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Evaluation of the Weldability in Spot Welding using Ultrasonic Technique

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Abstract Spot welding is the most widely used in automotive and aerospace industries. The quality of weld depends upon the size of nugget between the overlapped steel plates. Recently, the thickness of the steel plates is much thinner and hence, it introduces the smaller size of nugget. Therefore, it is necessary not only to develop the criterion to evaluate the quality of weld but also to obtain the optimal welding conditions for the better performance. In this paper, the steel plates, 0.5 mm through 1.5 mm thickness, have been spot welded at different welding conditions and the nugget sizes are examined by ultrasonic technique (C-scan type). The relationships between the nugget sizes and the weldability have been investigated. The result of ultrasonic technique shows the good agreement with that of the tensile test.

Keywords: spot welding, nugget size, nondestructive test, ultrasosnic technique.

I. Introduction

Spot welding is the most widely used for industrial purpose such as automobile and aerospace industries and household appliances due to its high performance. In these days, robotization and systemization of welding process made it possible to produce more precise and smaller electric parts. Thin steel plates are frequently used to implement this purpose. Therefore, welding conditions are limited to avoid defects such as deformation, damage, weakening of joining area. In addition, the nugget size between welded thin plates becomes smaller and smaller. However, the demands for the product life and its reliability are continuously increasing so that the weldability of the welded area is key issue to solve. Even though the weldability can be assessed in many ways, the nugget sizing is believed the most suitable method for the purpose (Arakawa et. al., 1985 and Murray, 1968).

In order to evaluate the welded area, the destructive tests such as the tensile test have been applied, which take more time and are complicate to measure the nugget sizes. Since the nugget size of the thin steel plate is not able to be seen by bare eyes, more efficient method is demanded. In this paper a nondestructive test is adopted to measure the small nugget by the limited welding conditions. Especially, the ultrasonic technique among nondestructive tests is one of the most available solutions to the defects inside materials, the sensitivity at the discrete boundaries, and its applicability in shop floor (Blitz and Simpson, 1996).

In addition, unlike the destructive inspection, the ultrasonic technique does not disturb the production line and provides relatively quick

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and precise inspection results. Therefore, its application is expected to contribute for the quality improvement and mass productivity (Drescher-Krasicka and Ostertag, 1999)

Nondestructive inspection by the ultrasonic technique is used to measure the nugget size between the thin steel plates and to inspect the weldability (Kim and Hong, 2005). The characteristics of reflection wave are used for testing plates because they offer an inspection potential owing to sensitivity to different types of boundary conditions and discontinuity along the propagation path which enables to size the defects or hidden parts. The generation and reception of normal incident waves in the test plates are easily carried out by non-contact NDT such as the water-immersion technique (Graham and Ume, 1997 and Hayashi and Endoh, 2000).

In this research the weldability of the spot welding has been evaluated by ultrasonic technique. The measured images are obtained and the results are compared with those of the tensile test. In addition, it has been tried to find out the corona bond to study its influence to the weldability.

II. Ultrasonic Scanning Technique

Ultrasonic C-scan is commonly used scanning method for testing relatively thin samples such as sheets of steel or carbon-fiber composites. Ultrasonic pulser/receiver supplies and receives electric pulses from focused transducer which moves in two dimensions to monitor any indication of material change on the oscilloscope screen for all probe positions. With automatic scanning, the echo signals are fed to a computer in which data of the position and amplitude of these signals are matched to those for the probe position, thus enabling discontinuous boundary to be located. The motion of the probe in one direction controls the voltage across the X-axis of the oscilloscope and that at right angles to this direction controls the voltage across the Y-axis. Ultrasonic beam is modulated by the received ultrasonic pulses and an echo is indicated on the screen by a spot in a position corresponding to the point of reflection and with brightness consistent with the echo amplitude. Although there is no longer any time base in the circuit, it is possible to estimate the depth of an echo by means of a gating device which can be manipulated to allow the detection of echoes at any desired depth, with the exclusion of those at other depths. With C-scanning, the depth of an echo can be evaluated by performing two scans along surfaces perpendicular to one another. Alternatively, the echo depth can be obtained approximately by repeating the scans with progressive gating so that different depths can be viewed in turn. In this study, C-scan in the plane parallel to the steel plates was made at the depth of the interfacial surface to determine the nugget size of spot welded plates for the different welding conditions. Figure 1 shows the equipment and configuration used in the ultrasonic immersion test.

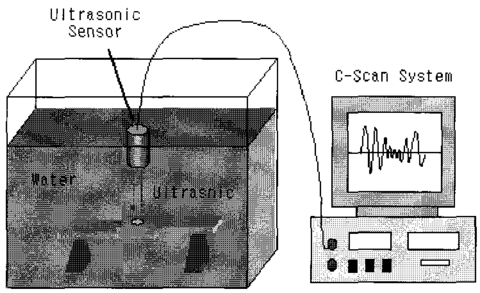


Fig. 1 Configuration of ultrasonic C-scan system

Since the spot welding less than 0.5 mm thickness steel plate causes difficulties in practice, the specimen with thickness between 0.8 mm through 1.4 mm are spot welded and tested by C-scan system. In order to confirm the relationship between C-scanned images and their weldability, the tensile test is carried out together. The specimens for the ultrasonic and tensile tests are a rolled stainless steel manufactured for automobile and shown in Fig. 2. In Table 1 the different welding conditions such as weld time, weld force, and welding current are given and the plate thickness of 0.8 mm, 1.0 mm, 1.2 mm, and 1.4 mm are examined, respectively.

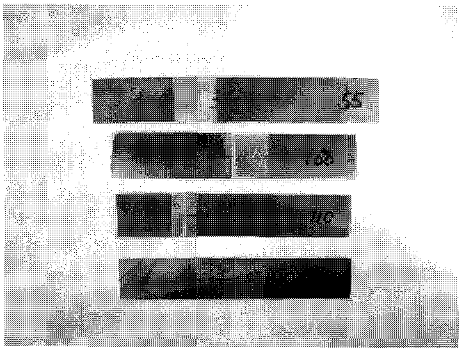


Fig. 2 Spot-welded thin plates for ultrasonic inspection

Table 1 Spot-welding conditions for plates

No	Specimen Thickness [mm]	Weld Time [Cycle]	Weld Force [Kgf]	Welding Current [KA]
1	0.8	8	290	10.7
2	0.8	9	250	9.8
3	0.8	8	290	10.7
4	0.8	9	250	9.8
5	1.0	9	350	12.0
6	1.0	11	300	10.8
7	1.2	11	400	12.7
8	1.2	15	280	10.3
9	1.4	13	450	13.3
10	1.4	18	320	11.0

III. Ultrasonic Inspection of Spot Welded Plates

In the experiment, the spot-welded area is inspected by C-scan immersion test using a 25 MHz ultrasonic sensor. The joining characteristics including the nugget size and corona bond between two steel plates are investigated. Reflected signal from the nugget is very small or approximately zero due to no impedance change in the interfacial boundary of two plates after welding. Since the two plates are melted and joined together, the incident ultrasonic signal penetrates the specimen and no reflected signal is detected. However, if the two plates are just surface contact in the region such as corona bond or un-welded area, then the different impedance at the boundary surface generates the reflected signal because of a drastic change of acoustic impedance between the stainless steel and air engaged inside two plates. Therefore, the melted area (nugget) is illustrated in the C-scan image by different color from that of the surface contact region. Figure 3 shows the experimental setup of the C-scan equipment. Figure 4 shows the typical image obtained from the ultrasonic

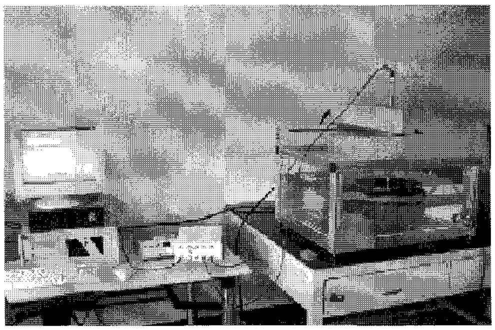


Fig. 3 Ultrasonic C-scan system in experiment

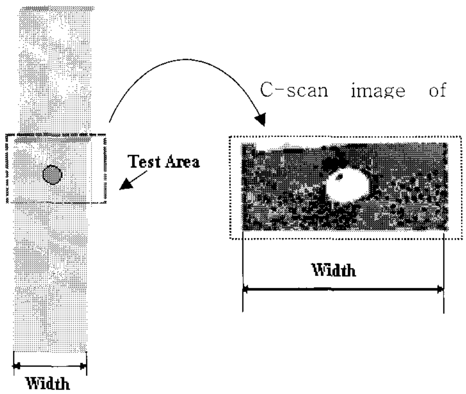
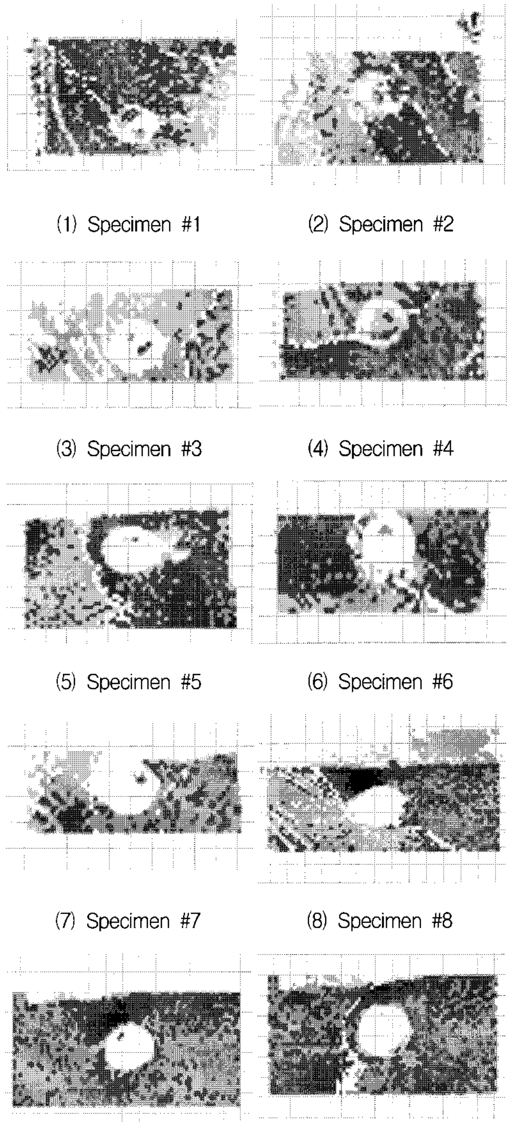


Fig. 4 A-scan signal and C-scan image of a spot-welded specimen

C-scan inspection. The width of the image in test area corresponds to that of the weld specimen of 30 mm in width. In Fig. 4, the white ellipse in the center of the image shows the spot welded area (nugget) and the gray part of the image the surface contact area (original color images are rendered into BW images for publication). Black and white intensity in the image represents the ultrasonic strength of reflected signal. However, it has no special quantitative meaning for detecting and sizing the nugget of the welded plate. The nugget has an elliptic shape although the electric welding rod has a circular tip. It is because the stainless steel plate is rolled in a specific direction. Figure 5 shows the C-scan images of steel plates welded according to the different welding conditions given in Table 1. Table 2 shows the measured major and minor diameters of the nuggets shown as white ellipses in the images. The relationship between the nugget size and its weldability is analyzed in the following section.

IV. Experimental Results and Discussions

Results in Fig. 5 represent the C-scan images of welding nuggets for four different plates obtained at two different welding conditions shown in Table 1. Fig. 5(1) is the ultrasonic C-scan image of 0.8mm steel plates welded at 290 Kgf and 10.7 KA in welding force and current. The nugget appearing as a white ellipse can be seen clearly and sized easily on the computer screen by measuring the major and minor diameter of the nugget. Fig. 5(2) also shows the C-scan images of the same plates welded at lower force and current. In this case, the nugget size looks as large as that in Fig. 5(1) but the shape and area of the nugget are little different from that in Fig. 5(1). First the nugget does not take a clear elliptic shape and its boundary is not as clear as that in Fig. 5(1). Secondly there exists a region inside the nugget which has a large reflection signal. It indicates that steel plates are not completely



(1) Specimen #1 (2) Specimen #2
(3) Specimen #3 (4) Specimen #4
(5) Specimen #5 (6) Specimen #6
(7) Specimen #7 (8) Specimen #8
(9) Specimen #9 (10) Specimen #10

Fig. 5 Ultrasonic C-Scan images for various plates (0.1-0.3 mm in thickness)

welded there and the effective area of the nugget becomes smaller. It also means that the electric current and force are not enough to melt the steel plate at the spot. From these results, an optimal welding condition could be designed and analyzed. The figures from Fig. 5(5) through (10) show the same C-scan images of the thicker plates. In those cases, the nugget is formed well and consistent in its shape with a clear solid ellipse, so that the nugget sizing is made with ease.

Fig. 6 Laser images of a welded spot in 0.15 mm plate

Fig. 6 displays a laser image taken from the front surface of the welded plates, where only one quarter of the welded spot is shown. In this figure, the quarter circle in the right lower corner represents the nugget and the quarter ring surrounding the nugget with different color is thought to be a heated region. It is expected that corona band would be located between the nugget and the heated band. However, corona band could not be identified well from C-scan images because the accuracy and resolution of ultrasonic scanning system is limited for thin plates and small welding spots.

The tensile test was also carried out by FHF-ER-401 Tensile Tester (Shimadzu-Japan) to verify the relationship of nugget size to the weldability. The weld tensile shear strength of each specimen was measured and compared with the nugget size obtained from the C-scan image. Through the results of the C-scan images and the tensile test, it is found that the weldability of the spot welded specimens is proportional to the nugget size. From Table 2 and Fig. 5 (1) and (3), the specimens #1 and #3 are welded at the same conditions but the nugget size of the specimen #3 is larger than that of the specimen #1, which results in the larger tensile strength. Rest of other specimens from #2 to #10 shows the similar results.

Table 2 Measurement results for nugget size and tensile strength

No	Specimen Thickness [mm]	Major Diameter [mm]	Minor Diameter [mm]	Tensile Strength [kgf/mm^2]
1	0.8	6.429	5.938	400
2	0.8	7.125	5.501	345
3	0.8	8.360	6.690	440
4	0.8	6.750	5.135	320
5	1.0	7.941	5.649	645
6	1.0	6.638	6.852	630
7	1.2	8.780	6.440	763
8	1.2	8.663	6.355	780
9	1.4	8.889	6.158	1010
10	1.4	8.148	7.244	1003

V. Conclusion

In order to evaluate the weldability of the spot welded steel plates, the nondestructive inspection using the ultrasonic C-scan technique has been implemented. The C-scan images clearly show the nugget size of the welded area and the results are compared with those of the tensile test. It is concluded that the C-can image characterizes the nugget size and shows its weldability. In addition, the weld tensile strength is proportional to the nugget size regardless of welding conditions. It is not easy to find out the corona bond but its influence on the weldability is observed from tensile tests.

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