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Study on Highly Accuracy Quality Evaluation of Spot Weld by use of Image Processing Technique

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Abstract

This paper discusses the feasibility of Ultrasonic Nondestructive Evaluation(UNDE) technique for spot weld quality. Ultrasonic c-scan image assisted by image processing technique was used for Nondestructive Evaluation(NDE) of spot weld quality. Ultrasonic testing results obtained were confirmed and compared by Optical Microscope and SAM(Scanning Acoustic Microscope) observation of the spot-weld cross section. The results show that the nugget diameter can be successfully measured with the accuracy of 0.5 mm. It was ascertained that ultrasonic c-scan technique is very effective method for the sake of the approach to the quantitative measurement of nugget diameter and the discrimination of the corona bond from nugget. Additional support for the above conclusions is provided by the results for galvanized steel. The ultrasonic results for galvanized welds generally correspond to the results for uncoated steel.

Finally, It was found that the above-mentioned technique can be sufficiently applied to NDE method for securing the Quality Assurance(QA) of spot welded products in production line.

INTRODUCTION

Spot welding has wide use with a high work efficiency in the automotive and aerospace industries. In case of producing a medium-size passenger car on automotive production line, the number of spot welds are estimated to being upward of 3,000 point. Therefore, it's being very important assignment to secure the quick determination of optimal welding condition and the NDE technique which can be evaluate spot weld quality with more efficiency and high reliability.

Up to the present, the technique mainly used to test spot welds on production lines has been depended entirely upon destructive chisel or peel testing. The problem with destructive testing, however, is its high cost and the large

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amount of time it takes to destroy a welded part.

It is well-known that the measurement of nugget diameter can be available to the estimation of tensile-shear strength which is most important parameter in spot weld quality. The aim of this study is the approach to the quantitative measurement of nugget diameter and the discrimination of the corona bond from nugget by utilizing UNDE technique for spot weld quality.

This paper discusses the feasibility of ultrasonic c-scan technique for NDE of spot weld quality. UNDE for spot weld quality was performed by the immersion method with the mechanical and the electronic scanning of pointfocussed ultrasonic beam(25MHz). Ultrasonic c-scan images are enhanecd by applying the advanced image processing technique.Ultrasonic image data obtained were confirmed and compared by Microscope and SAM observation of the spot-weld cross section.

EXPERIMENTAL DETAILS

Spot weld experiments

Resistance spot welding is a joining process in which coalescence of the metal sheets produced at the faying surface by the heat generated at the joint by the resistance of the work to the flow of electric current. The welding experiments were performed using the conventional resistance spot welder. Sample of good welds, bad welds, stick welds and others have been generated in the production line environments. Welding regions of different diameters ranging from no weld to expulsion were obtained by changing the weld current levels which were then chosen to cover a range significantly above and below the value specified by AWS and RWMA A-class, but the weld times and the electrodes force were held constant. The exact welding condition is given in Table 1. The uncoated 1.6mm thick steel sheet(S11/S45) and the galvanized 0.8 mm thick automotive steel sheet(G11/G65) used in this study were originally supplied by the Toyota Co. works in Japan. Five pieces of specimens every each welding condition are prepared. Weld specimens were 50mm long and 30mm wide respectively. Overlap of the strips during welding was approximately 30 mm.

Table 1 Welding condition

Specimen	Electrode force(Kg)	Weld time (cycle)	Weld current (KA)
S11/15	360	16	11.5
S21/25	360	16	8.6
S31/35	360	16	8.0
S41/45	360	16	7.0
G11/15	400	12	8.0
G21/25	400	12	7.0
G31/35	400	12	4.2
G41/45	400	12	4.0
G51/55	400	12	2.4
G61/65	400	12	2.1

Ultrasonic experiments

A schematic diagram of UNDE system(AT 7000:Hitachi) for spot weld quality used in this study is shown in Fig 1. The system consists of equipments, including a pulser/receiver(frequency band 1-100 MHz, gain 60 dB)and peak detector(frequency band 10-30 MHz), gate delay 50 ns, gate width ±30 ns and a focusing type transducer(frequency 25 MHz, focal length in water 20 mm) to send and receive ultrasonic waves, a precision triaxial scanner and its controller unit, and a computer for data and image processing. The transducer is attached to the precision scanner, which can be move in X,Y,Z directions under computer control.

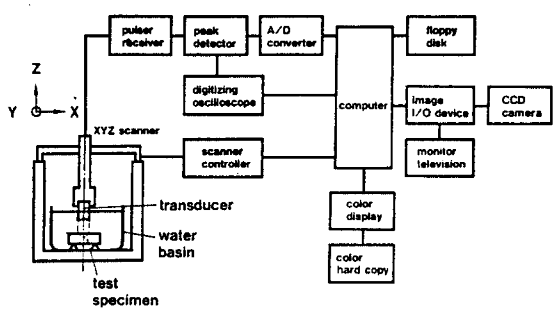

Fig 1 Configuration of mechanical scanning UNDE system

Ultrasonic beam is focused on the boundary of the unbonded counterparts to detect the RF signal(B_1 echo). The B_1 echo amplitude can be detected by setting up an electric gate at this location, converted to digital data by an A/D converter and then stored in the computer.

By using this stored data, an image input/output device can display an acoustic c-scan image on a screen. A block diagram of the electronic system for c-scan imaging is shown in Fig.2. The used transducer for electronic scanning was 25 MHz linear array transducer with 192 elements, 0.2 pitch. The scanning process for c-scan imaging is a combination of repeated electronic scanning of an ultrasonic beam in the X-direction utilizing a linear array transducer with orthogonal scanning in the Y-direction. On group among the array transducer elements acts as a pulse echo procedure to generate a converging ultrasonic beam and receave the echoes from the object under investigatin. The acoustical field of the generated and received beam is converged with a cylindrical acoustic lens attached along the array and by delay control for signals fed to and obtained from corresponding elements. The processing time using the electronic scanning method for the given scanning area is about 1 sec. compared to 60 sec. with mechanical scanning.

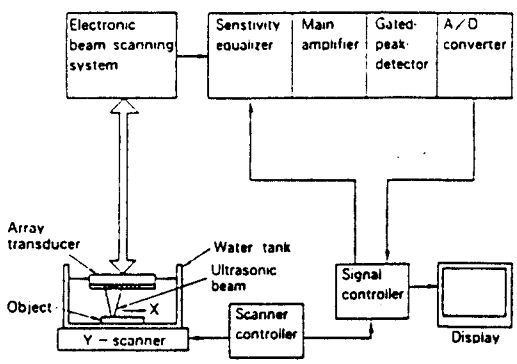

Fig 2 Configuration of electronic scanning UNDE system

Fig 3 shows schematic illustration of echo models and microphotographs of weld cross section. An example of an ultrasonic signal model for no bond, nugget, and corona bond displaced on an oscilloscope screen is an A-scan. In these models, the amplitudes of the echo levels are assumed to depond on the ratio of bonding to delamination area. Usually the displayed signals of the reflected ultrasound from bonding-to-delamination interfaces varies as shown in Fig 3. The first(leftmost) group of signals visible is the surface echo. The next signal is the surface echo(B_1 echo) reflected back from the surface of a specimen. The propagated ultrasonic waves are reflected also at the flaw(void). The propagating time from surface to bonding boundary shows the thickness of the specimen, if the material is homogeneous and its sound velocity is constant. Therefore, by measuring this B_1 echo by setting an electric gate at this location, the amplitude of the B_1 echo can be detected easily.

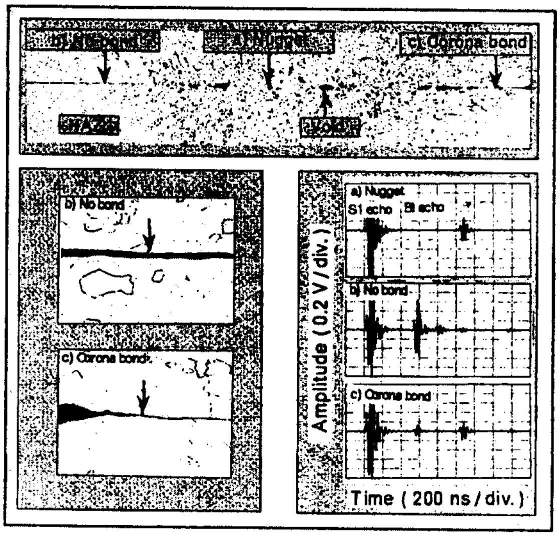

Fig 3 Schematic illustration of echo models and microphotographs of spot weld cross section

Image processing algorithm for nugget evaluation

The following image processing algorithm was used for the sake of the approach to the quantitative measurement of nugget diameter and the discrimination of the corona bond from nugget. The flow chart of image processing is shown in Fig 4(A). Fig 4(B) shows the concept of threshold level determination based on the discrimination criterion. Fig 4(C) shows an example of ultrasonic c-scan image extracted by image processing.

Image contrast T, the number of image element $h(k)$ of intensity k of total image elements within the range of evaluation window N,event probability in each echo level expressed as follows,

$$p_k = h(k)/N \qquad (1)$$

can be considered as probability distribution of echo level. At this time, total average and total dispersion of image are respectively

$$\mu_T = \sum_{k=0}^{T-1} k \cdot p_k \qquad (2)$$

$$\sigma^2_T = \sum_{k=0}^{T-1} (k-\mu_T)^2 \cdot p_k \qquad (3)$$

where, if we define the threshold level as t_1, t_2 in arbitrary point (i, j), we can obtain the following three-valued image $F(i, j)$.

$$F(i,j) = \begin{bmatrix} F_L(F(i,j) \in C_L,\ C_L = [t_0, \cdots, t_1 - 1]) \\ F_M(F(i,j) \in C_M,\ C_M = [t_1, \cdots, t_2 - 1]) \\ F_H(F(i,j) \in C_H,\ C_H = [t_2, \cdots, t_3 - 1]) \end{bmatrix} \qquad (4)$$

Each class C_L, C_M, C_H correspond to each level of nugget, background,and corona bond. If $t_0=0, t_3=T$, Event probability of intensity distribution in each level is

$$\omega_x = \sum_{k \in C_x} p_k \quad (X = L, M, H) \qquad (5)$$

and, average level becomes

$$\mu_x = \sum_{k \in C_x} k \cdot p_k \quad (X = L, M, H) \qquad (6)$$

At this time,as a criterion indicating the degree of separation in each classes, discrimination criterion(degree of class separation) θ can be calculated by applying the following equation,

$$\theta = \sigma^2_B / \sigma^2_T \qquad (7)$$

σ^2_B is dispersion in each classes

$$\sigma^2_B = \omega_L \cdot \mu^2_L + \omega_M \cdot \mu^2_M + \omega_H \cdot \mu^2_H + \mu^2_T \qquad (8)$$

when θ is maximum value,combination of threshold level given ideal condition of separation in each class can be obtained.In case

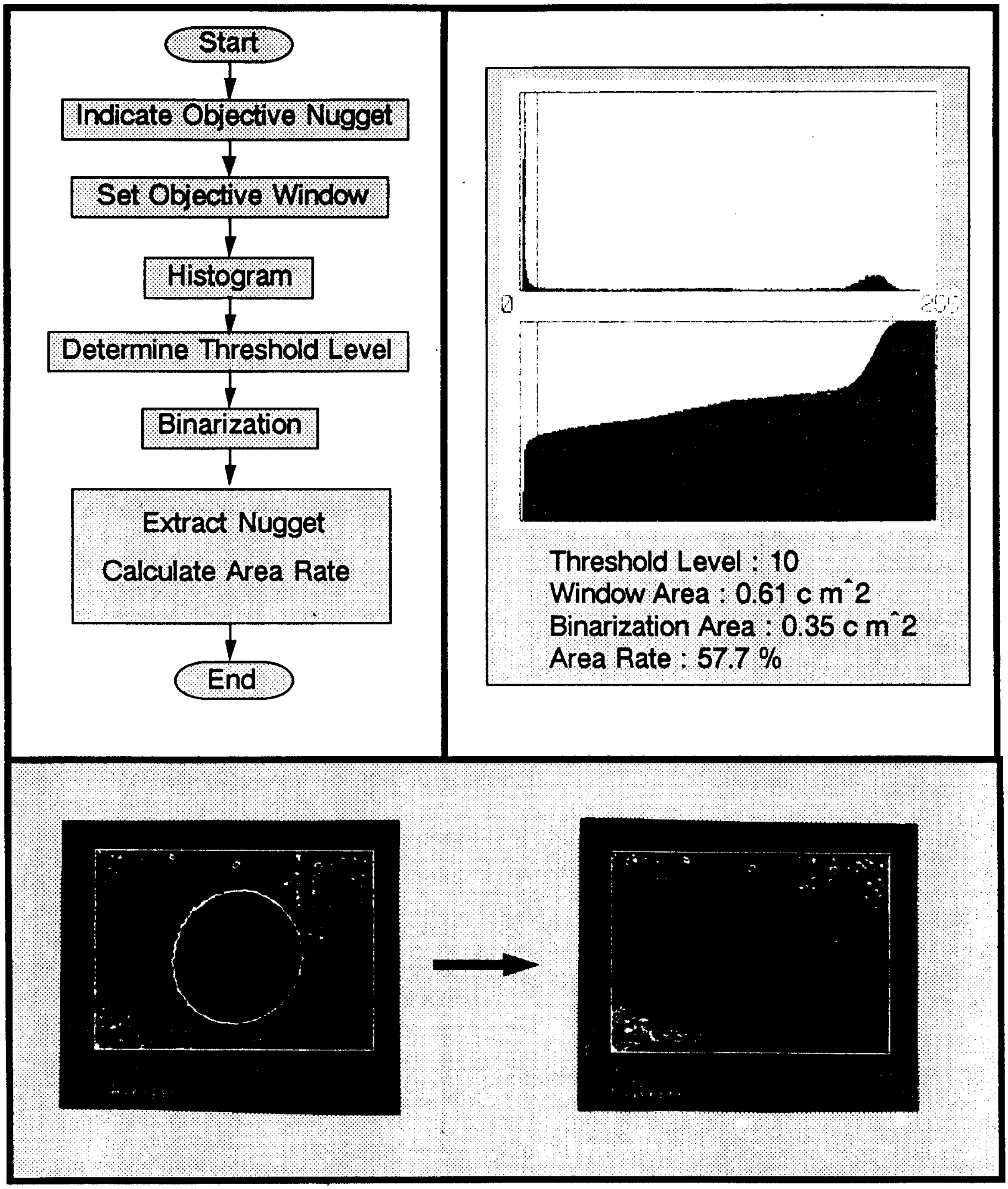

Fig 4 (A) flow chart of image processing. (B) concept of threshold level determination.
(C) example of ultrasonic c-scan image extracted by image processing

of equation (7), total dispersion σ_T^2 is constant regardless of threshold level, optimal threshold level can be determined by means of combination of threshold level maximizing σ_T^2 dispersion in each class. Using by above-mentioned algorithm,an example of the discrimination between nugget and corona bond is shown in Fig 4(C).

After welding and ultrasonic measurements, all the specimens were subsequently sectioned through the nugget normal to the plane of the sheet mechanically polished for metallographic examination by optical microscope and SAM. The shear strengths of the spot welds were measured in a tensile test mechine.Failures occurred both through the nugget and in the base metal adjacent to the weld.

RESULTS AND DISCUSSION

Generally the patterns of spot-welds formation fall into 3 categories, that is, good bond, no bond, lack of bond. Fig 3 shows a schematic illustration of typical spot-weld crosssection and ultrasonic RF signal detection. As illustrated in Fig 3, the first(leftmost) group of ultrasonic signal pattern visible is the surface echo(S_1 echo) reflected back from the urface of a upper sheet. The next signal is the B_1 echo reflected back from the interface of the upper sheet and the lower sheet. Of course, the propagating time from surface echo to B_1 echo shows the thickness of the upper sheet, if the material is homogeneous and its sound velocity is constant. Because ultrasonic wave in nugget has penetrated both pieces, B_1 echo cannot be detected, but, in no bond can be detected definitely and in corona bond very weakly, respectively.

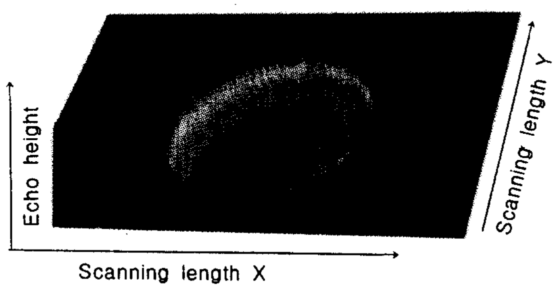

Fig 5 Example of 3-D scanning resulf

Representative results of UNDE for uncoated steel sheet are shown in Fig 6. As illustrated in Fig 6, UNDE information of A) mechanical c-scan image, B) electronic c-scan image, and C) c-scan image of extracted nugget by image processing technique was confirmed and compared by (a) optical microscopic and (b) SAM observation of the spot-weld cross section. It was ascertained that ultrasonic c-scan image C) enhanced by applying the advanced image processing technique is very effective method for the sake of the approach to the quantitative measurement of nugget diameter and the discrimination of the corona bond from nugget. The UNDE results show that the nugget diameter can be successfully measured with accuracy.

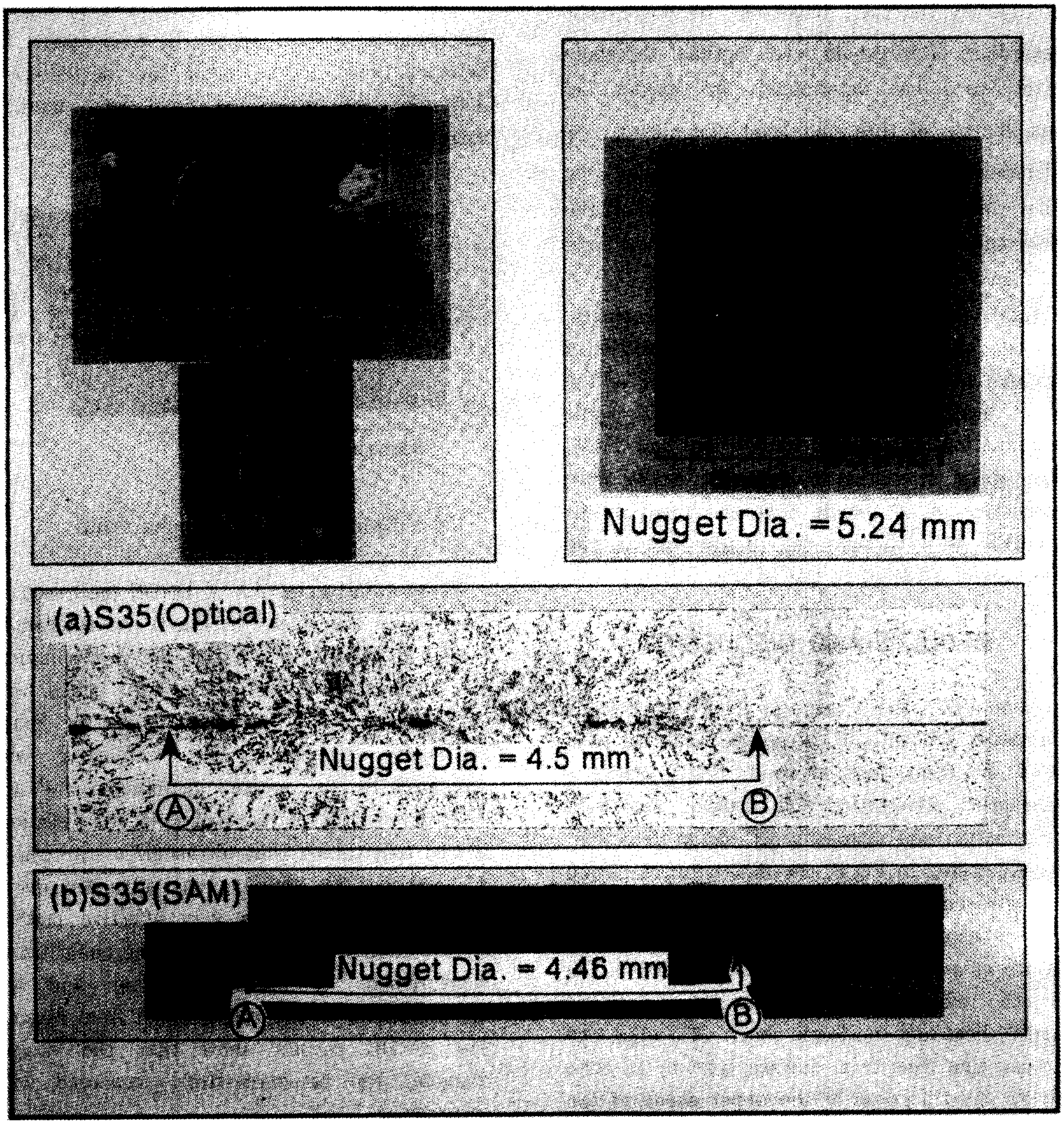

Fig 6 Spot weld quality evaluation by ultrasonic c-scan image and metallographic observation

Several representative original mechanical c-scan image (A), c-scan image (B) of extracted nugget by image processing technique for galvanized steel sheet are shown in Fig 7. For 8.0 KA(G11), a complete nugget was formed and can be detected expulsion. In case 4.0 KA(G41,G42), both melted(in the middle of the spot) and corona bond(in the periphery of the spot) areas which does not contribute to the weld strength were found. For 2.4 KA, it can be known that no-bond and partial corona bond was formed by insufficient welding current. Optical microscopic observation of the spot-weld cross section for galvanized steel sheet is shown in Fig 8.

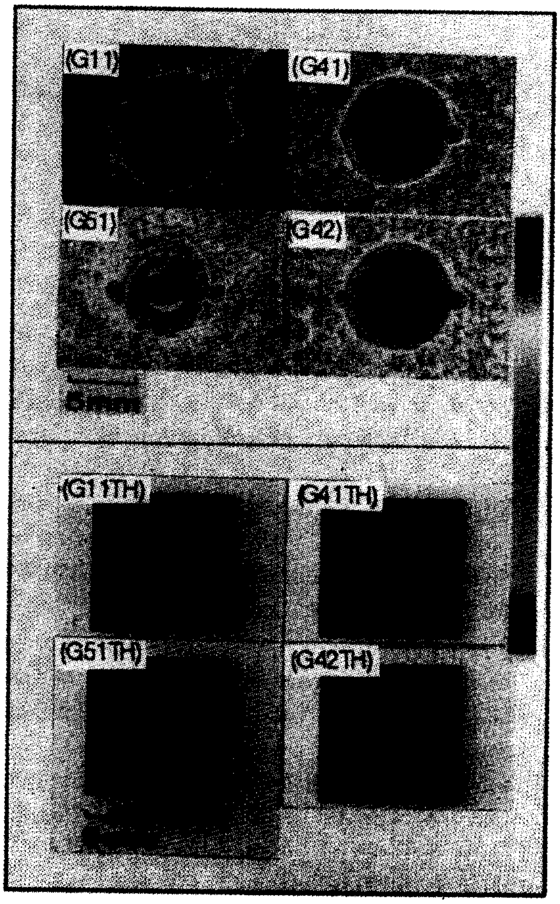

Fig 7 Typical tracing of mechanical c-san image for the galvanized steel

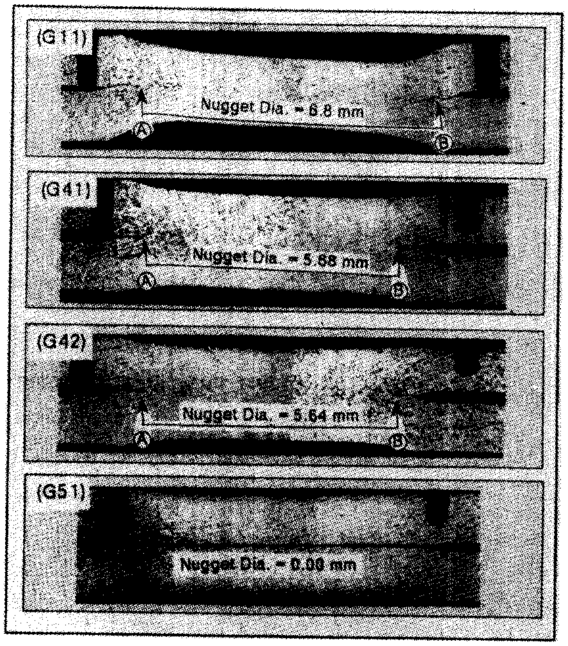

Fig 8 Typical tracing of optical photomicrographs of the weld cross section for the galvanized steel

Fig 9 shows comparison of nugget diameter between ultrasonic testing and microscopic measurement of the weld cross section. The results show that the nugget diameter can be successfully measured with the accuracy of 0.5 mm. It was ascertained that ultrasonic c-scan technique is very effective method for the sake of the approach to the quantitative measurement of nugget diameter and the discrimination of the corona bond from nugget.

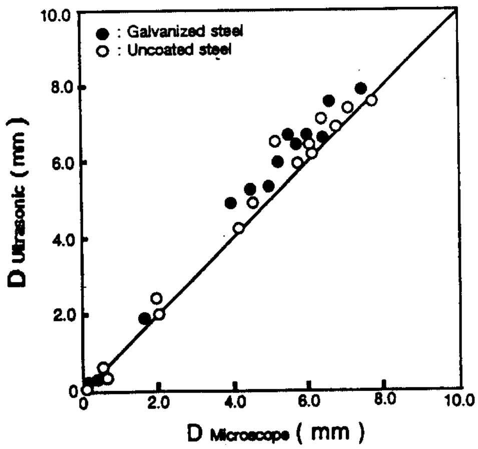

Fig 9 Comparison of nugget diameter between ultrasonic testing and microscopic measurement of the weld cross section

CONCLUSION

The experimental results presented in this paper illustrate the feasibility of Ultrasonic Nondestructive Evaluation(UNDE) technique for spot weld quality. Ultrasonic c-scan image assisted by image processing technique is very effective method for the sake of the approach to the quantitative measurement of nugget diameter and the discrimination of the corona bond from nugget. Ultrasonic testing results obtained were confirmed and compared by Optical Microscope and SAM(Scanning Acoustic Microscope) observation of the spot-weld cross section. The results show that the nugget diameter can be successfully measured with the accuracy of 0.5 mm. It was found that Ultrasonic c-scan image technique can be sufficiently applied to NDE method for securing the Quality Assurance(QA) of spot welded products in production line.

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