*Mouna Amara[1,2], Fatima Zahra Khedim[1], Ljubica Milović[3], Mohammed Hadj Meliani[1*], Rami K. Suleiman[4]*

# INSPECTION BY NDT-DT TESTING TO ANALYSE AND CONTROL FRICTION ROTATING WELDING OF AISI 304L AND AISI 316L STAINLESS STEEL GRADE

# ISPITIVANJE IBR-IR ZA ANALIZU I KONTROLU ZAVARIVANJA TRENJEM ROTACIJOM NERĐAJUĆIH ČELIKA AISI 304L I AISI 316L

Originalni naučni rad / Original scientific paper
Rad primljen / Paper received: 28.02.2025
https://doi.org/10.69644/ivk-2025-02-0329

Adresa autora / Author's address:
[1] Laboratory of Theoretical Physics and Materials, Hassiba Benbouali University of Chlef, Chlef, Algeria *email: m.hadjmeliani@univhb-chlef.dz , hadjmeliani@univ-metz.fr
M. Amara https://orcid.org/0009-0009-1774-7403
F.Z. Khedim https://orcid.org/0009-0008-9244-8537
M. Hadj Meliani https://orcid.org/0000-0003-1375-762X
[2] Laboratory of Mechanics and Materials, Hassiba Benbouali University of Chlef, Chlef, Algeria
[3] University of Belgrade, Faculty of Technology and Metallurgy, Belgrade, Serbia
Lj. Milović https://orcid.org/0000-0001-9618-055X
[4] Interdisciplinary Research Center for Advanced Materials, King Fahd University of Petroleum & Minerals (KFUPM), Dhahran, Saudi Arabia R.K. Suleiman https://orcid.org/0000-0002-6776-9266

**Keywords**
- NDT
- friction welding
- AISI steel
- tensile testing
- DT
- defects

*Abstract*

*The quality of the weld primarily depends on the parameters used during the welding process, including rotational speed, friction time and pressure, and forging time and pressure. Initially, welding operations are carried out on austenitic stainless steel bars, specifically from the AISI 304L and AISI 316L families, under a constant rotational speed. The first objective is to analyse the steel AISI 304L using the effect of two simultaneous parameters, namely two different forging times and two different forging pressures. The second objective is to evaluate the effect of five different friction phase times on AISI 316L, while keeping the other parameters constant, including friction pressure and forging pressure. Subsequently, a quality control is performed on all welded joints using non-destructive testing (NDT) techniques such as dye penetration testing, X-rays, and ultrasonics, in order to assess the impact of the aforementioned welding parameters on the quality of the joints. The results obtained indicate the presence of defects in some of the welded joints, estimated at 25 % in terms of joints, predominantly associated with low forging times or pressures.*

**Ključne reči**
- IBR (ispitivanje bez razaranja)
- zavarivanje trenjem
- čelik AISI
- ispitivanje zatezanjem
- IR (ispitivanje razaranjem)
- greške

*Izvod*

*Kvalitet zavarenog spoja uglavnom zavisi od primenjenih parametara tokom postupka zavarivanja, uključujući brzinu rotacije, vreme i pritisak trenja, kao i vreme i pritisak iskivanja. Zavarivanje je izvedeno sa epruvetama od čelika tipa AISI 304L i AISI 316L, sa konstantnom brzinom rotacije. Prvi zadatak je analiza čelika AISI 304L korišćenjem efekta dva simultana parametra, zapravo, dva različita vremena iskivanja, i dva različita pritiska iskivanja. Drugi zadatak je procena uticaja pet različitih vremena faze trenja kod čelika AISI 316L, pri konstantnim ostalim parametrima, uključujući pritisak trenja i pritisak iskivanja. Zatim je izvedena kontrola kvaliteta svim zavarenim spojevima ispitivanjem bez razaranja (IBR), metodama penetrantima, rendgenskim zračenjem i ultrazvukom, radi procene dejstva gore navedenih parametara zavarivanja na kvalitet spojeva. Dobijeni rezultati pokazuju prisustvo grešaka kod nekih zavarenih spojeva, u obimu 25 % s obzirom na spojeve, koji su u najvećoj meri povezani sa kratkim vremenima i malim pritiscima iskivanja.*

## INTRODUCTION

Nanostructured materials have played a significant part in the manufacture of thermoelectric devices /1/. Research on welding continues to gain momentum with the advancement of technology and the increasing complexity of industrial installations. Welding remains the most widely used assembly method in various aspects /1-4/. Consequently, welding inherently involves materials, as it utilises human-made substances combined with a heat source, which can take different forms /4/, such as arc welding /5-6/, gas welding /7-8/, friction welding, and others /9-10/. The most critical parameters of this process are those that influence the nature of the joint, including design characteristics and specifications, speed, time, and cost /11-14/. Ultimately, the aim is to achieve superior mechanical properties for a welded joint. The parameters employed in welding operations are further discussed in this work. According to the results of several published research studies, friction welding is one of the most cost-effective and environmentally friendly assembly processes, applicable to a wide range of materials, including steel, aluminium, crystalline and semi-crystalline polymers, among others /15-18/. The ideal weld is one that ensures continuity in mechanical, metallurgical, and physical properties between the joined parts, making the weld indistinguishable from the surrounding metal.

Friction welding is a solid-state joining process capable of producing high-quality welds when the parameters are well-controlled and properly applied, whether between two pieces of the same material or dissimilar materials /19-20/. The pieces to be friction welded are brought into contact, generating heat through friction at the interface, driven by the rotation of one part on one side and the application of axial force on the second part on the other side. The friction increases the temperature around the interface of the two pieces, sometimes reaching approximately 1000 °C, before it rapidly decreases due to natural cooling, governed by the transition of the initially solid material into a viscous state, in other words, through the reduction of friction /19-23/.

In this modest study, we will conduct several solid-state welding operations in our laboratory, varying friction time using austenitic steel from the AISI family. Stainless steels are widely used in various practical applications, such as nuclear, chemical, and petrochemical industries /9/. Stainless steels are identified as iron-based alloys containing 8 to 25 % nickel and 12 to 30 % chromium. Thus, different types of stainless steels can be subdivided into three categories: martensitic, ferritic, and austenitic. Austenitic stainless steels represent the largest group and are widely used in liquid processing systems and hydraulic machinery due to their excellent corrosion resistance, good machinability, low cost, and weldability /10/. Austenitic steels exhibit relatively low mechanical properties, with a yield strength ($R_e$) ranging from 180 to 240 N/mm², which can be significantly improved through work hardening and especially by adding nitrogen, typically around 0.12 to 0.22 % /11/. Stainless steel is easy to weld, although there is a difference depending on the type. For example, austenitic stainless steels, particularly the AISI 300 series, are easier to weld than martensitic and ferritic steels, which belong to the AISI 400 series. The AISI 304L and AISI 316L stainless steels, which are the focus of our work, are the most commonly used for general applications, containing 18 to 20 % Cr and 8 to 10.5 % Ni. Due to the low carbon content, they are less prone to carbon release during welding. AISI 304L and AISI 316L steels are widely used for general applications because their 18 to 20 % Cr and 8 to 10.5 % Ni content give them good mechanical properties and excellent corrosion resistance.

It has been observed that welding parameter values vary significantly from one article to another, heavily dependent on the material's nature and the sample's cross-section /1-3/. Therefore, making an objective comparison between these results is very challenging. Hassan et al. /22/, Arzour et al. /1/ identified a parameter that plays an important role in the evolution of the mechanical properties of the welded joint. These authors, part of the USTHB group, successfully explained that during a portion of the friction phase, the initial microstructure of the metal is altered twice around the joint interface: first during the temperature rise to its peak value, and second during the subsequent temperature decrease until the end of the friction phase. Research on welding continues to gain momentum with the advancement of technology and the increasing complexity of industrial installations. Welding remains the most widely used assembly method in various aspects /1-4/. Consequently, welding inherently involves materials, as it utilises human-made substances combined with a heat source, which can take different forms /4/, such as arc welding /5-6/, gas welding /7-8/, friction welding, and others /9-10/. The most critical parameters of this process are those that influence the nature of the joint, including design characteristics and specifications, speed, time, and cost /11-14/. Ultimately, the aim is to achieve superior mechanical properties for a welded joint. The parameters employed in welding operations are further discussed in this work. According to the results of several published research studies, friction welding is one of the most cost-effective and environmentally friendly assembly processes, applicable to a wide range of materials, including steel, aluminium, crystalline and semi-crystalline polymers, among others /15-18/. The ideal weld is one that ensures continuity in mechanical, metallurgical, and physical properties between joined parts, making the weld indistinguishable from the surrounding metal.

## METHODOLOGY

### *Experimental test: material, tension test and NDT*

This section is dedicated to presenting the material used in this research, with particular emphasis on the welding parameters. The following outlines all the experimental conditions under which the study is conducted, the chosen methodology, the materials, the techniques, and the equipment utilised to successfully carry out the investigation.

### *Rotary friction welding operations*

The fundamentals of friction welding are straightforward. At the beginning of the process, two components are brought into contact, creating a resistive torque due to the applied frictional forces. The energy generated is converted into heat, causing the temperature to rise to its maximum value, which remains below the melting point. This period is referred to as the first stage of friction phase. Subsequently, some of the accumulated heat begins to diffuse, and during this stage, a portion of the plasticised metal starts to be extruded under the effects of rotation and frictional pressure, leading to the formation of the characteristic flash associated with welding. This period, known as the second stage of the friction phase, plays a significant role in determining the final microstructure of the welded joint. The rotating piece is then disengaged from the chuck and rapidly decelerated. Figures (1 - a, b, c) illustrate the steps of rotary friction welding.

a) b) c)

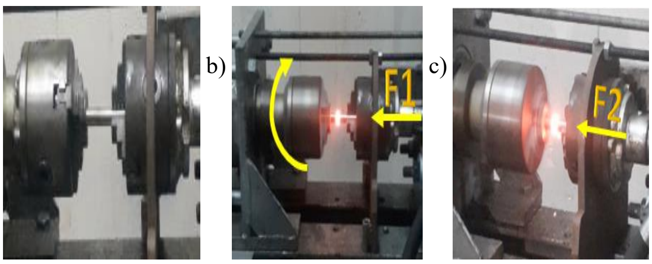


Figure 1. a) Initial positioning of two pieces to be welded; b) result of friction between the rotating piece on the left and the piece subjected to axial translation F1, leading to an increase in temperature around the interface of the two parts; c) heat diffusion accumulated during rotation, which allows for the forging process restrained by the application of an axial force F2.

The welding operations are performed using a direct-drive friction welding machine. This study begins with the optimisation of welding parameters, focusing on friction pressure and time at a constant rotational speed of 3000 rpm, with the objective of analysing the effects of forging time and pressure on joint quality. Figure 2 shows an example of a weld joint obtained through rotary friction welding.

Figure 2. Profile of a friction weld joint.

*Means and material used*

From a practical standpoint, we welded stainless steels from the AISI 304L and AISI 316L series which are among the most commonly used for general applications due to their chromium content of 18 to 20 % and nickel content of 10 to 12 %. For all our operations, we used samples with a length of 45 mm and diameter of 12 mm, cut directly from 6 m bars. After cutting, special attention is given to ensuring the flatness of the surfaces that would be brought into contact during welding.

*Welding parameters*

During our welding operations three friction times are used for the same friction pressure and for the forging time and pressure, which are broken down as follows.

Table 1. Welding parameters.

| Velocity of rotation | Friction time | Frictional pressure | Forging pressure (MPa) | Forging time |
|---|---|---|---|---|
| 3000 $min^{-1}$ | 5 s | 140 MPa | 0, 280, 300 | 0 s, 5 s, 8 s |

*Non-destructive testing*

Three tests were made on welded joints compared to those made on base material; these are penetrant testing, radiography and ultrasound.

*Penetrant testing*

This method is employed to detect surface defects around the welded joint. Joint surfaces must be thoroughly cleaned before inspection to remove all impurities using a solvent, ensuring more accurate results. For this purpose, we used five products in sequence: solvent, penetrant, developer, water, and clean cloths. First, the penetrant is applied to the surface of the welded joint to highlight any open discontinuities. After 15 to 20 minutes, excess penetrant is removed, allowing the surface to dry, and the developer is applied. The developer's application enables capillary action to draw out the penetrant from within the defects, causing coloured indications to appear by contrast against the white background of the developer.

*Radiography*

The objective of using radiography is to detect internal defects that could be detrimental to the weld. The equipment used includes: a Control panel, a COMET generator, and a View box (for interpreting images). During the process, the receiver is exposed to an X-ray beam passing through the material. The material absorbs the radiation based on its composition and density, producing a grayscale image of the material's internal structure on the receiver. In the presence of defects, this typically results in darker or sometimes lighter shades on the radiograph.

*Ultrasonic testing*

There are two types of ultrasonic tests: manual and automatic. The latter is not suitable for small parts, so we utilised the manual type. The equipment required includes an ultrasonic pulse unit (A-scan). Specifically, an OLYMPUS EPOCH 600 device with serial number 110113301, operating at a frequency range between 1 and 20 MHz, and a bottle of oil. Initially, oil is applied to the interface between the transducer and the part being examined. The piezoelectric element of the transducer generates mechanical vibrations that propagate through the part, reflecting off its surfaces. Part of the acoustic beam is intercepted by any defects and reflected back to the transducer, which converts the vibration into an electrical signal. On the display screen, a characteristic echo appears at a specific time base distance, allowing for detection of defects, their location, and extent.

*Tension testing*

Rotary friction welding (RFW) between two contacting surfaces generates a heat flux around the interface. In this process, one sample remains stationary while rotating and the other moves linearly under the influence of an axial force. The movement of the two pieces increases the temperature to around 1000 °C, depending on the friction between the surfaces, the material's conductivity, and the diameter used. This temperature reduces the solid material around the interface to a plastic state. As friction decreases and the temperature begins to drop upon exposure to air due to rotation, the process transitions into the forging phase. This marks the creation of a new deformation zone by contact, intensifying material consumption and defining the final shape of the flash, as shown in Fig. 3.

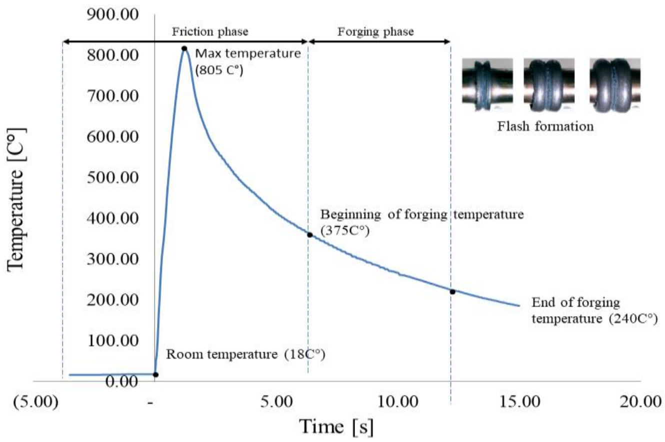


Figure 3. Example of nominal tensile curve of friction welding operation.

Tensile tests are carried out on an INSTRON 5500 universal testing machine with a load capacity of ±100 kN. All tests are carried out under the same welding conditions, under a quasi-static strain rate of $1.6 \cdot 10^{-3}$ $s^{-1}$. Regardless of the gasket configuration, specimens are cut in the axial direction according to standard specification of ISO 6892-1: 2009 (F), an effective diameter of 6 mm was retained, the line of the gasket interface is placed in the centre of the specimen. This allowed the use of an extensometer, placed on either side of the gasket interface. Nominal tensile curves are recorded in stress-deformation, concerning the base metal and welded joints, by use of AISI 316, AISI 304, Fig. 4.

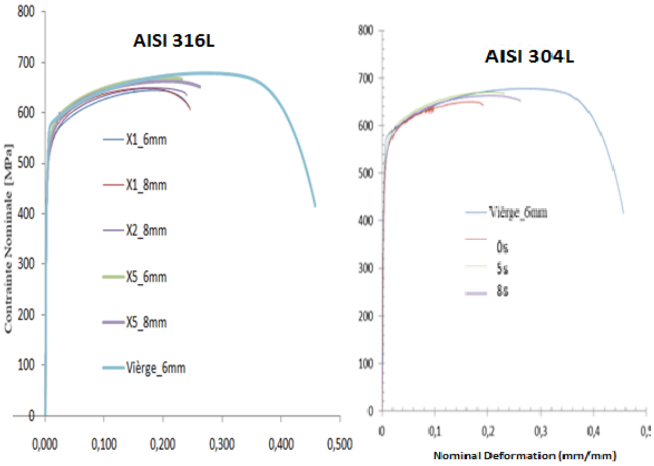


Figure 4. Nominal post-weld tensile tests: AISI 316L for different diameters (left); and AISI 304 L for different welding times (right).

## RESULTS AND DISCUSSION

### *Friction welding operations on AISI 304L and AISI 316L*

In this study, five welding operations are performed to analyse the effects with and without forging. Three forging pressure values are selected (0, 280, 300 MPa) and friction times (0, 5, 8 s) as shown in Table 2. Non-destructive test was initially conducted on pieces intended for welding and then on the welded pieces, including both with and without flash. The welded samples are shown in Fig. 5, and Table 2 summarizes the obtained results.

Table 2. Conditions of welding operations.

| Effect of friction time on AISI 304L | | | | | |
|---|---|---|---|---|---|
| Conditions | (1) | (2) | (3) | (4) | (5) |
| Rotational speed (rpm) | 3000 | | | | |
| Frictional pressure (MPa) | 140 | | | | |
| Friction time (s) | 5 | | | | |
| Forging pressure (MPa) | 0 | 280 | 300 | 280 | 300 |
| Forging time (s) | 0 | 5 | 5 | 8 | 8 |
| Effect of friction time on AISI 316L | | | | | |
| Conditions | (A) | (B) | (C) | (D) | (E) |
| Rotational speed (rpm) | 3000 | | | | |
| Frictional pressure (MPa) | 140 | | | | |
| Friction time (s) | 4 | 5 | 7 | 9 | 11 |
| Forging pressure (MPa) | 280 | | | | |
| Forging time (s) | 5 | | | | |

### *Non-destructive testing*

There are different types of defects when it comes to a weld, these defects can be detected and listed by non-destructive testing techniques. This section deals with NDT tests, such as penetrant test, ultrasound and radiography.

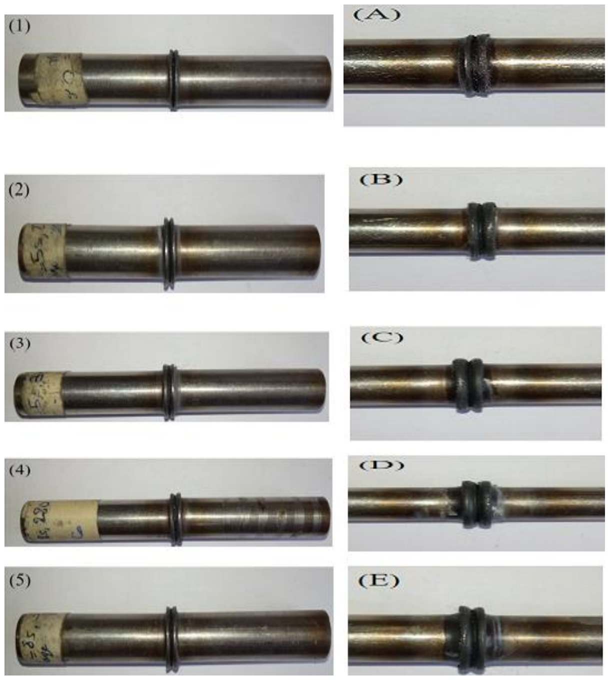


Figure 5. Different situation of positions of welding.

### *Penetrant test*

Penetrant tests of the five seals for AISI 316 reveal that there are no defects leading to the surface, for the friction times shown in Fig. 5, A and B.

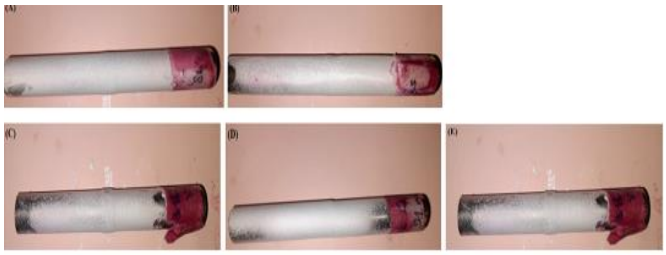

Figure 6. Penetrant joint inspection, conditions (A, B, C, D and E).

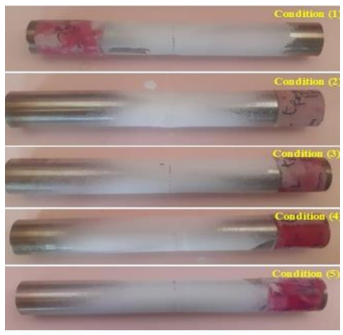

Figure 7. Penetrant inspection of joints, conditions 1-5.

### *X-ray*

Figures 8, 1 to 5 display radiographic images obtained for five welding conditions. This inspection is visual, based on colour changes at the weld joint over a limited area. If the colour changes to a different hue, it indicates the presence of volumetric defects due to penetration. Additionally, it is worth noting that the quality control of welded joints obtained through X-ray inspection is also performed on AISI 316L, as shown in Fig. 9.

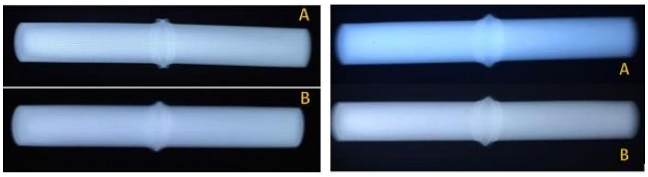


Figure 8.1, 8.2. X-ray inspection, workpieces 1, 2, sides A, B.

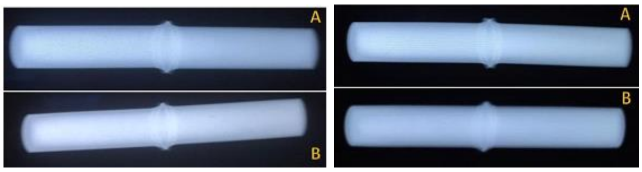


Figure 8.3, 8.4. X-ray inspection of the third piece side A, side B, and fourth piece side A, side B.

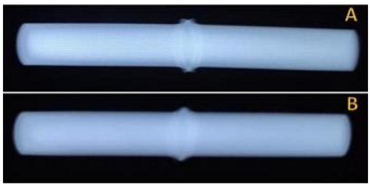


Figure 8.5. X-ray inspection of fifth piece side A, side B.

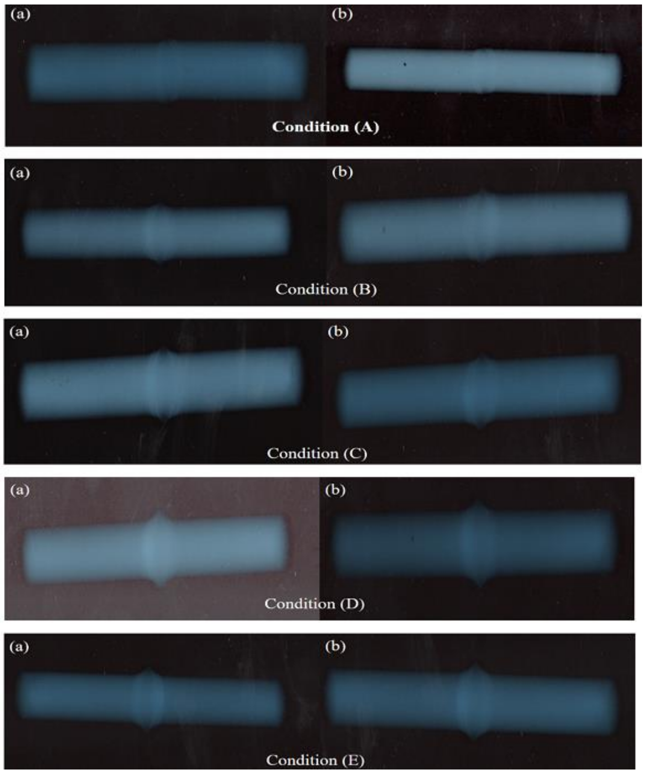


Figure 9. X-rays of welded joints (conditions A, B, C, D and E).

In these images we note the presence of post-X-ray examination defects, which results in an area where the colour is lighter or much darker. The use of this technique on all joints welded by rotary friction shows that no defects appear for the five conditions, Fig. 9, and the result shows that this process generates fewer macroscopic volume defects.

*Ultrasonic test*

This examination is also visual. The appearance of peaks between the initial peak and baseline peak indicates the presence of a defect at a distance shown on ultrasonic device screen. If peak amplitude is larger, the defect is more significant, and vice versa. The following Figs. 10 display results obtained from the ultrasonic device in the form of peaks.

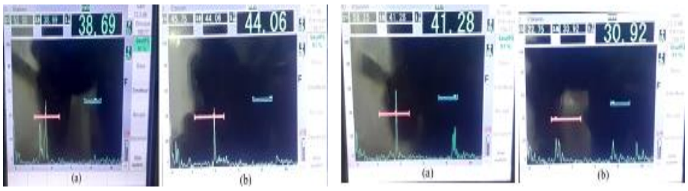


Figure 10a. (left) condition (1), (right) condition (2); a) with bead, b) without bead.

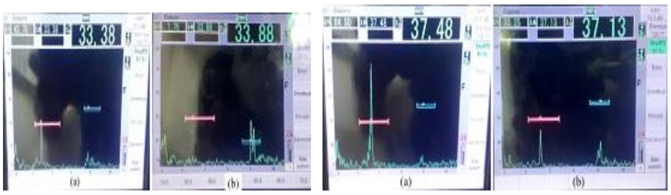


Figure 10b. (left) condition (3), (right) condition (4); a) with bead, b) without bead.

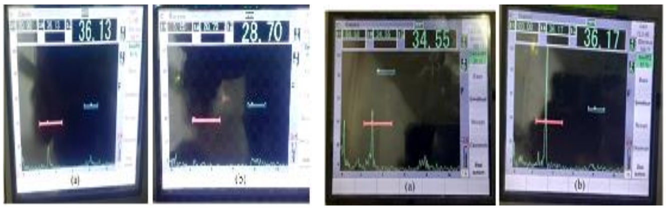


Figure 10c. (left) condition (5), (right) condition (A); a) with bead, b) without bead.

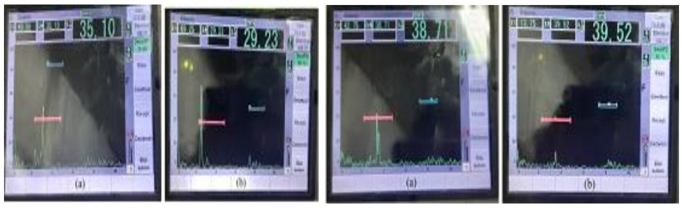


Figure 10d. (left) condition (B), (right) condition (C); a) with bead, b) without bead.

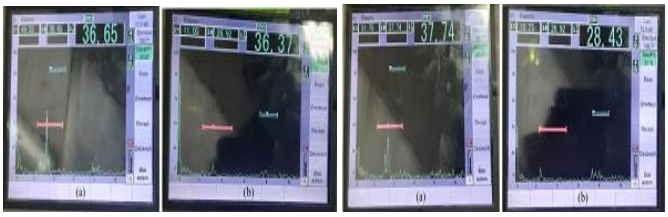


Figure 10e. (left) condition (D), (right) condition (E); a) with bead, b) without bead.

For the pieces with flash, two adjacent peaks appear under all five conditions. This result may be attributed to discontinuities around the flash, creating the impression of a defect. Additionally, peak intensity is nearly consistent across all cases, indicating that the examination of pieces with flash does not provide reliable information (Figs. 10 c and d-left). In contrast, the analysis of pieces without flash reveals a single peak under all five conditions. Peak intensity is at its maximum and exceeds the threshold for the first two conditions (A and B), corresponding to pieces welded with friction times of 4 and 5 s, in respect (Figs. 10 c-right and d). Subsequently, the peak intensity decreases with increasing friction time for the last three conditions, with times of 7, 9, and 11 s, in respect.

*XRD analysis*

X-ray diffraction (XRD) analysis of the AISI 316/AISI 316 welded joints reveals a different spatial distribution of austenite in two cases: the weld bead (3rd stage of the friction phase, 5.26 s) and the thermally treated piece ($T$ = 820 °C, holding time 0.5 h, and air cooling) compared to the base metal. XRD results indicate grain refinement in the thermally treated case; however, in the welding case, we observe that refinement is limited to the core (Fig. 11). Additionally, no phase changes are detected, confirming that welding parameters are effectively controlled in this regard.

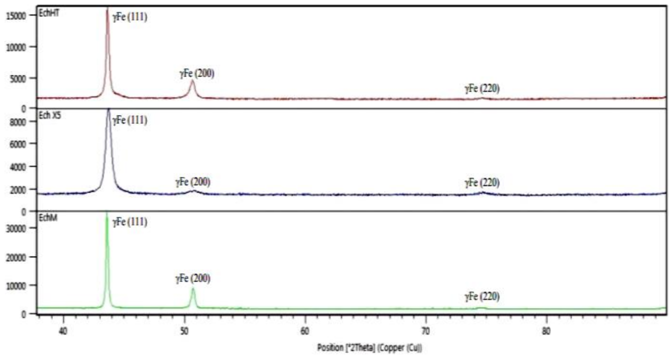


Figure 11. XRD analysis profile: base metal (EchM), 3rd stage of 5.26 s friction phase (Ech X5), and heat treated (EchHT).

*EDX analysis*

An analysis by EDX concerning the AISI 316/AISI 316 joint for a time of 5.26 s of the 3rd stage of friction phase, measurements made on the weakly deformed zone (ZFD) and the highly deformed plastic zone (ZPHD) thermo-mechanically, confirms the good distribution of alloyed elements (Fe, Mo, Cr, Ni) in the weld seam (Figs. 12 a and b).

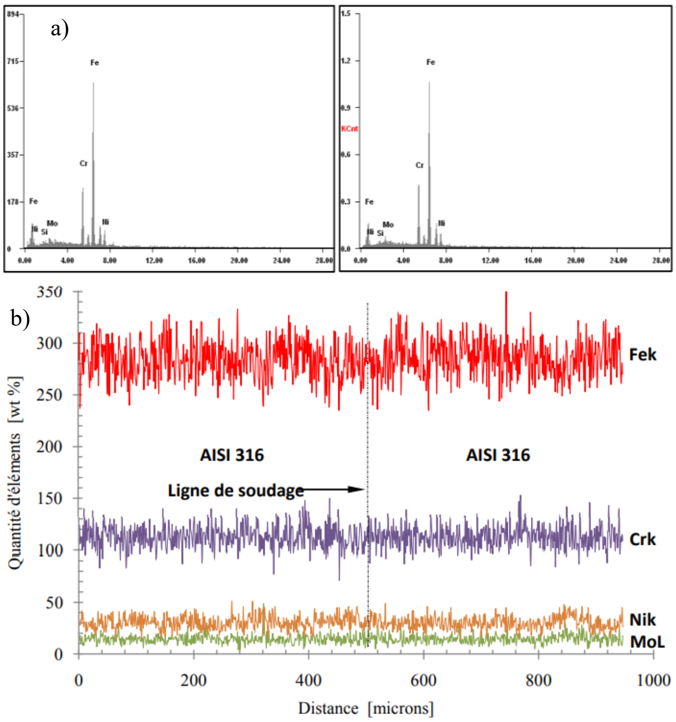


Figure 12. a) Examples of EDX, b) EDX analysis profile (5.26 s), (AISI 316-AISI 316).

The results of EDX analysis (Fig. 13), confirm that AISI 316 is more refractory than AISI 304, since alloyed by an amount of Cr and Mo, the latter has a great capacity to preserve the heat generated by the welding process which results in a low cooling rate and softening on the AISI 316 side due to grain growth.

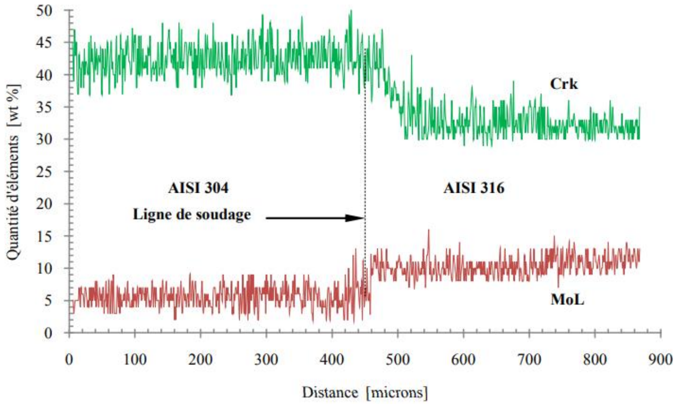


Figure13. EDX profile for the case 3.76 s, AISI 316/AISI 304.

CONCLUSIONS

In this work the objective is twofold: first, to investigate the effect of friction phase duration; and second, to assess the impact of two different forging times on weld quality. To achieve this, NDT methods are applied to all joints. The study includes two austenitic steels, AISI 304 and AISI 316.

Dye penetrant tests reveal surface discontinuities due to the use of penetrant liquid. This technique, while easier and less costly compared to methods as radiography and ultrasonic testing, shows the following.

For AISI 316, no defects are detected across all five conditions (A to E). For AISI 304, the absence of forging results in surface defects on the joint (condition 1), highlighting the importance of the forging phase.

The appearance of certain defects in joints for conditions (3) and (5) may be attributed to increased forging pressure.

Following the dye penetration analysis, X-ray inspection is performed on the same samples. This confirmed that rotary friction welding produces fewer macroscopic volumetric defects under AISI 304 steel welding conditions, with no macroscopic defects observed.

A third analysis using ultrasonic tests reveals that defect size increases when: friction time is shorter, around 4 and 5 seconds; however, for the last three conditions with friction times of 7, 9, and 11 s, the defect size is very small. The no-forging condition (condition 1) shows the largest defect size. Forging pressure significantly affects defect size reduction, with defects disappearing in conditions (3) and (5).

Based on these findings, it is preferable to weld AISI 316 using conditions (C), (D), and (E) to minimise defect size and quantity.

Following the dye penetration analysis, X-ray inspection is performed on the same samples. This confirmed that rotary friction welding produces fewer macroscopic volumetric defects under AISI 304 steel welding conditions, with no macroscopic defects observed. The results are confrimed by refrerences /24-25/. A third analysis using ultrasonic tests reveals that defect size increases when friction time is shorter, around 4 and 5 seconds. However, for the last three conditions with friction times of 7, 9, and 11 s, the defect size is very small. The no-forging condition (condition 1) shows the largest defect size. Forging pressure significantly affects defect size reduction, with defects disappearing in conditions (3) and (5). Based on these findings, it is preferable to weld AISI 316 using conditions (C), (D), and (E) to minimise defect size and quantity, /26/.

REFERENCES


1. Arzour, F.Z., Amara, M., Suleiman, R.K., M. Hadj Meliani (2023), *Thermomechanical effect on the properties of stainless steels using rotative friction welding: an experimental study on 304L and 316L grades*, Int. J Adv. Manuf. Technol. 129: 3849-3861. doi: 10.1007/s00170-023-12522-7
2. ASM Committee on friction welding. *Friction Welding*, In: Welding, Brazing, and Soldering, 9th Ed., Vol.6, pp. 719-728. Materials Park, OH, USA: ASM International, 1989.
3. Nicholas, E.D. (1977), *Friction welding*, Metal Construction, 9(1): 23-25.
4. Dunkerton, S.B. (1986), *Toughness properties of friction weld in steels*, Weld. J, 65(8): 193S-202S.
5. Gourd, L.M., Principles of Welding Technology, 1986. Hodder Arnold, ISBN-13 978-0713136029
6. Van Leeuwen, W.H., Frich, S. (1986), *Mechanised ultrasonic inspection of radial friction welds*, In: 3rd lnt. Lnt. Conf., The Welding Institute, London, pp.303-311.
7. Nicholas, E.D., Thomas (1986), *Metal deposition by friction welding*, Weld. J, 65(8): 17-27.
8. Knipstrom, K.E., Bekkari, B. (1997), *A novel joining process - Friction stir welding*, Svetsaren, Esab, Sweden, 1-2: 49-52.
9. Fitch, A., Fauth, F. (2002), *Residual stress field in friction stir welded marine garde aluminium alloy*, ERSF, ME, 197: 11.
10. Nixon, J., Influence of environmental pressure on friction stud welding, report from SERC program Underwater Processes for Automated Applications, Marine Technology Centre, Cranfield Institute of Technology, UK, 1990.
11. Blakemore, G.R. (1992), *Design and implementation of a total control system for a portable friction welding machine*, paper 6, In: 4th Int. Conf. - Computer Technology in Welding, TWI, Cambridge, UK, 1992.
12. Brown, P., McGowan, C., Blakemore, G., et al. (1997), *Evaluation of hydro marine systems HMS 3000 portable friction welding machine*, In: ASM Int. European Conf. - Welding and Joining Science and Technology, Madrid, Spain, 1997.
13. Yamashita, Y., Fujita, K. (2001), *Newly developed repairs on welded area of LWR stainless steel by friction surfacing*, J Nucl. Sci. Technol. 38(10): 896-900. doi: 10.1080/18811248.2001.9715112
14. Lindemann, Z., Skalski, K., Włosinski, W., Zimmerman, J. (2006), *Thermo-mechanical phenomena in the process of friction welding of corundum ceramics and aluminium*, Bull. Polish Acad. Sci., Techn. Sci. 54(1): 1-8.
15. Sahib, M.H., *Friction welding and properties of welds for dissimilar alloys*, Doctoral thesis, Production Engineering and Metallurgy Department, Technology University of Iraq, 1994.
16. Hiadari, A.L., Hassani, A.L., *Friction welding for the austenitic stainless steel 316L with different type from copper*, Master thesis, Production Engineering and Metallurgy Department, Technology University of Iraq, 1997.
17. Hazra, M., Rao, K.S., Reddy, G.M. (2014), *Friction welding of a nickel free high nitrogen steel: influence of forge force on microstructure, mechanical properties and pitting corrosion resistance*, J Mater. Res. Technol. 3(1): 90-100. doi: 10.1016/j.jmrt.2013.12.001
18. Kimura, M., Kusaka, M., Kaizu, K., et al. (2016), *Friction welding technique and joint properties of thin-walled pipe friction-welded joint between type 6063 aluminum alloy and AISI 304 austenitic stainless steel*, Int. J Adv. Manuf. Technol. 82: 489-499. doi: 10.1007/s00170-015-7384-8
19. Pandia Rajan, S., Senthil Kumaran, S., Kumaraswamidhas, L.A. (2015), *Friction welding of 304 austenitic stainless steel tube to tube plate joints using an external tool*, J Adv. Mech. Des. Syst. Manuf. 9(3): 1-8. doi: 10.1299/jamdsm.2015jamdsm0045
20. Hassan, A.J., Boukharouba, T., Miroud, D., Ramtani, S. (2019), *Metallurgical and mechanical behavior of AISI 316 - AISI 304 during friction welding process*, Int. J Eng. 32(2): 306-312. doi: 10.5829/ije.2019.32.02b.16
21. Titouche, N.-E., Boukharouba, T., Amzert, S.A., et al. (2019), *Direct drive friction welding effect on mechanical and electrochemical characteristics of titanium stabilized austenitic stainless steel (AISI 321) research reactor thick tube*, J Manuf. Proc. 41: 273-328. doi: 10.1016/j.jmapro.2019.03.016
22. Hassan, A.J., Boukharouba, T., Miroud, D. (2019), *Characterizations of friction welding joint interface for AISI 316*, J China Weld. 28(1): 42-48. doi: 10.12073/j.cw.20180811001
23. Hassan, A.J., Lechelah, R., Boukharouba, T., et al. (2017), *History of Microstructure Evolution and Its Effect on the Mechanical Behavior During Friction Welding for AISI 316*, In: Boukharouba, T., Pluvinage, G., Azouaoui, K. (Eds.), Applied Mechanics, Behavior of Materials, and Engineering Systems, Springer Cham., 2017, pp.51-65. doi: 10.1007/978-3-319-41468-3_5
24. Habib, L., Azzeddine, H., Boukhris, L. (2020), *Experimental study of tensile shear test in friction stir spot welding*, Struct. Integr. Life, 20(2): 173-175.
25. Maslarević, A., Bakić, G., Rajičić, B., et al. (2023), *Influence of plasma transferred arc welding parameters on the obtained microstructure of 316L coating*, Struct. Integr. Life, 23(2): 123-128.
26. Jovičić, R., Jeremić, L., Milošević, N., et al. (2021), *Repair welding of pressure equipment with unacceptable defects*, Struct. Integr. Life, 21(2): 163-167.