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Development of new inspection technique for spot welds using a matrix arrayed ultrasonic probe

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Abstract

In this paper we have evaluated inspection performance of spot welds using portable TOSHIBA 3D Ultrasonic Inspection Equipment "Matrixeye", which is possible to visualize the welding area within spot welds 3-dimentionally using a matrix-arrayed probe. The matrix-arrayed probe, in which 64 piezoelectric elements are arranged as 8 x 8 matrix arrangement, can acquire more than 4000 ultrasonic echo data within 0.2 second. "Matrixeye" can synthesize 3-dimensional ultrasonic image by SAFT (Synthetic Aperture Focusing Technique) installed in the parallel signal processing board. "Matrixeye" can check the quality of welding with additional data e.g. an averaged diameter, area, Major axis, miner axis, thickness and dip of the welding part. Besides "Matrixeye" has automatic measurement function, in which measurement is automatically starting by sensing the probe contact with the welding surface, and automatically stopping by sensing the position and tilt of the probe within a setting level. The results measured by "Matrixeye" have good correlation with the shearing strength. So, it is applicable to inspection equipment if the spot welding.

Keyword: Ultrasound, Inspection, Matrix-arrayed probe, Spot welding, 3D, UT, SAFT

1. Introduction

Generally X-ray and ultrasonic wave are applied to inspect defects within materials non-destructively. Although conventional ultrasonic inspection methods are relatively easy to use, expertise and experience in the ultrasonic inspection are required to judge the results of ultrasonic inspection[1]. Toshiba's "Matrixeye" is aiming at realizing easy operative inspection equipment without any special knowledge and experience. Toshiba's "Matrixeye" is originated from the inspection technique for the purpose of applying to advanced nuclear power plants[2]. And the original technique was developed to realize the visual inspection for structures without optical visualizing method. After that, 3-dimensional visualization technique, which is realized by a matrix-arrayed probe and SAFT (Synthetic Aperture Focusing Technique) imaging method, had been developed based on the above technique, and had applied to Toshiba's "Matrixeye"[3].

A standard model of Toshiba's "Matrixeye", which is 256 channels type, was launched out at the beginning of 2002. And it has been already applied to the inspection of automobile parts, railroad and in the laboratories. Then in the middle of 2004 a portable "Matrixeye" has come out to the market. The potable "Matrixeye" is 64-channel type hand-carry equipment. A spot welding inspection is the one of application of the potable "Matrixeye". In this paper, especially we introduce the spot welding application and performance of spot welding inspection.

2. Summary of "Matrixeye"

2.1 Outline of "Matrixeye"

Standard model of "Matrixeye" shown in Fig.1 consists of 3D-UT unit, display and operation PC and 256 channel matrix-arrayed ultrasonic probe, so to speak "Ultrasonic Camera". The 3D-UT unit consists of an image processing unit and an electric scanner. An image-processing unit can synthesize 3-dimensional ultrasonic image from ultrasonic echo date acquired by the electric scanner. An electronic scanner control transmission and reception process of the piezoelectric elements arranged within the matrix-arrayed ultrasonic probe. Portable type of "Matrixeye" is shown in Fig.2. It is 64-channel all-in-one type equipment. 10.4-inch liquid-crystal display, Pentium III CPU, parallel processing circuit for 3D image synthesis and 64 channel electronic scanner is installed within the unit. And not only the matrix-arrayed probe but also linear-array probe are applicable. The basic functions of Portable model follow in the standard model. Specification of standard and portable equipments is shown in Table 1.

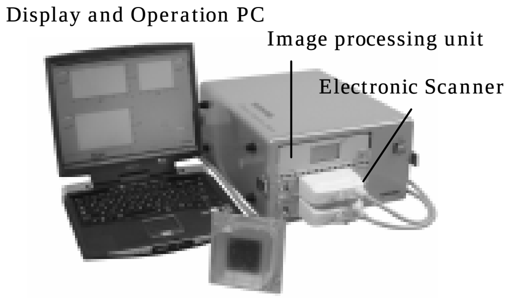


Fig.1 3D Ultrasonic Testing system (256ch)

Fig.2 Portable “Matrixeye”

Table 1 Specification of “Matrixeye”

Item		Spec.	
		Standard type (256ch)	Portable type (64ch)
Equipment	Size	350x200x490mm	350x250x170mm
	Weight	15kg (exclude PC)	7kg
	Display	External PC	10.4” SVGA
	Power	Power Supply 100V AC, 50/60Hz	Power Supply 100V to 240V AC, 50/60Hz
Signal Processing	AD Converter	200MHz(12bit)	100MHz(12bit)
	Processing	64parallel	32parallel
Electronic Scanning	T/R cannel	256ch	64ch
	Pattern of T/R	Any T/R pattern is possible	Any T/R pattern is possible
	Frequency range	2-35MHz(within –3dB)	3-35MHz(within –3dB)
	Range of gain	20-80dB/1dB step	20-80dB/1dB step
	Data acquisition time	< 2sec	< 0.2sec
	Band Pass Filter	Narrow band and wide band can be selected	Narrow band and wide band can be selected
	Driving voltage	-200V	-200V
Others	CPU	External PC	Pentium III
	HD		40GB
	OS		Windows XP
	Other		USBx2, LAN, D-SUB 15pin

As an example of the image, a visualized image of “3D-UT” letter processed from backside of a Plexiglas panel is shown in Fig. 3. “X-Y View” is a perspective plane image from the direction of the matrix-arrayed probe. “Y-Z View” and “Y-Z View” are perspective side views from the directions of side angles which are 90 degree each other. And the above three perspective views can be changed to display slice image within 3D image.

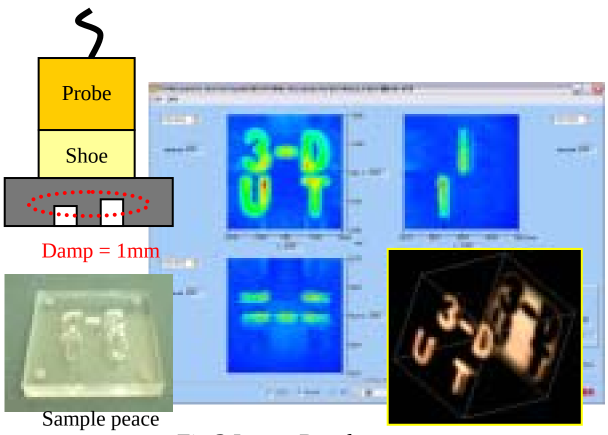


Fig.3 Image Result

The other offline viewer also visualizes a bird's eye view image attached in Fig. 3. As above things, "Matrixeye" can display internal inspection results of metals, resin materials and composite materials as 3-dimentional images more visually than the other conventional inspection method.

2.2 Matrix-arrayed ultrasonic probe (Ultrasonic Camera)

A picture and structural figure of a typical matrix-arrayed probe is shown in Fig. 4. Within the probe 256 piezoelectric elements are installed as a matrix-array arrangement. Each piezoelectric element can transmit ultrasonic waves and receive ultrasonic waves independently. So, it can collect 65,536 (256 transmissions x 256 receptions) ultrasonic echo data. But, usually 8,192 (32 transmissions x 256 receptions) ultrasonic echo data is enough to visualize a good qualified image by "Matrixeye".

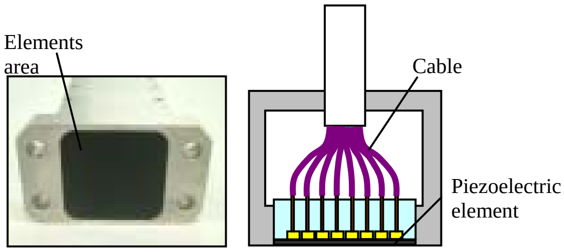


Fig. 4 Matrix array probe

2.3 Image synthetic process

. "Matrixeye" can synthesize 3D image by SAFT (Synthetic Aperture Focusing Technique) imaging method from a large number of echo data acquired by the electro scanner. The acquired echo data include a large quantity of information within the inspection object because the acquired ultrasonic echoes are propagated through many paths within the object.

Summary of 3D image synthetic process is as follows. (In this case, the element's arrangement of the probe is 8 x 8 and elements are shown as P 1, P2,,,,P64.).

(1) Data acquisition processing

(a) Wide-angle ultrasonic waves are transmitted from P1, and its reflected echo is received by all elements. After the moment, the all received echo data are converted and saved as digital data in parallel.

(b) The above process is repeated from P1 transmission to P64 transmission.

(c) The parallel processor within the image-processing unit synthesize 3D image within the objects from the digitized echo data.

(2) 3D image synthetic processing by SAFT (Defect is located at position A)

(a) The amplitude data, extracted from P1-P1 wave data according to a P1-A-P1 flight time T11, is added to the image value within mesh A.

(b) After the above process is repeated from P1-P2 wave data to P64-P64 wave data, the echo peak data of the defect A are added as image data of A with High value as a result

(c) On the contrary, image synthesis of the position without defect. The echo data from this position are a kind of random noise. So, they canceled each other and intensity level of synthesized image is almost zero.

(d) Because of above process, 3D image with good S/N ratio can be visualized.

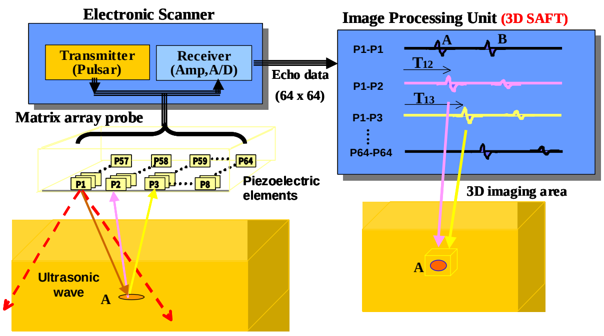


Fig.5 A conceptual architecture of "Matrixeye"

However, calculation load of SAFT 3D imaging process is huge capacity. Usually mare than hundreds million times calculations are required. So, the parallel processing software and hardware is developed for the 3D SAFT imaging in order to realize high-speed processing.

2.4 Sample of 3D imaging

Inspection samples are shown in Fig.5 and Fig.6. Fig.5 shows an image of oxide layer within an aluminum die-casting parts. Fig.6 shows an image of delamination within CFRP (Carbon Fiber Reinforced Plastics).

Sample of Oxide layer within aluminum

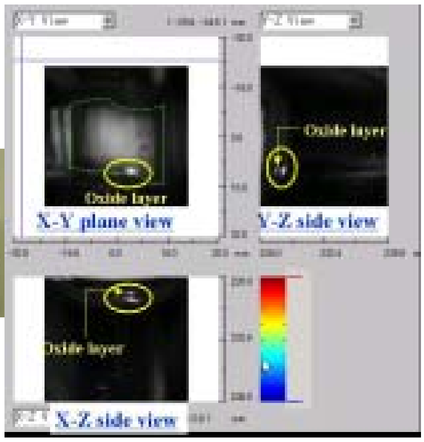


Fig.5 Image of Oxide layer within aluminum

CFRP sample

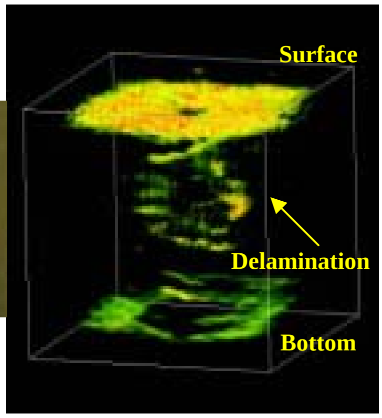


Fig.6 Bird's-eye view of Delamination Defect within CFRP

3. Spot welding inspection

The portable "Matrixeye" for spot welding inspection has an exclusively application for spot welding inspection, be based on above the portable "Matrixeye". The application uses 3 dimensions of images, which are this technical good point freely and output a diameter (it is not a nugget) of a joint and output a state of spot welding with an image and numerical value. In addition, we developed probe exclusively for spot welding and realized miniaturization in spite of being a matrix.

3.1 Matrix-arrayed probe for spot welding inspection

Fig.10 shows the probe, which we developed exclusively for spot welding inspection. And table 2 shows the specifications of the probe. The probe has 64 elements arranged as 8x8 matrix-array, and pitch of elements is 1.5mm. It is possible to visualize within square area of 12 x12mm. In addition, it is possible to use the probe in common for inspecting spot welding with different diameters. We designed to minimize an external size of the probe in order to approach a narrow spot welding area. The shoe is installed on the tip of the probe in order to realize good contact and enough strength. Fig.11 shows three kinds of shoe types. A hard type shoe (a) is applicable to contact with a flat surface of the welding part, and is possible to speedy inspection. A soft type shoe (b) is applicable to contact with a curved surface of the welding part. And a prism type shoe (c) is possible to approach from the side of the welding area.

Fig.10 Probe for spot welding

Table 2 Specification of probe

Item	Spec.
Number of Elements	8x8
Frequency [MHz]	15
Array pitch [mm]	1.5
Element size [mm]	1.0
Case dimension [mm]	16x16(flange: 24) x35

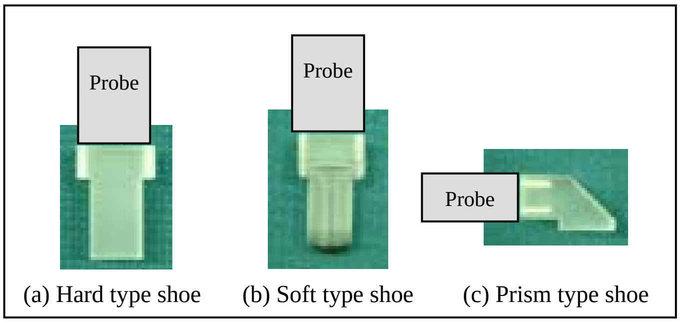


Fig.11 Shoe variation

3.2 A principle of spot welding inspection

Fig.12 shows an image of the spot welding part measured by “Matrixeye”. When spot welding is not good, an ultrasonic echo reflected from by the bottom of the first sheet can be observed. On the contrary, when it is joined well by spot welding, an ultrasonic beam transmits through the joint area, and reflected by a bottom of the welding part. In the displayed cross section slice image, brightness shows the strength of a reflected echo. “Matrixeye” extracts the bottom of welding area (shown within a dotted line), on which joint area’s condition is reflected. “Matrixeye” can calculate a diameter of joint area, and can measures a major axis and a minor axis from the image automatically.

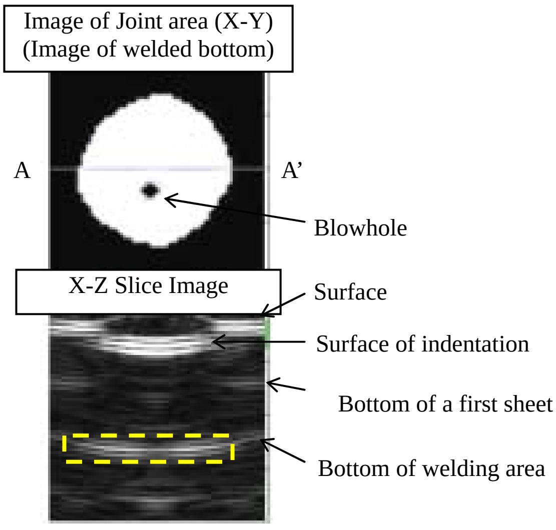


Fig.12 Image of spot weld

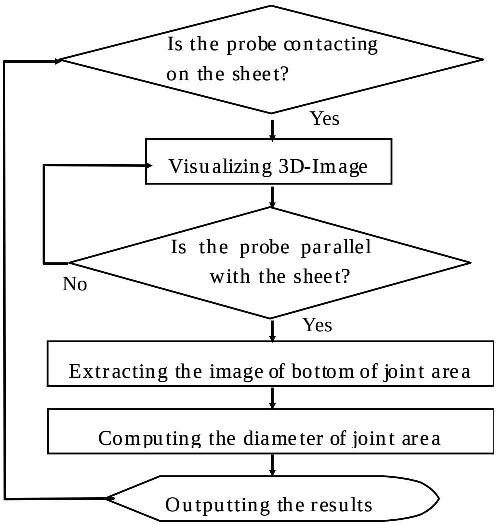


Fig.13 Flowchart

3.3 An operation procedure of spot welding inspection

Fig.13 shows an operation procedure flow of spot welding inspection by “Matrixeye”. In automatic measurement mode, the software within “Matrixeye” judges whether the probe comes in contact with a welding part, and then it start to visualize 3D images. After “Matrixeye” start to visualize the image continuously, the image data are automatically acquired when the probe becomes in parallel with surface of the sheet of the welding part. Then “Matrixeye” extracts bottom image of welding area from 3D image. “Matrixeye” calculates the diameter of joint area from its 3D image, and outputs the other inspection results. All these process are automatic. It is necessary for users only to make adjustments to parallelism from the image. It takes 0.5 seconds to visualize for a 3D image, it is possible to inspect for less than 5 seconds for some inspector who gets used to this inspection.

3.4 Test result

Fig.14 shows an output image of a test result. “Matrixeye” displays an image of a joint area on upper left of the screen, an image of cross section view on the under left, and some numerical value of the inspection result about spot welding status on the screen of right side.   It shows averaged diameter that be calculated from left image in diameter column. “Matrixeye” judges the good or bad by measured diameter and threshold, which is determined by n root of t. (n is set by user, e.g. 4.0. t is thickness of a first sheet.)   And “Matrixeye” outputs not only major axis and minor axis of the joint area from the output image, but also depth of indentation, thickness of weld from the original 3D image automatically.

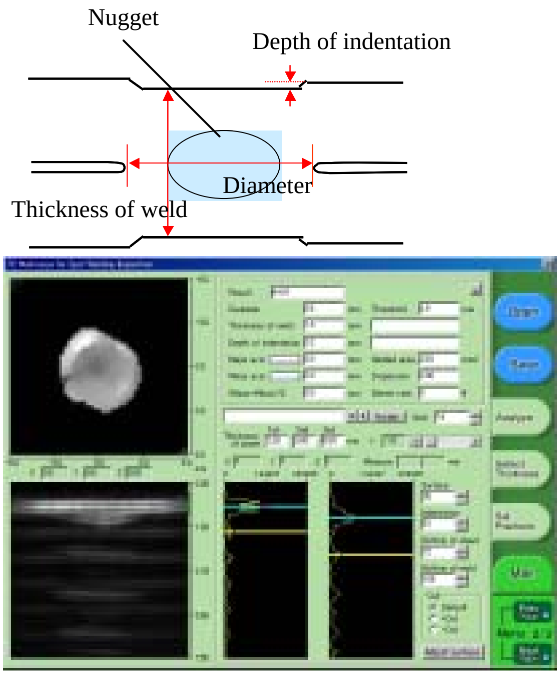


Fig.14   Display of results

4. Result of measurement

4.1 Diameter of Real nugget and test result measured by "Matrixeye"

Table3 and fig.15 shows test results of high-strength-steel spot welding test pieces (2.0mm thick+0.84mm thick) supplied by an automotive manufacturer. Diameters of nuggets are measured by observation after destruction. "Matrixeye" measures diameters from both sides. One side (side 1) is from sheet of 2.2mm; another side (side 2) is from sheet of 0.84mm. When the nugget's size is large, the diameters of joint areas measured by "Matrixeye" and the diameters of real nuggets are good correlation. And the value of "Matrixeye" is equal to it by the measurement from both sides well. But, when the nugget's size is smaller than 2mm, measurement accuracy is worse. The reason, why some deterioration in the range of smaller nugget size occurs, is that "Matrixeye" doesn't measure nugget but corona-bond.

Table 3 Diameter by "Matrixeye" and true diameter

No.	Diameter of Nugget(Distractive measurement) [mm]	Diameter (by Matrixeye)	
		Side1	Side2
1-1	3.9	4.8	4.8
1-2	4.3	4.9	-
2-1	3.8	4.8	-
2-2	3.9	4.8	5.0
3-1	3.7	4.6	4.7
3-2	3.7	4.5	4.6
4-1	3.6	4.4	4.5
4-2	3.6	4.6	-
5-1	4.1	4.2	4.5
5-2	3.4	4.2	4.5
6-1	3.4	4.5	4.2
6-2	3.2	4.4	-
7-1	3.0	4.3	3.9
7-2	3.3	4.7	4.4
8-1	1.1	4.0	3.4
8-2	1.9	3.8	3.6
9-1	0.8	3.8	3.4
9-2	1.2	3.4	3.1

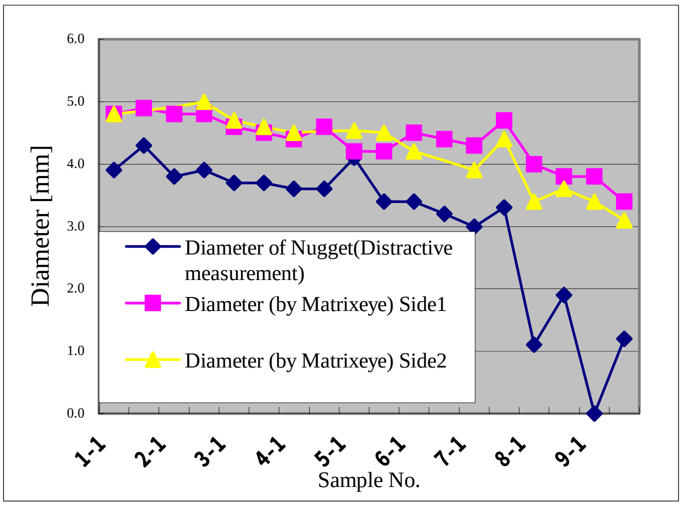
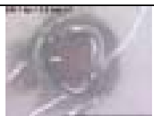
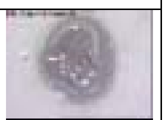
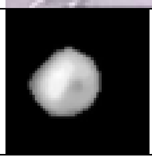
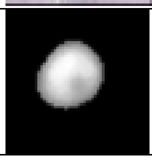
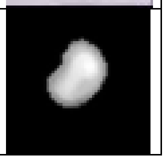


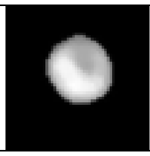
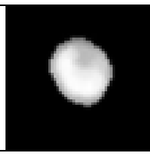
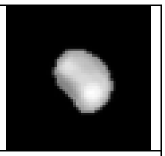
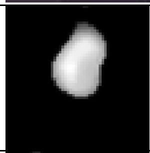
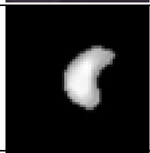
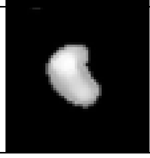
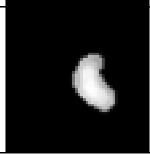
Fig.15 Diameter by "Matrixeye" and real diameter (nugget)

4.2 Results of destructed test and the image by "Matrixeye"

Table.4 shows pictures of the destructed spot welding samples and the images of joint areas visualized by "Matrixeye". It seems that "Matrixeye" can visualize a corona-bond from both sides clearly.

Table 4 Pictures of destructed spot welding samples and measured mages

	No.1	No.3	No.5
Pictures of destructed spot welding samples			
Measured mages (side1)			

Measured mages (side2)			
	No.7	No.9	
Pictures of destructed spot welding samples			
Measured mages (side1)			
Measured mages (side2)			

4.3 Shearing strength and measurement value by "Matrixeye"

Fig.16 shows relation between shearing strength and measurement value by "Matrixeye". It seems to good correlation between shearing strength and measurement value by "Matrixeye".

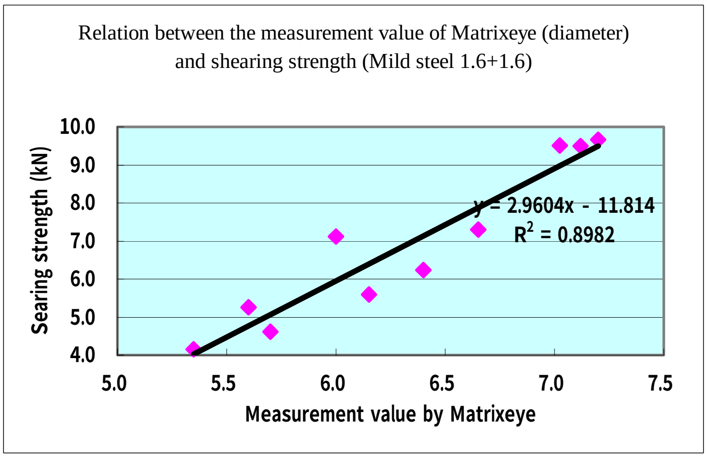


Fig.16 Measurement value by "Matrixeye" and shearing strength

5. Measurement of nugget size

As mentioned above, the measurement with matrix-arrayed probe and its visualization enable the nondestructive evaluation of shape and size of corona bond. However, the nugget size is another important information, which is demanded in the production line. In order to clarify the basic characteristics of nugget, the measurement with a focused probe and immersion method was performed on the special sheet, which is prepared by the grinding of lower sheet of spot weld after removing upper sheet. Fig.17 shows the scanning graphs, or the relation between the scanning position and the amplitude of back wall echo. It is seen that the nugget area indicates a little higher amplitude than that at the surrounding area. When "Matrixeye" is applied to this plate, a same result is also obtained, as shown in Fig.18. This means that nugget size and shape can be evaluated by ultrasonic testing with focused probe or matrix-arrayed probe, although the amplitude at the nugget shows different change from the one reported in the measurement based on the multiple reflections.

Fig.19 shows one example of nugget shape obtained from the measurement of spot welds with focused probe.

Fig 17 Scanning graphs of single plate with fusion area (nugget)

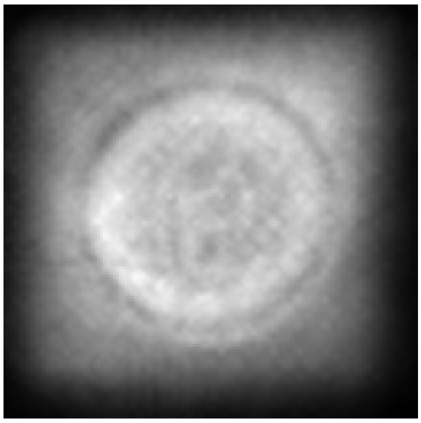
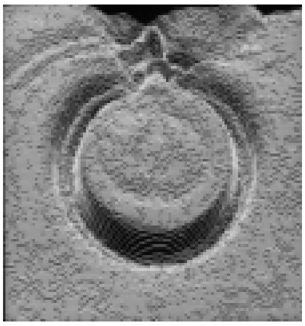
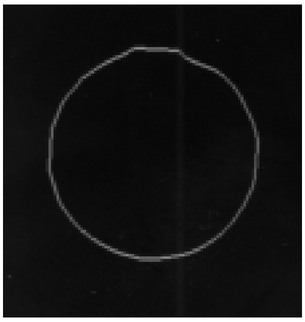


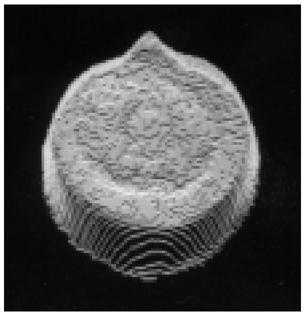
Fig.18 Image of fusion area (nugget)



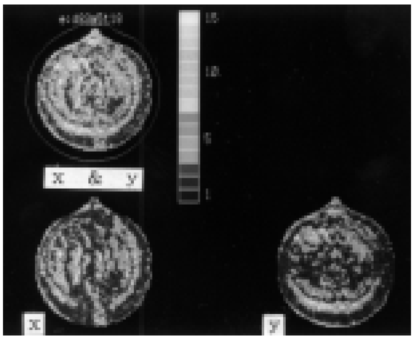
(a) Scanning graph



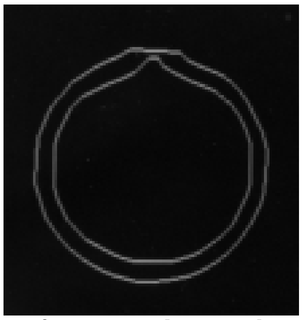
(b) Boundary of corona bond



(c) Scanning graph in corona bond



(d) Gradient distribution in corona bond area



(e) Shape of nugget and corona bond

Fig.10 Shape of nugget and corona bond

This shape is obtained as follows. First, the boundary of corona bond is determined as the lower area in the scanning graphs. Next, two orthogonal gradients of scanning graph are calculated in the corona bond area. Since the gradient has the limited values at the boundary of nugget, the boundary of nugget is given by the potion with the limited values of gradient. The extracted shape and size of nugget are confirmed by the destructive test, which shows well agreement.

6. Future Development

We developed the spot welding inspection technique using 3-dimensional visualizing technique and matrix-arrayed probe technique. And we confirmed that this new inspection technique could be applicable to automatic spot welding inspection system “Matrixeye”. In the future development, we will improve the inspection algorithm using 3D SAFT imaging data and optimize the matrix arrayed probe technology for achieving more accurate and more robust inspection of spot welding. It has a possibility to integrate the automatic inline inspection system using a robot technology.

REFERENCES

1) S. Satonaka, T. Takashima, K. Terada, T. Nishiwaki, Y. Kohno: Ultrasonic Evaluation of Fusion and Solid-Phase Bonding in Spot Welds, IIW Doc. No. III-1045-95(1995).
2) Hirokazu Karasawa, Mamoru Izumi, Takehiko Suzuki, Satoshi Nagai, Masaaki Tamura, Shyuuichi Fujimori: Development of under sodium 3D visual inspection technique by using matrix-arrayed ultrasonic transducer, Journal of Nuclear Science and Technology, vol.37, No.9. pp.769～779, September 2000.
3) Abe Motohisa, Hirokazu Karasawa, Matrixeye Portable 3D Ultrasonic Inspection System, TOSHIBA REVIEW Vol.60, No.4, 2005, PUBLISHED by TOSHIBA CORPORATION.