultrasonic bonding machine. The flash around the bond area increased with the increase in bonding energy. Good bonding was obtained by using the appropriate range of input bonding energies. When the input bonding energy exceeded the optimum

Table 2. Conditions of ultrasonic bonding

Type of joints	Input energy, E_i	Pressure, P	Amplitude, A	Horn tip diameter, D
1050W/1050N	350J	0.31 MPa	68 µm	7 mm
	400J			
	450J			
	500J			
5052/SUS304	600J	0.27 MPa	50 µm	6 mm
	800J			
	1000J			
	1200J			
	1400J			
5052/SPCC	800J	0.27 MPa	50 µm	6 mm
	1000J			
	1200J			
	1400J			
	1500J			

range, a hole was developed in the bond area (Japanese Society for Non-destructive Inspection, 2008), (Abdelaleem, 2003), (Abdelaleem, 2004). Figure 2 shows examples of cross-sectional microstructures near the bond interface of the dissimilar combinations at different bonding conditions, and smooth interface and no un-bonded region nor were intermetallic compounds observed in the structure of the joints.

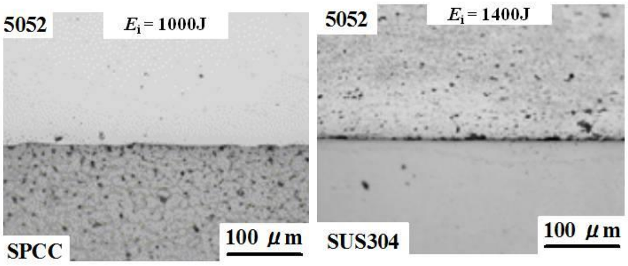

Figure 2. Examples of microstructures near the bond interfaces of 5052/SUS304 and 5052/SPCC

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3.2 Results by electronic probe micro analyzer (EPMA)

Figure 3a shows the results of line analysis for 1050N/1050W 5052/SUS304 combinations. The constituent elements mutually diffuse each other by a few micrometers near the bond interface. In the case of 5052/SUS304, Al and Mg in 5052 diffuse to SUS304, while in the SUS304 side, Fe, Ni, and Cr diffuse to 5052 side. In the case of 5052/SPCC combination, Al and Mg in 5052 diffuse to SPCC, while in the SPCC side Fe diffuses to 5052 side, Fe diffuse to 5052 side. No intermetallic compound was observed near the bond interface.

3.3 Ultrasonic testing

The major aim of non-destructive evaluation of materials is quantitative prediction of their mechanical properties. Recent advances in ultrasonic technology have demonstrated the use of ultrasonic waves for evaluating several important welding variables (Morita, 1999), (Flood, 1999), (Japanese Society for Non-destructive Inspection, 2008), (Ohashi, 1979). S. Rokhlin have reported that ultrasonic waves could be used to estimate shear strength of spot welds (Rokhlin, 1985). We tried to evaluate ultrasonic bonds quantitatively by ultrasonic testing and find a correlation between result of ultrasonic testing and a tensile shear test. In order to perform ultrasonic testing under the same condition it is necessary to define the standard echo height using the standard test block and adjust the working sensitivity using the echo height. The working sensitivity was set to 100 % by using the

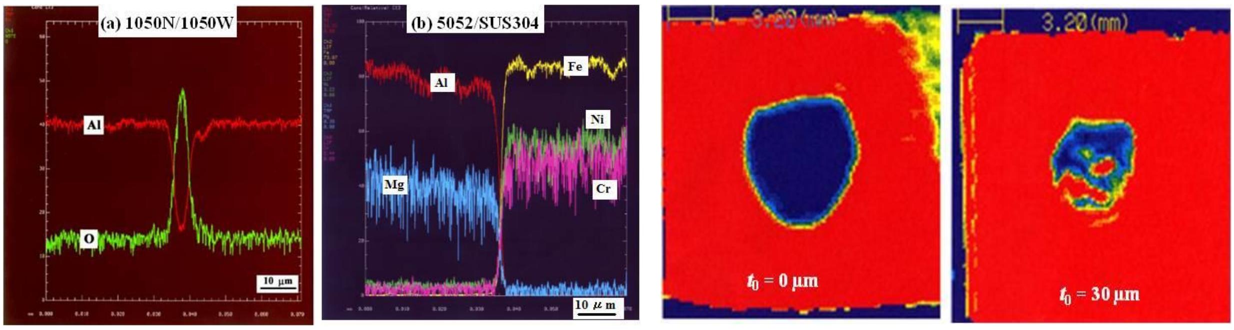

Figure 3. Results of EPMA line analysis (a),
C-scope images for different oxide film in 1050W/1050N (Ei = 400 J) (b)

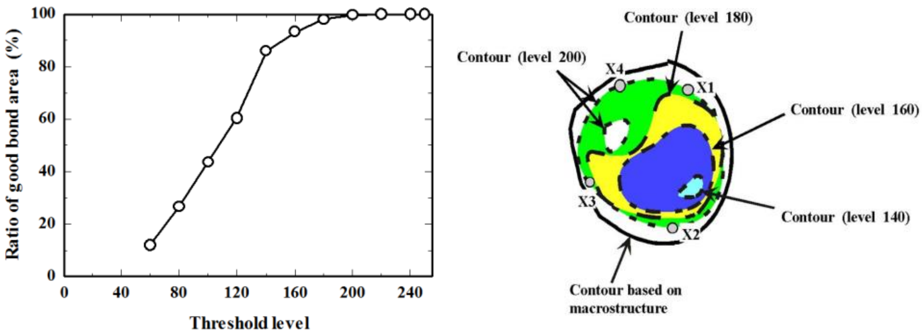

Figure 4. Ratio of good bond area Vs threshold level (Ei = 1400 J) (a),
contours at several threshold level after the tensile shear test (Ei = 1200 J) (b)

back wall echo from the upper sheet of the specimen bonded. When a probe frequency over than 20MHz, the ultrasonic transmission loss becomes larger on the specimen surface. Usually, 2 or 5 MHz probe is used for the conventional ultrasonic testing. The resolution for detecting a flaw becomes better when a higher frequency probe is used. Hence, the frequency was decided to be 10MHz in this work.

Figure 3b shows examples of C-scope images from the bond interfaces for the anodically-oxidized film thickness of 0 and 30 μm, respectively, in 1050W/1050N (Ei=400J). The area of dark blue region corresponding to the good bonding decreased with the increase in the oxide film thickness for the same input energy. It was possible to evaluate the bonds with the oxide film by ultrasonic testing. Then the authors tried to evaluate quantitatively the ratio of good bond area. For this, it is convenient to binarize the C-scope images by using the appropriate threshold echo height level. It is possible to obtain quantitatively the ratio of good bonded area in the bond area by analyzing this image. For this purpose it is convenient to binarize the image by using the appropriate threshold level. Figure 4a shows the relation between the ratio of good bond area and threshold level for the 5052/SUS304 combination. The ratio of good bond area smoothly increases with the increase in the threshold level, it was also the same for 5052/SPCC and 5052N/5052Wcombinations.

Figure 4b shows the contours at different threshold levels including the contour by the macrostructure of the bond after the tensile shear test for 5052/SPCC combination (Ei = 1200 J). The location marked X1, X2, X3 and X4 show the area corresponding to the boundaries between ductile and not-ductile area. The good bond area was decided by using the result when binarized at the threshold level of 200 for all joints. Though the data of the ratio of good bond area and input energy at the threshold level of 200 varied widely, the ratio of good bond area was more than 75 % in average except for the case of input energy Ei = 600J in the

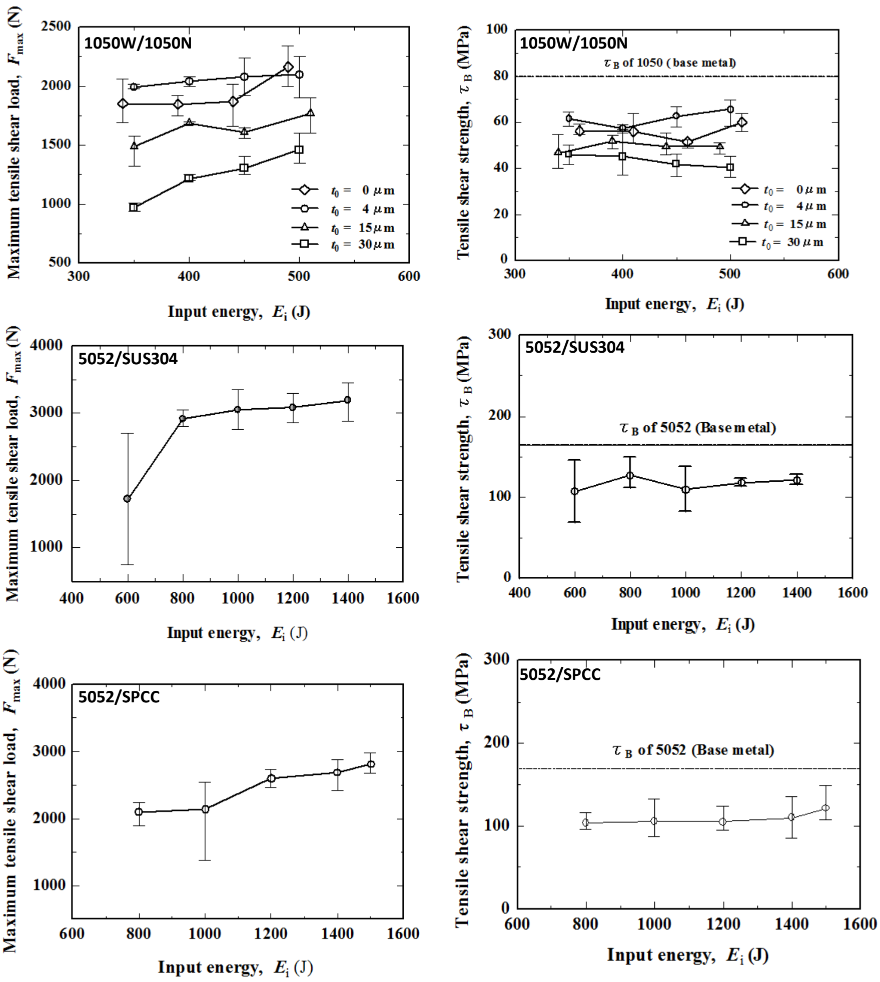

Figure 5. Relation between the maximum tensile shear load and input energy (a), relation between tensile shear strength and input energy (threshold level of 200) (b)

case of 5052/SUS304 combination (in this case input energy is too low to obtain good bonding). The ratio of good bond area tended to increase with the increase in the input energy.

3.4 Tensile shear test

Tensile shear test was performed for the same specimens after performing ultrasonic testing to evaluate the mechanical properties of bonds. Figure 5a shows the relation between the maximum tensile shear load and input energy for 1050W/1050N, 5052/SUS304 and 5052/SPCC of welded joints. The maximum tensile shear load tended to increase with the increase in the input energy. Figure 5b shows the relation between tensile shear strength and input energy for all combinations. A good correlation between the maximum tensile shear load and the ratio of good bond area by ultrasonic testing is obtained. The tensile shear strength is larger in all joints than that in 5052/5052 probably due to oxide film that in 5052 is more easily destroyed by the harder dissimilar metal than that for SUS304 or SPCC. In the case of 1050W/1050N, the tensile shear strength did not depend on the input energy indicating that good correlation between the results of the good bond area and the maximum tensile shear load. The strengths in $t0 = 0$ and 4 μm were nearly the same indicating that the oxide film up to 4 μm did not influence the bond quality. When t0 is increased to 15 or 30 μm, the strength decreased and became half of the base metal.

4 CONCLUSIONS

Ultrasonic testing immersion method C-scope mode was useful to evaluate the ultrasonic bonding. It was necessary to remove the influence of the roughness of the specimen surface to apply ultrasonic testing for evaluating ultrasonic bonds. The correlation between the results of ultrasonic testing and mechanical properties of the joints was established when the appropriate threshold level 200 was adapted.

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