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Development of New Apparatus to Evaluate Ultrasonic Reflection Characteristic for Wrinkling in Press Forming

YUJI SEGAWA[1], **TAKUYA KURIYAMA**[2], **YASUO MARUMO**[3], **TAEKYUNG LEE**[4], **YASUHIRO IMAMURA**[5], **TOMOHIRO NONAKA**[6] **AND YUTAKA SAKATA**[7]

[1]Department of Mechanical Engineering, National Institute of Technology, Miyakonojo College, 473-1, Yoshio-cho, Miyakonojo, Miyazaki 885-8567, Japan.

[2]Graduate School of Science and Technology, Kumamoto University, 2-39-1, Kurokami, Chuo-ku, Kumamoto 860-8555, Japan.

[3]Faculty of Advanced Science and Technology, Kumamoto University, 2-39-1, Kurokami, Chuo-ku, Kumamoto 860-8555, Japan

[4]Magnesium Research Center, Kumamoto University, 2-39-1, Kurokami, Chuo-ku, Kumamoto 860-8555, Japan

[5]Technical Division, Faculty of Engineering, Kumamoto University, 2-39-1, Kurokami, Chuo-ku, Kumamoto 860-8555, Japan

[6]Department of Integrated System Engineering, Nishinippon Institute of Technology, 1-11, Aratsu, Kanda-machi, Miyako-gun, Fukuoka 800-0344, Japan.

[7]Department of Integrated System Engineering, Nishinippon Institute of Technology, Japan

Email: *y_segawa@cc.miyakonojo-nct.ac.jp, marumo@mech.kumamoto-u.ac.jp, t-lee@mech.kumamoto-u.ac.jp, nonaka@nishitech.ac.jp, ysakata@nishitech.ac.jp*

Abstract: *It is difficult to completely prevent the formation of defects in metal press forming, unless inspecting the entire products. This study suggests an in-process inspection using an ultrasonic measurement in order to avoid such a problem. This method is effective for detecting wrinkles formed in a material during the process. A numerical analysis clarified the relationship between wrinkle shapes and the reflection behaviour of ultrasonic waves. In this study, we developed an experimental apparatus that provided quantitative data explaining the relationship between ultrasonic reflection intensity and the wrinkle shapes. The die of the developed apparatus was in sufficient contact with the specimen machined into the wrinkle shape. The ultrasonic reflection characteristics varied by the wrinkle characteristics.*

Keywords: *press forming, defect detect, wrinkle, in-process, ultrasonic measurement*

Introduction

Press forming is a processing method for a mass production while maintaining a constant quality. The investigation of defects, such as wrinkles on the material surface, in press-formed products has been one of the most important issues for manufacturers. In general, the sampling inspection method is adopted considering the cost in the industry. However, these methods often miss the outflow of defective products except for the investigation samples. Although there have been a number of studies thus far (Katayama et al. [1], Koga et al.[2], it is still difficult to prevent the defects completely as various factors and complex relationship are related to the formation of defects.

To solve such a problem, researchers have suggested an in-process monitoring of defects using various types of sensors. For example, Traversin and Kergen [3] controlled blank-holder force using various sensors embedded in the die. Siegert et al. [4] embedded displacement transducers in the upper and lower binders in order to measure a wrinkle height required for a closed-loop control of a press forming. Doege et al. [5] performed a contactless online measurement of the material flow with an optical sensor in a die. Yang et al. [6] utilized AE sensors to detect the position of friction sources during a press forming. Lo and Yang [7] developed new embedded-type displacement sensors that enabled the closed-loop control of blank-holder force. Mahayotsanum et al. [8] achieved the optimization of process management with a draw-in sensor. Nonaka et al. [9] successfully detected a scrap-jumping in a pierce processing using a fibre line-laser sensor.

Among a number of suggested approaches, the in-process measurement using the ultrasonic wave has been reported by Saiki et al. [10][11], Stancu-Niederkorn et al. [12] and Hagino et al. [13] to be effective for monitoring the contact state between a tool and workpiece. According to the work of Nonaka et al. [14], the ultrasonic measurement using die-embedded probe successfully detected wrinkles generated during a press forming.

The relationship between the wrinkles and ultrasonic reflection characteristics must be clarified to introduce this method into the actual manufacturing process. Numerical analysis can be a good tool for resolving such problems. Finite difference time domain (FDTD) method (Yee [15]) was developed to analyse the

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electromagnetic field. Recently, the FDTD method has been effectively used for the elastic wave analysis (Satyanayan et al. [16], Hagino et al. [17], Jinno et al. [18]). We visualized the propagation and reflection behaviour of ultrasonic waves in a sample containing periodic wrinkles using the FDTD method (Segawa et al. [19]).

This work developed an experimental apparatus to clarify the relationship between the wrinkles and ultrasonic reflection characteristics. The obtained data from this apparatus were compared to those calculated from a numerical analysis, providing the reliability of the apparatus. Then, operational checks and the ultrasonic measurement were performed using the developed experimental apparatus.

Principle and Estimation

The wrinkles in the present samples were detected based on the ultrasonic reflection intensity I defined as the maximum amplitude of reflected wave. The ultrasonic reflection intensity is affected by the contact state of two media in contact with each other. Fig.1 shows the relationship between the reflection intensity and the contact state of die and workpiece. I_0 is the reflection intensity at the contact state between the upper die and air, which always shows the highest value. The reflection intensity decreases as the contact area with the workpiece is increased. In this experiment, the wrinkle is evaluated by a relative reflection intensity I/I_0.

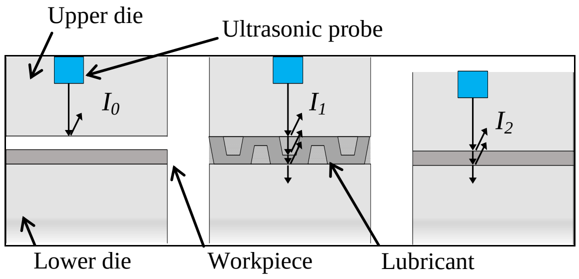


Fig.1 *Variation in reflection intensity with the conditions of wrinkles* ($I_0>I_1>I_2$)

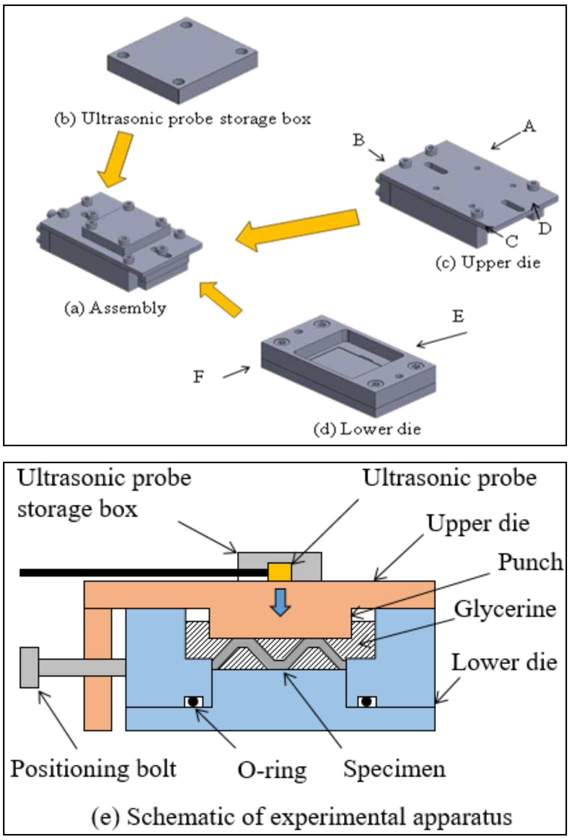
Experimental Apparatus

Fig.2 shows the structure of developed experimental apparatus. The apparatus is composed of three parts made of S50C steel: the ultrasonic probe storage box, the upper die and the lower die. These components were then assembled by bolting, as shown in Fig.2(a). Glycerine was used because it easily flowed into the narrow space formed by the wrinkled structure.

The ultrasonic probe storage box was manufactured to fix the position of the ultrasonic probe. A groove for setting the ultrasonic probe was provided on the lower surface of the box. A rubber plate was sandwiched between the groove and the upper surface of ultrasonic probe. The rubber plate was designed to be larger than the gap between the groove and ultrasonic probe in order to apply the elastic force, providing a sufficient contact between the probe and the upper die. Glycerine was also applied to this area. The probe frequency was 2.25 MHz.

The upper die consisted of four components, viz., A, B, C and D. The upper die A contained a punch with a height of 30 mm considering that the irradiation distance of ultrasonic wave was larger than the near field length for all frequencies used in the present study. Vertical and horizontal dimensions of punch were set to be 60 mm and 50 mm, respectively, in order to avoid affecting the ultrasonic propagation. The lower surface of the upper die was grinded to obtain the sufficient contact with the specimen. The grooves for bolting were provided to fix the upper and lower dies in the upper die A. These grooves were machined to respond the lateral movement of the lower die. Four screw holes in the centre of the upper die A were provided for fixing the ultrasonic probe storage box. Four bolts in the corner of the upper die assembled the upper dies A-D.

The lower die was composed of two components of E and F integrated by bolting. The groove was also fabricated for fixing the specimen and receiving the glycerine lubricant in the lower die. As a result, the gap between the specimen and die could be filled with glycerine during the entire experimental process.



(e) Schematic of experimental apparatus

Fig.2 *Experimental apparatus*

The O-ring was placed on the lower surface of lower die E to prevent glycerine from leaking out of the gap between the lower die E and F. Finally, we prepared three types of the lower die F with different heights considering the wrinkle height used in this work. The positioning bolt in Fig.2(e) is passed through the upper die B. The positioning bolt moves the lower die laterally. The moving direction of the lower die is constrained by the upper die C and D when the lower die is moved. Consequently, the movement of the ultrasonic irradiation position can be performed accurately by the positioning bolt, the upper die C and D. The gap between the upper and lower dies to place specimens, shown in Fig.2(e), was set to be 5% lower than the height of specimen to tightly bind the die and specimen.

Fig.3 shows peripheral equipment connected to the developed experimental apparatus. A pulsar receiver performed the transmission and reception of ultrasonic waves through the ultrasonic probe. The ultrasonic wave was then displayed on the oscilloscope, of which the data were recorded by the computer.

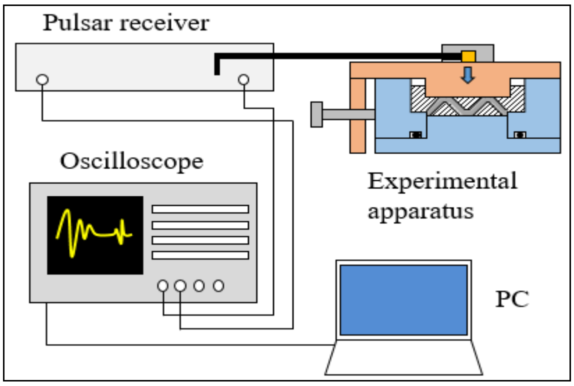


***Fig.3** Experimental apparatus and peripheral equipment*

Specimen

Fig.4 shows the scheme of the specimen used in the present work. The specimen was made of A1050 pure aluminum. The wrinkles of specimen were produced in the trapezoidal shape by the electro-discharge machining. The surface roughness of the specimen was increased from 0.14 μm to 3.36 μm after this process.

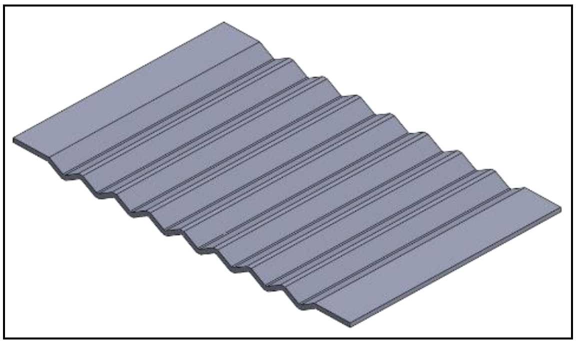


***Fig.4** Scheme of specimen*

Fig.5 describes the shape parameters for periodic wrinkle including a specimen thickness t_w, wrinkle height h, wrinkle slope angle α, contact width c_w and wrinkle wavelength λ_w. Thirteen different specimens were prepared with various shape parameters, of which the ranges are summarized in Table 1. The contact width c_w was fixed to be 1.0 mm for all cases.

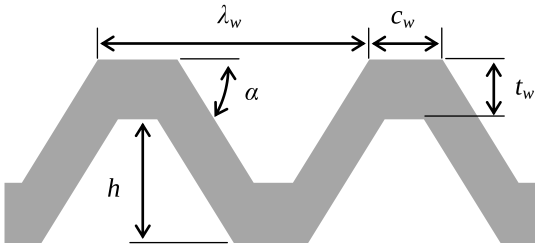


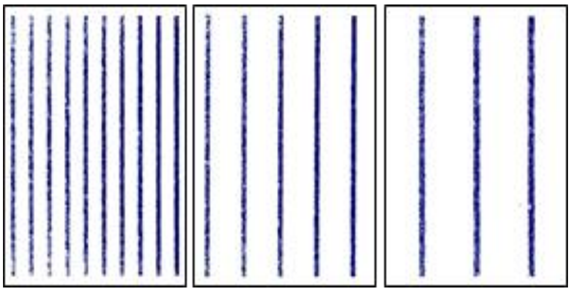
***Fig.5** Shape parameters for periodic wrinkle*

***Table 1**. Specimen dimensions*

t_w [mm]	1.0-2.0
h [mm]	0.5-2.0
α [deg]	5.60-36.87
λ_w [mm]	4.0-12.0

Contact between the Upper Die and Specimen

The experiment was performed to confirm the contact between the upper die and the specimen using a pressure-sensitive paper made by ARUFUN. This paper was sandwiched between the upper die and the specimen. The contact area between the upper die and the specimen was transferred to this paper when the experimental apparatus was assembled. Fig.6 shows the contact areas between the upper die and specimen transferred to the pressure-sensitive paper, suggesting that the upper die and the specimen were contacted sufficiently. Sufficient contacts were also obtained for the other specimens considering the clear pattern printed on the pressure-sensitive papers. These results demonstrated that the method of setting the gap between the upper die and lower die are effective to control the contact between the upper die and specimen.



(a) (b) (c)

***Fig.6** Contact areas between upper die and specimen transferred on pressure-sensitive paper, (a)λ_w= 4.0mm, (b) λ_w= 8.0mm and (c) λ_w= 12.0mm*

Ultrasonic Measurement

Fig.7 shows a reflected wave measured from the specimen, which varied by the contact state between the die and specimen. The amplitude of the reflected wave represented the magnitude of the reflection intensity. Fig.8 shows the results of ultrasonic measurement under different contact conditions on the bottom surface of upper die. The presented values were determined by averaging the maximum amplitudes obtained from hundred times of measurements. I/I_0 was 0.908 in contact with glycerine. The measured reflection rate (92%) was consistent with the theoretical value (90%). I/I_0 was slightly decreased to 0.810 in contact with the wrinkled specimen, while the value was more reduced to 0.738 with the flat plate produced by the electro-discharge machining. The acoustic impedance was decreased in the order of S50C steel, A1050 aluminium, glycerine and air. The reflection of the ultrasonic wave was increased with increasing difference in the acoustic impedances, providing the validity of the trends shown in Fig.8. It is concluded from these results that the developed experimental apparatus could successfully measure the difference in reflection intensity caused by the presence or absence of wrinkles.

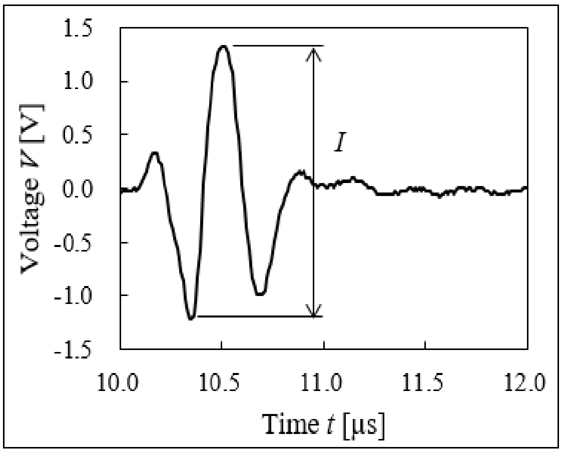


Fig.7 *Reflected wave measured at tw= 2.0mm, h= 0.5mm, α= 9.00deg and λ_w= 8.0mm*

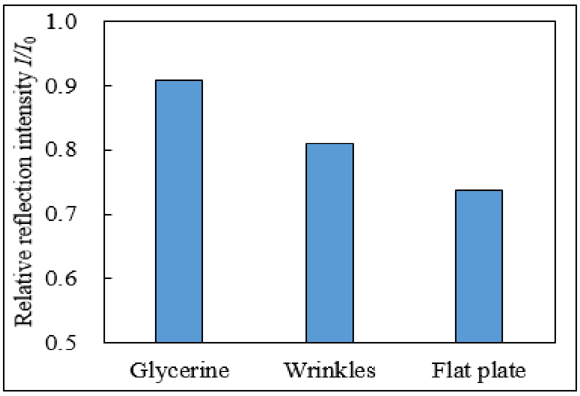


Fig.8 *Comparison between contact states and relative reflection intensity (Parameters of wrinkles are tw= 2.0mm, h= 0.5mm, α= 5.60deg and λ_w= 12.0mm)*

I_0 varied from 0.1 to 0.2 during repetitive experiments. Such scattered data would result from the change in the contact state between the ultrasonic probe and the upper die. The reflection intensity also varied. These results are likely attributed to the glycerine lubricant leaking out of the groove in the ultrasonic probe storage box when the upper die was tilted. Therefore, the experiment using the developed apparatus should be performed under the condition that fixes the upper die horizontally.

Fig.9 shows the change in I_0 with time immediately after embedding the ultrasonic probe in the upper die and fixing this part horizontally. I_0 exhibited a suppressed scattering within a deviation of 0.02 after one minute from commencing the experiment; note that the deviation was 0.1 before applying the horizontal condition, suggestive of the importance of horizontal calibration of the upper die. However, it is noted that I_0 was radically increased in the initial stage (i.e., the first one minute) of the experiment. This could arise from the flow of glycerine between the ultrasonic probe and the upper die. It is thus strongly recommended to avoid the unreliable data obtained immediately after installing the ultrasonic probe.

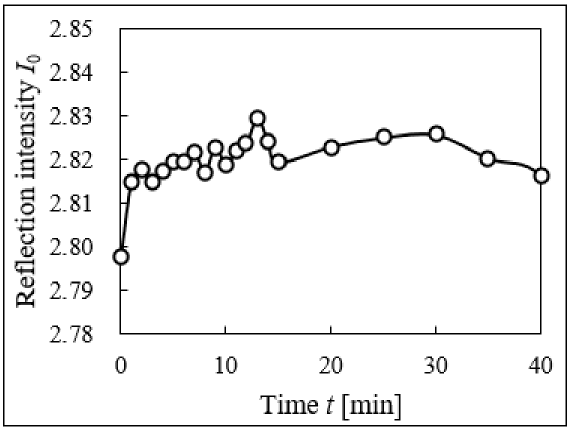


Fig.9 *Relationship between reflection intensity I_0 and time after assembling ultrasonic probe*

Conclusions

The experimental apparatus was developed to reproduce the FDTD analysis model, of which the operational checks were performed. The following conclusions were drawn from this work:

- The die and specimen showed a sufficient contact when assembled in the developed experimental apparatus.
- The developed apparatus successfully distinguished the difference in reflection intensity induced by the presence or absence of wrinkles, proving its ability of evaluating the relationship between the wrinkle shape and the ultrasonic reflection characteristic.
- The experiment should be performed at least one minute after embedding the ultrasonic probe in the upper die to obtain reliable data.

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References

[1] Katayama, T., Nakamachi, E., Nakamura, Y., Ohata, T., Morishita, Y., Murase, H. “Development of process design system for press forming—multi-objective optimization of intermediate die shape in transfer forming”, Journal of Materials Processing Technology, 155-156, PP.1564-1570, 2004.

[2] Koga, N., Asaka, M., Junlapen, K. “Deep-drawing and ironing of 1050 aluminum sheets loaded with vibration using NC servo press machine”, Journal of Japan Institute of Light Metals, 57 (6), PP.240-244, 2007 (in Japanese).

[3] Traversin, M., Kergen, R. “Closed-loop control of the blank-holder force in deep-drawing: finite-element modelling of its effects and advantages”, Journal of Materials Processing Technology, 50 (1), PP.306-317, 1995.

[4] Siegert, K., Ziegler, M., Wagner, S. “Closed loop of the friction force. Deep drawing process”, Journal of Materials Processing Technology, 71 (1), PP.126-133, 1997.

[5] Doege, E., Seidel, H.-J., Griesbach, B., Yun, J.-W. “Contactless on-line measurement of material flow for closed loop control of deep drawing”, Journal of Materials Processing Technology, 130-131, PP.95-99, 2002.

[6] Yang, M., Manabe, K., Hayashi, K., Miyazaki, M., Aikawa, N. “Data fusion of distributed AE sensors for the detection of friction sources during press forming”, Journal of Materials Processing Technology, 139 (1), PP.368-372, 2003.

[7] Lo, S.-W., Yang, T.-C. “Closed-loop control of the blank holding force in sheet metal forming with a new embedded-type displacement sensor”, The International Journal of Advanced Manufacturing Technology, 24 (7), PP.553-559, 2004.

[8] Mahayotsanun, N., Sah, S., Cao, J., Peshkin, M., Gao, R. X., Wang, C.-T. “Tooling-integrated sensing systems for stamping process monitoring”, International Journal of Machine Tools & Manufacture, 49 (1), PP.634-644, 2009.

[9] Nonaka, T., Sakata, Y., Marumo, Y., Okinishi, Y., Horinouchi, T., Ogawa, I., Watanabe, S. “Development of Detection Technology of the Scrap-Jumping in Pierce Processing”, Applied Mechanics and Materials, 182-183, PP.472-476, 2012.

[10] Saiki, H., Sakata, Y., Satonaka, S., Marumo, Y., Zhan, Z. H. “Estimation of Contact Conditions of Frictional Interface in Forging Processes Using Ultrasonic Examination”, Transactions of the Japan Society of Mechanical Engineers, Series C, 59 (562), pp.1934-1939, 1993 (in Japanese).

[11] Saiki, H., Sakata, Y., Marumo, Y., Zhan, Z. H. “Estimation of frictional shearing stress under lubricated contact conditions in ring upsetting (application of ultrasonic examination)”, Transactions of the Japan Society of Mechanical Engineers, Series C, 60 (577), PP.3171-3176, 1994 (in Japanese).

[12] Stancu-Niederkorn, S., Engel, U., Geiger, M. “Ultrasonic Investigation of Friction Mechanism in Metal Forming”, Journal of Materials Processing Technology, 45 (1), PP.613-618, 1994.

[13] Hagino, N., Endou, J., Katoh, S., Ishihama, M. “Reflection and Transmission Characteristics of Ultrasonic Waves in Flat Surface Die - Visualization of Contact Conditions between Die and Workpiece During Stamping 1-”, Journal of the Japan Society for Technology of Plasticity, 54 (632), PP.826-830, 2013 (in Japanese).

[14] Nonaka, T., Sakata, Y., Marumo, Y., Okinishi, Y., Horinouchi, H., Ogawa, I., Watanabe, S. “Application of Sensors to In-Process Defect Detection in Sheet Forming”, Steel Research International, Special Edition, PP.387-390, 2012.

[15] Yee, K. S. “Numerical Solution of Initial Boundary Value Problems Involving Maxwell’s Equations in Isotropic Media”, IEEE Transactions on Antennas and propagation, 14 (3), PP.302-307, 1966.

[16] Satyanarayan, L., Sridhar, C., Krishnamurthy, C. V., Balasubramaniam, K. “Simulation of ultrasonic phased array technique for imaging and sizing of defects using longitudinal waves”, International Journal of Pressure Vessels and Piping, 84 (12), PP.716-729, 2007.

[17] Hagino, N., Endou, J., Ishihama, M., Komiya, S., Katoh, S. “Propagation behavior of ultrasonic wave around boundary surfaces of workpieces and dies”, Procedia Engineering, 81, PP.1073-1078, 2014.

[18] Jinno, K., Sugawara, A., Ohara, Y., Yamanaka, K. “Analysis on Nonlinear Ultrasonic Images of Vertical Closed Cracks by Damped Double Node Model”, Materials Transactions, 55 (7), PP.1017-1023, 2014.

[19] Segawa, Y., Miyazaki, Y., Marumo, Y., Imamura, Y., Nonaka, T., Sakata, Y. “Analysis of Ultrasonic Wave Reflection for Wrinkle Shapes of Press-formed Products Using FDTD Method”, The Proceedings of the 2016 Japanese Spring Conference for the Technology of Plasticity, PP.53-54, 2016 (in Japanese).