International Journal of Engineering Innovation & Research
Volume 5, Issue 4, ISSN: 2277 – 5668

Ultrasonic Inspection of DP Steel Joints Made by EBW

Hodúlová Erika, Kovaříková Ingrid, Šimeková Beáta

***Abstract* – As an electron beam welding of duplex stainless steels offers a variety of advantages over traditional welding processes. Problems that are typically occurring due to the cooling is the ratio of ferrite and austenite, such as solidification cracking and formation of porosity. Ultrasonic non-destructive testing can be used for quality assessment of EBW duplex steel joints. In this paper, a novel approach for the detection of defect is proposed using a suitable ultrasonic testing method without the scattering and refraction in austenite.**

***Keywords* – Non-destructive Inspection, Duplex Steel, Ultrasound Inspection, Austenite.**

I. Introduction

Duplex steels are nowadays the very often used construction materials in different industries. DP is a dual phase steel, the structure is formed of ferrite and austenite. The ratio of austenite and ferrite 50/50% provides good mechanical properties and good corrosion resistance in particular [1-3]. The joining of these steels are currently often provide by using the concentrated energy beam welding (LW and EBW). These processes allow to create a deep and narrow welds with a very narrow HAZ, to form a minimum deformation of welded materials [4-7]. The EBW method is not required the using of filler material for joining, weld gap is very small and it creates the narrow weld. The problem is the rapid cooling of the weld after welding, thereby the structure of the weld is forming by ferrite, which amount may be up to 60-90%. This is already provided by the application of weld heating after welding process, to achieve ferrite ratio of 40-50% (8-10). By using the incorrect welding parameters it indicates a lack of root filling with molten metal, which often causes the formation of cavities in the weld root. However the non-destructive inspection of duplex and superduplex steels is a big challenge as those steels, being composed of ferrite and austenite, have some particularities. When using ultrasound, for instance, its waves propagate well in ferrite, but suffer strong attenuation, scattering and refraction in austenite. This paper describes the ultrasound testing of weld joints made by EBW. The aim is to propose the concrete ultrasound method for DP steel welds testing [10-12].

II. Experiments

Prepared samples were welded by EWB method with the following parameters: welding voltage - 55kV, welding current - 45 mA, welding speed - 10mm.s^{-1}, focusing current - 585 mA and the welding position - PA. Dimensions of the sample was 200 x 200 x 5 mm.

The detection of internal indications in weld joints was performed by ultrasound reflection method. It was used the ultrasound equipment Olympus Epoch LTC with 4MHz probe and angle of 70 °.

As the second method was used Phased Array ultrasound testing method. The measurement was performed by Olympus OmniScan MX2 with 10 MHz probe PA10L16-A00 (Table I).

Table I Parameters of ultrasound scanning

	Classic UT method	PA
Probe frequency	4 MHz	10 MHz
Probe /Wedge angle	70°	39°
Gain	66 dB	66 dB
Sound Velocity	5960 m/s	3100 m/s

Calculation minimum defect dimension, which can be measured by Phased Array probe with a frequency of 10 MHz in homogeneous material with fine-grained structure:

$$\lambda/2 = \frac{c}{f}/2 = \frac{3100 \text{ m/s}}{10\ .\ 10^6 \text{ Hz}} = 0{,}31/2 = 0{,}155 \text{ mm} \qquad (1)$$

III. Results And Discussion

Testing of samples by using the Olympus UT Epoch LTC equipment with the probe of 70° despite a various changes of parameters, it was difficult to obtain the useful results.

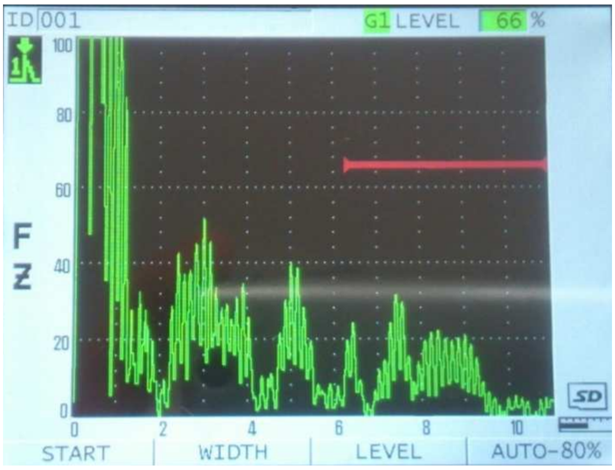

Fig. 1. Olympus EPOCH LTC scan report

The problem is in the dimension of austenite grains, and when using the classical probe the ultrasound beam is breaking at the grain boundaries, to obtain a noise results due to the structure of the material (Fig. 1).

Based on this knowledge was used the Phased Array ultrasound testing method.

The sample was testing by using the angle PA probe at a frequency of 10 MHz. In the weld the internal defects are not presence, also the testing by using the greater sensitivity probe no indicate the defects just the external defect was detected by the using a transverse ultrasonic waves of 3100 m/s and 40 dB amplification (Fig. 2). Using of 10 MHz frequency probe during the testing shows the worse ratio of signal/noise ratio because the austenitic grain size.

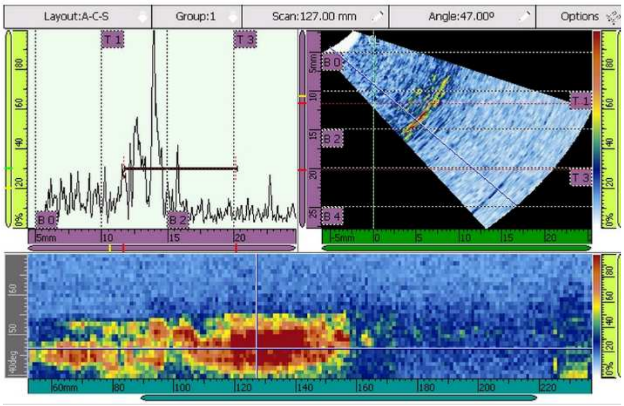

Fig. 2. Phased Array A-C-S scan with the 10 MHz probe

IV. Conclusion

The ultrasound testing was performed on samples from duplex stainless steel joined by electron beam welding. The test was performed by ultrasound testing equipment Olympus Epoch LTC using an angular probe 4 MHz with an angle of 70°. This method of ultrasound testing does not provide useful results due to the ferrite - austenite structure of duplex steel, which indicates the false defect causes by the refraction of the ultrasound beam at the austenite grain borders. The high noise was noted and also with changing parameters of the device cannot be distinguished initial, defect and end echo from noise. The results show, that the classical ultrasonic testing with fixed angle probe of 70 ° cannot be used for testing of this type of material. The grain size of the structure is very difficult for the ultrasound scanning by classic angular probe with a fixed angle from the view of probe sensitivity, therefore was choose based the Phased Array method, which achieves better S/N ratio. The Phased Array ultrasound testing method was carried out by Olympus OmniScan MX2 device with angular probe with a frequency of 10 MHz. The sample were tested with a probe of 10 MHz frequency, with no internal defects in the weld was found, the probe experienced external defect the not fully melted weld root, and at a probe frequency of 10 MHz can be seen considerable amounts of noise from the austenitic grains of the material structure. The Phased Array testing method is suitable for the weld joints defects detection in case of the shorter length of defects as the probe aperture. If the length of the defect aperture is shorter than the probe, it may be from a linearscan (no motion sensor) to detect a possible increase of the defect dimensions earlier and more accurately than manually by measuring the height and length of the defect from the probe move on the surface. The sectorial B-scan can be relatively easily on the basis of local color differences to identify even small defects and diffraction echoes that are in A-scan difficult to distinguish from noise.

Appendix

We thank to SlovCert Ltd. company for support and help at the realisation of the experiments.

Acknowledgment

This research is supported by VEGA Grant No. 1/0481/14 and APVV-0248-12 which are supported by Slovak Republic Ministry of Education.

References

[1] N. Ruiz-Reyes, P. Vera-Candeas, J. Curpián-Alonso, J.C. Cuevas-Martínez, J.L. Blanco-Claraco: "High-resolution pursuit for detecting flaw echoes close to the material surface in ultrasonic NDT", Original Research Article, NDT & E International, Volume 39, Issue 6

[2] Kučík P., Kováčik, M., Hyža, R. "Practical using of ultrasonic probes in energy industry", www.ndttrade.cz, 2014

[3] R. Regazzo, M. Regazzo "Ultrasound – basics of ultrasonic defectoscopy", 2013, ISBN 978-80-7300-466-8

[4] D. Kanzler, C. Műller, J. Pitkänen "Probability of Defect Detection of Posiva's Electron Beam Weld" http://www.posiva.fi/en/databank/working_reports/probability_of_defect_detection_of_posiva_s_electron_beam_weld.1874.xhtml?xm_col_type=5&cd_offset=32#.VHS6cIuG8gU

[5] D. Stegemann, B. Raj, AK. Bhaduri "NDT for Analysis of Microstructures and Mechanical Properties of Metallic Materials", Reference Module in Materials Science and Materials Engineering, 2016

[6] Lingyu Yu, Zhenhua Tian "Guided wave phased array beam forming and imaging in composite plates", Ultrasonics, Volume 68, May 2016, Pages 43-53

[7] G.H. Kim, at all "Qualification of phased array ultrasonic examination on T-joint weld of austenitic stainless steel for ITER vacuum vessel", Fusion Engineering and Design, 2016

[8] [8] HODÚLOVÁ, Erika - KOVAŘÍKOVÁ, Ingrid [Sukubová, Indrig] - ŠIMEKOVÁ, Beáta - ULRICH, Koloman. Ultrasonic inspection of thin duplex steel weld joints by TOFD. In Applied Mechanics and Materials. Vol. 752-753. (2015), s. 584-587. ISSN 1660-9336.

[9] Léonard Le Jeune, Sébastien Robert, Eduardo Lopez Villaverde, Claire Prada: Plane Wave Imaging for ultrasonic non-destructive testing: Generalization to multimodal imaging, Ultrasonics, Volume 64, January 2016, Pages 128-138

[10] H.-J. Krause, G.I. Panaitov, Y. Zhang: SQUIDS: Nondestructive Testing, Reference Module in Materials Science and Materials Engineering, 2016, Current as of 28 October 2015

[11] Marie-Aude Ploix, Philippe Guy, Bertrand Chassignole, Joseph Moysan, Gilles Corneloup, Rachid El Guerjouma: Measurement of ultrasonic scattering attenuation in austenitic stainless steel welds: Realistic input data for NDT numerical modeling, Ultrasonics, Volume 54, Issue 7, September 2014, Pages 1729-1736

[12] B. Chassignole, R. El Guerjouma, M.-A. Ploix, T. Fouquet: Ultrasonic and structural characterization of anisotropic austenitic stainless steel welds: Towards a higher reliability in ultrasonic non-destructive testing, NDT & E International, Volume 43, Issue 4, June 2010, Pages 273-282

AUTHORS' PROFILES

First A. Author
Erika Hodúlová (female, 29.06.1978, Slovakia) is a scientific and research employee of Slovak University of Technology, Faculty of Materials Science and Technology since May 2003. She received her PhD. (2007) in Machining Technologies and Materials, in research of lead-free solder joints interface and she received her associated professor – doc. (2013) in research of application of lead-free solders in soldering process. During her practice at the Faculty she was actively involved in solution of several scientific projects as VEGA, APVV and from 2010-2011 she was a principal investigator in a VEGA project dealing with brazing/soldering. Also she has the experience with the international projects, she is currently the principal investigator of two bilateral projects between Slovakia - Portugal and Slovakia – China. She has been registered in many professional databases, while the most significant case seems to be her registration as the Delegate and Chair Person in IIW (International Institute of Welding) commission XVII „Brazing, soldering and diffusion welding“, sub-commission XVII-C „Soldering“ and expert in Commission IV- Power Beam Processes and Commission V – Non-destructive Testing and Quality Assurance of Welded Products. In 2014 she presented on NMJ 2014 – International Conference on Nano-Joining and Micro-Joining in Switzerland her required presentation: “Reliability of Lead-free Solder Joints in Microelectronics“. She is a co-author of several CC publications and reviewer for Journal of Alloys and Compounds and Welding in the World.

Second B. Author
Ingrid Kovaříková (female, 11.12.1975, Slovakia) is a scientific and research employee of Slovak University of Technology, Faculty of Materials Science and Technology since September 2000. She received her PhD. (2007) in Machining Technologies and Materials, in research of the metal matrix composites application. During her practice at the Faculty she was actively involved in solution of several scientific projects as VEGA, APVV. Also she has the experience with the international projects. She has been registered in many professional databases, while the most significant case seems to be her registration as the **Delegate in IIW (International Institute of Welding) commission XVII „Brazing, soldering and diffusion welding“, and expert in Commission IV- Power Beam Processes.** She is a co-author of several IF, CC publications.

Third C. Author
Beáta Šimeková (female, 09.09.1981, Slovakia) is a scientific and research employee of Slovak University of Technology, Faculty of Materials Science and Technology since September 2005. She received her PhD. (2009) in Machining Technologies and Materials, in research of the Reliability of Lead-free Solder Joints in Microelectronics. During her practice at the Faculty she was actively involved in solution of several scientific projects as VEGA, APVV. Also she has the experience with the international projects. She has been registered in many professional databases, while the most significant case seems to be her registration as the expert in IIW (International Institute of Welding) commission XVII „Brazing, soldering and diffusion welding“, and expert in Commission IV- Power Beam Processes. She is a co-author of several IF, CC publications and reviewer for Journal of Alloys and Compounds.

[1] HODÚLOVÁ, Erika - PALCUT, Marián - LECHOVIČ, Emil - ŠIMEKOVÁ, Beáta - ULRICH, Koloman. Kinetics of intermetallic phase formation at the interface of Sn-Ag-Cu-X (X = Bi, In) solders with Cu substrate. In Journal of Alloys and Compounds. Vol. 509, Iss. 25 (2011), s.7052-7059. ISSN 0925-8388. V databáze: WOS ; SCOPUS. **IF 2.726**

[2] SOPOUŠEK, Jiří - PALCUT, Marián - HODÚLOVÁ, Erika - JANOVEC, Jozef. Thermal Analysis of the Sn-Ag-Cu-In Solder Alloy. In Journal of Electronic Materials. Vol. 39, Iss. 3 (2010), s.312-317. ISSN 0361-5235. V databáze: SCOPUS ; WOS. **IF 1.675**

[3] PALCUT, Marián - SOPOUŠEK, Jiří - TRNKOVÁ, Lýdia - HODÚLOVÁ, Erika – SZEWCZYKOVÁ (ŠIMEKOVÁ), Beáta - OŽVOLD, Milan - TURŇA, Milan - JANOVEC, Jozef. Thermal analysis of selected tin-based lead-free solder alloys. In Kovové materiály. Metallic materials. Vol. 47, No.1 (2009), s.43-50. ISSN 0023-432X. V databáze: WOS ; SCOPUS. IF 0.546

[4] ŠIMEKOVÁ, Beáta - HODÚLOVÁ, Erika - KOVAŘÍKOVÁ ROD. SUKUBOVÁ, Ingrid - PALCUT, Marián - ULRICH, Koloman. Growth of the IMC at the interface of SnAgCuBi (Bi = 0,5; 1,0) solder joints with Cu substrate. In Tehnički Vjesnik - Technical Gazette. Vol. 19, No. 1 (2012), s.107-110. ISSN 1330-3651. V databáze: WOS ; SCOPUS. **IF0.615**

[5] HODÚLOVÁ, Erika - ŠIMEKOVÁ, Beáta - KOVAŘÍKOVÁ ROD. SUKUBOVÁ, Ingrid - LECHOVIČ, Emil - ULRICH, Koloman. Research and development of lead-free solder for microelectronics in consideration of the environmental andf qualitative aspects. In Welding in the World. Vol. 58, no. 5 (2014), s. 719-727. ISSN 0043-2288. V databáze: SCOPUS ; WOS ; MLJ. **IF 0.424**

[6] HODÚLOVÁ, Erika - ŠIMEKOVÁ, Beáta - KOVAŘÍKOVÁ ROD. SUKUBOVÁ, Ingrid. Structural Changes of the IMC in Lead Free Solder Joints. In Materials Transactions, Special Issue on Nanojoining and Microjoining II, ©XXXX The Japan Institute of Metals and Materials, **IF 0.610**