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Non-Destructive Testing of Brazed Joints Made in Thin-Walled Austenitic Steel Pipes

Abstract: The article discusses methods used in the non-destructive testing of brazed joints made in thin-walled austenitic steel pipes using nickel and silver-based filler metals. Comparative tests involving the use of the radiographic and the ultrasonic method revealed the possibility of applying ultrasonic technique when defining quality levels in relation to brazed joints in thin-walled pipes. The ultrasonic method may serve as a cheaper alternative to the radiographic method in the automation of the non-destructive testing of the above-named joints in batch production.

Keywords: non-destructive testing, brazing, thin-walled non-ferromagnetic steel pipes

DOI: *10.17729/ebis.2019.1/4*

Introduction

The brazing of thin-walled pipes made in austenitic steels is a characteristic special process used, among other things, in the aviation industry (in the production of aero-engines) [1, 2, 3] and in the manufacturing of heat exchangers [4]. Elements of pipes intended for brazing should have a capillary gap, the width of which should be restricted within the range of 0.02 mm to 0.08 mm [1,2]. As can be seen, elements to be joined should be matched in a slightly sliding manner. However, in cases of general applications it is recommended to use gaps, the width of which is restricted within the range of 0.05 mm to 0.2 mm [5]. Elements to be joined should be wetted using a filler metal characterised by good wettability and a melting point lower than that of the base material. A brazed joint is formed as a result of diffusion phenomena (adhesion and cohesion).

The quality of brazed joints in thin-walled pipes is significantly affected by the preparation of elements to be brazed. In spite of precise cutting, trimming, deburring, necking pipe ends and bending performed using numerically-controlled benders, in certain areas a gap can be overly small, impeding the flow of the braze front, or excessively large, leading to the decay of the so-called capillary effect. The foregoing results primarily from the presence of small distortions in thin-walled elements during heat treatment. Consequently, the brazed joint area may contain numerous imperfections defined in the PN-EN ISO 18279:2008 standard [6]. Depending on their types, shapes and location in brazed joints, imperfections are categorised in

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six primary groups (cracks, voids, solid inclusions, bonding imperfections, imperfections of shapes and dimensions as well as miscellaneous imperfections) based on assessment criteria and quality levels (D – moderate, C – intermediate, B – strict, A – particularly strict). The authors of the standard point to the limited applicability of the assessment as brazed joints contain imperfections, which, depending on operational requirements, are considered to be particularly damaging. The determination of the effect of imperfections on the service life of joints is difficult as brazed joints have not been the subject of such detailed research as that concerning, e.g. welded joints [7]. Because of the capillary nature of the joints, most imperfections are located in parallel to the joint surface [8]. Some of the most significant imperfections in relation to joints in thin-walled pipes are extensive lacks of penetration [2].

Test specimens

Non-destructive tests involved the use of four specimens of seamless thin-walled pipes made of chromium-nickel steel grade 18-8 having the austenitic structure. The diameters of the specimens amounted to 25.4 mm and 9.5 mm. The geometry of the specimens is presented in Figure 1. The brazing of the ends was performed using the induction method as well as

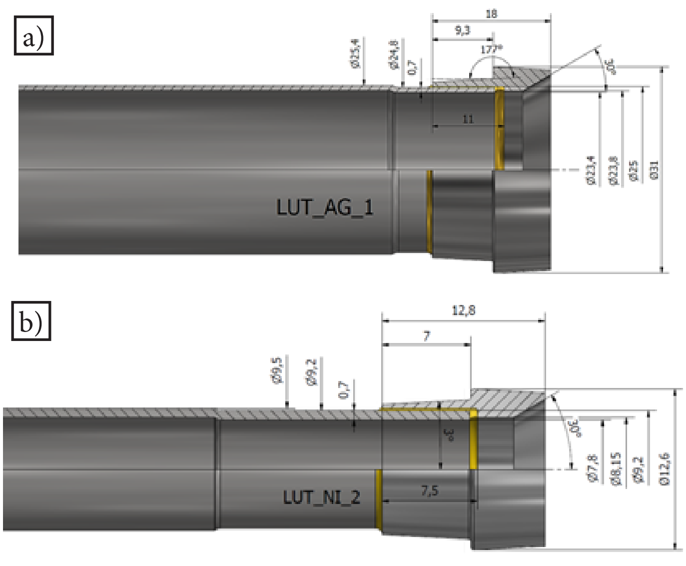

Fig. 1. Geometry of the specimens brazed using: a – silver-based filler metal and b – nickel-based filler metal

a silver-based (AgCu42Ni2) and nickel-based (BNi-2) brazing metal. The external generating line within the brazed joints was inclined at an angle of 3° in relation to the pipe axis.

Non-destructive tests of welded joints

When assessing the quality level of brazed joints on the basis of PN EN ISO 18279 [6] it is recommended, in accordance with the requirements of the PN-EN 12799:2003 standard [9], to use conventional non-destructive methods, i.e. visual, penetrant, radiographic, ultrasonic and thermographic tests. The primary qualification criterion applied when assessing the quality of brazed joints in thin-walled pipes made of austenitic steels is the joint filling degree, calculated in relation to the length of the joint, where the aforesaid degree should amount to a minimum of 80% [2, 10].

Visual tests

Visual tests of brazed joints in thin-walled pipes made of austenitic steels are (because of their specific nature) obligatory. Some of the more important requirements related to the above-named joints include the entire filling of the gap with the brazing metal as well as the obtainment of the continuous meniscus of the brazing metal both inside and outside the pipe at the contact with the end, yet without the excess flash outside the joint area. The excess flash of the braze is removed mechanically. Visual tests should be performed in relation to the 100%

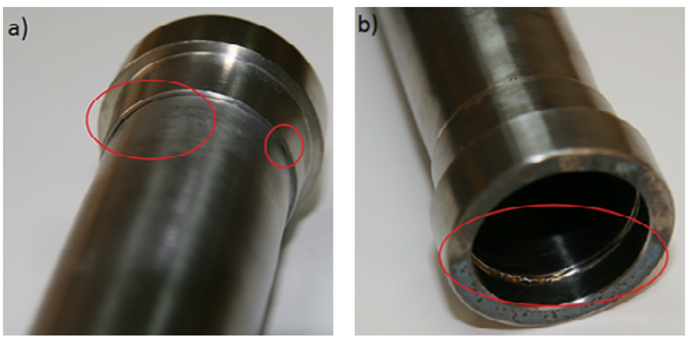

Fig. 2. Brazed joints made using the silver-based brazing metal with imperfections: a) outside specimen no. LUT-AG-1 – gap is not filled with the brazing metal, b) – inside specimen no. LUT-AG-2 – gas pores on the braze surface

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of the meniscus line, also checking the surface for cracks, cuts etc. A visual test should cover 100% of an element [1, 2]. Exemplary brazing imperfections detected during the visual test of brazed joints made using the silver-based brazing metal are presented in Figure 2.

Penetrant tests

Significantly higher inspection reliability when detecting surface imperfections (porosity, underfill, lack of wetting, cracks etc.) than that of the visual method is characteristic of penetrant tests [11]. However, it should be noted that the entire removal of penetrant residue can be difficult or impossible, which, in turn, can pose a problem in cases of repeated, e.g. repair brazing. The presence of penetrant remaining in the joint may impede the spreading of the filler metal.

In cases of brazed joints in pipes having small diameters, the performance of both visual and penetrant tests inside pipes may encounter serious difficulties or even prove impossible. If the latter turns out to be the case, it might be advisable to perform radiographic tests.

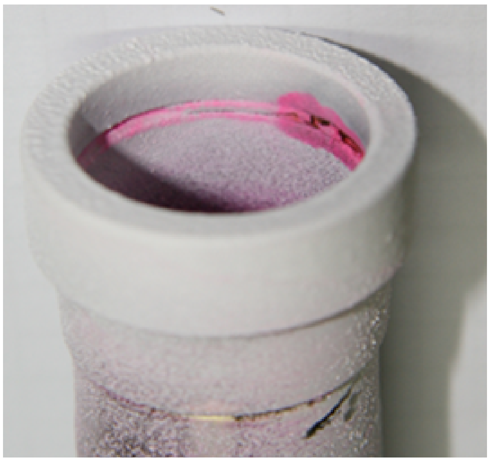

Fig. 3. Brazed joint made using silver-based brazing metal no. LUT-AG-2 containing gas pores on the braze surface, detected using the penetrant method

Radiographic tests

One of more popular techniques applied when testing brazed joints is the radiographic method. Presently used state-of-the-art X-ray equipment featuring computer-generated real-time imaging enables the performance of the automated assessment of radiograms based on the analysis of obtained images involving the use of the function of histogram adjustment and thresholding (improving the contrast of an image) and the Canny edge detection algorithm (making it possible to precisely identify the border between two areas) [4]. The use of computed tomography supported by a specialist software programme enables the spatial identification of objects along with the quantitative analysis of joint quality [11].

The sensitivity of radiographic method-based tests is significantly affected by the chemical composition of a brazing metal. If the coefficient of X-radiation absorption by the filler metal is similar to that by the base material (e.g. when the joining of stainless steel elements is performed using nickel-based filler metals), the application of the radiographic method in tests of brazed joints containing a narrow gap may encounter various problems [12]. The aforesaid problems do not occur if a filler metal is characterised by the absorption coefficient significantly different from that of the base material.

Radiographic tests involved four specimens of brazed joints, two of which were made using the silver-based brazing metal, whereas the remaining two were made using the nickel-based brazing metal (see Figure 1). One of the specimens brazed using the silver-based brazing metal revealed a joint filling degree (with brazing metal) amounting to less than 80%. Radiograms related to the above-named specimen (made in two different positions), containing the description of detected brazing imperfections, are presented in Figure 4. The assessment of the percentage-based filling of the entire joint surface (as the projection of imperfection surface) was performed using the AutoCad software developed by the Autodesk company. Various types of imperfections grouped on the outer contour are illustrated in Figure 5 (in pink). In relation to the above-named joint, the total surface area of the projection

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of imperfections amounted to 46%. Other specimens satisfied related qualification criteria.

In cases of the radiograms obtained for the brazed joints made using the nickel-based brazing metal, the indication of an imperfection was significantly less clear that that in the brazed joints made using the silver-based filler metal.

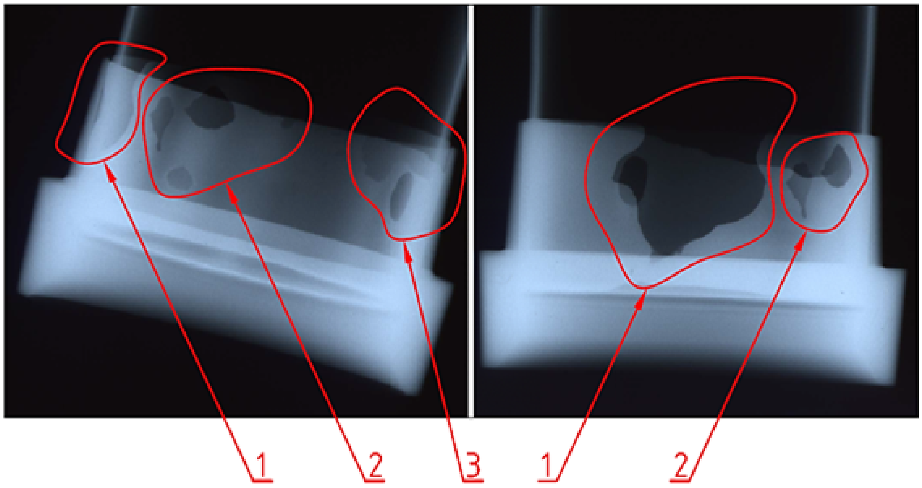

Fig. 4. Radiograms of the brazed joint made using the silver-based filler metal – determined LUT-AG-1, with areas containing imperfections: 1 – braze-lacking area, 2 – gas pores, 3 – braze-lacking area containing a gas pore

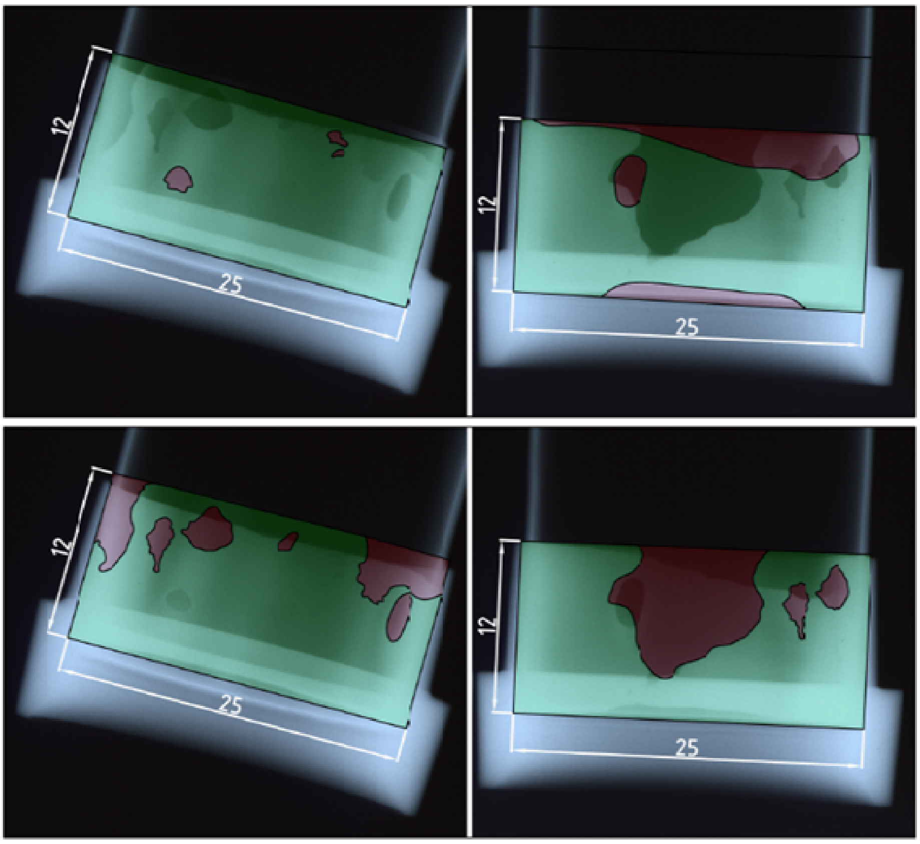

Fig. 5. Radiograms of the brazed joint presented in Figure 4 with marked areas containing imperfections

Ultrasonic tests

Ultrasonic tests are used significantly more seldom in tests of brazed joints in thin-walled pipes. Usually, the above-named joints are composed of three layers of materials characterised by various physical properties. Because of the necessity of adjusting a probe to the shape of a surface being tested as well as due to an increased damping factor value as well as because of local changes in the velocity of ultrasonic waves in the brazed joint area in pipes made of austenitic steel [13, 14], the interpretation of obtained indications and their assessment may prove problematic [14, 15]. The most recent research indicates the possibility of using tandem type probes when assessing the quality of FSW girth joints in pipes made of austenitic steels having thicknesses restricted within the range of 2 mm to 8 mm [14]. Previous publications also refer to the possibility of testing thin-walled elements using traditional ultrasonic probes [16, 17].

The initial ultrasonic tests of the above-presented brazed joints involved the use of a digital ultrasonic defectoscope provided with various conventional frontal probes, including a miniature Krautkrämer G15MN 611 probe featuring a delay line adjusted to surfaces being tested. Because of the fact that the aforementioned tests did not produce satisfactory results, the depth of imperfection deposition was identified using a DA412 miniature tandem probe having the operational range of 0.6 mm to 60 mm and provided with a DMS2 thickness gauge (Krautkrämer) enabling the imaging of A and B type signals. Despite the fact that the probe was not

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adjusted to the shape of test surfaces within the brazed joint area, it was possible, in relation to the specimens brazed using the silver-based filler metal, to obtain proper indications of extensive imperfections detected using the radiographic method. The scanning of each joint was performed in two lines around the entire joint circumference. The results related to specimen LUT-AG-2, obtained in the ultrasonic test, are put together with those obtained using the radiographic method and presented in Figure 6. Because of the exceeding of the measurement range of the probe it was not possible to obtain proper indications of imperfections in relation to the specimens brazed using the nickel-based filler metal (the length of the path to the brazed layer amounted to approximately 0.5 mm).

Thermographic tests

Thermographic tests are not frequently applied in relation to brazed joints, which is related to difficulties concerned with the quantitative assessment of the brazed joint filling degree. Although the thermographic images obtained in the tests enable the unequivocal indication of the joint area not filled with the brazing metal during the brazing process, recently published test results point out that it is not possible to precisely determine the location of boundaries of the wetting of the gap with the brazing metal and show the presence of apparent indications resulting from the fast heating of the edges [18]. In addition, the obtainment of the highest value of temperature contrast is possible after a strictly specified time. For instance, in relation to overlap brazed joints discussed in publication [18], the above-named time amounted to 2 seconds following the initiation of heating. As can be seen above, in terms of thin-walled pipes, the performance of the quantitative assessment of an thermographic image can be difficult in relation to the entire circumference of a pipe.

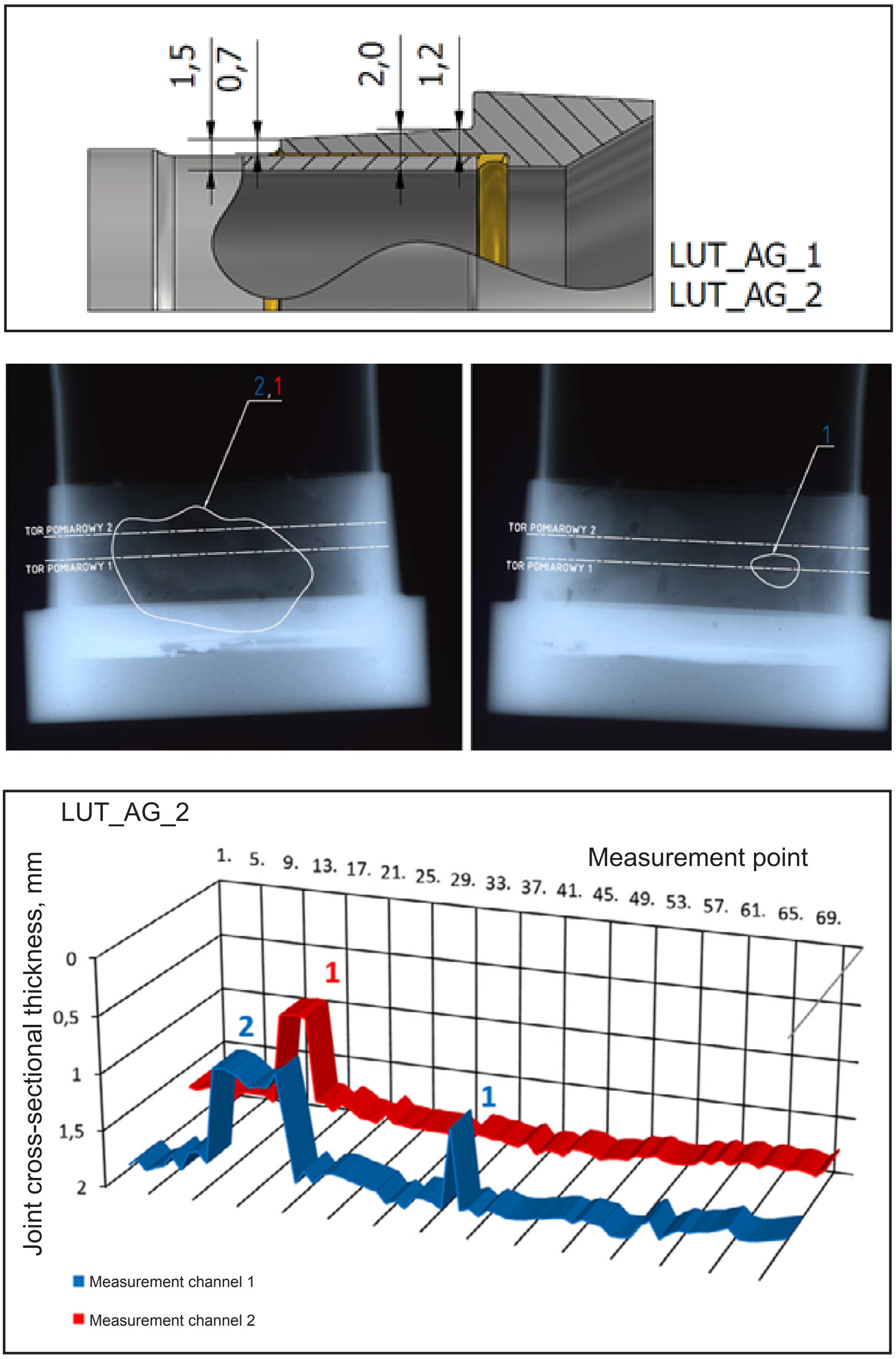

Fig. 6. Dimensions of the brazed joint made using silver-based filler metal LUT_AG_2, with the radiograms of the joints and with the graph of the thickness measured from the bottom of the joint or the imperfection areas in relation to measurement channels: no. 1 - 1,2 blue braze-lacking areas, no. 2 - 1 red, braze-lacking area

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Summary

Strict quality requirements concerning brazed joints in thin-walled pipes made of austenitic steels necessitate the satisfaction of a number of requirements at the stage of initial assembly, during the brazing process and when performing non-destructive acceptance tests of joints. The primary non-destructive methods used to assess the quality of brazed joints include visual, penetrant radiographic and ultrasonic tests.

Obligatory visual tests are used to verify whether a gap is entirely filled with the brazing metal as well as whether continuous meniscus of the brazing metal was obtained inside and outside the pipe (in the area of contact with the end), yet without the excessive flash outside the joint area. Penetrant tests are characterised by significantly higher reliability than that of the visual method (when searching for surface imperfections). However, the removal of penetrant may appear difficult or impossible, which can pose a problem in the event of repeated brazing. In addition, the performance of both visual test and penetrant tests inside pipes can prove impossible in relation to brazed joints in small-diameter pipes. Regrettably, the above-named methods cannot be used to assess the quality of brazed joints. One of the most popular methods used when testing brazed joints is the radiographic method. Because of the state-of-the-art image processing technology, the above-named method enables the precise assessment of joint quality. The sensitivity of radiographic method-based tests is significantly affected by the chemical composition of a brazing metal. If the coefficient of X-radiation absorption by the filler metal is similar to that by the base material (e.g. when the joining of stainless steel elements is performed using nickel-based filler metals), the application of the radiographic method in tests of brazed joints containing a narrow gap may encounter various problems. The aforesaid problems do not occur if a filler metal is characterised by the absorption coefficient significantly different from that of the base material.

Ultrasonic tests are used significantly more seldom in tests of brazed joints in thin-walled pipes. Usually, the above-named joints are composed of three layers of materials characterised by various physical properties. Because of the testing of multilayer structures and due to the necessity of adjusting a probe to the shape of a surface being tested as well as because of an increased damping factor value and due to local changes in the velocity of ultrasonic waves in the brazed joint area in pipes made of austenitic steels, the interpretation of obtained indications and their assessment may appear problematic.

Ultrasonic tests verified by radiographic tests can be used to assess the quality of brazed joints (of specific geometry) in thin-walled pipes made of stainless steels. The use of special miniature ultrasonic probes having the contact area adjusted to the geometry of pipes subjected to tests can increase assessment accuracy. The ultrasonic method can pose a cheaper alternative to the radiographic method and can be used in the automation of the non-destructive tests of brazed joints in batch production.

The thermographic method is still not widely used in industrial practice when performing quantitative assessments related to the quality of brazed joints made in thin-walled pipes.

The article was developed within the statutory work of Department of Strength and Fatigue of Materials and Structures at AGH entitled Strength of Materials and Structures – work no. 11.11.130.375.

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