Journal of Engineering and Sustainable Development
https://jeasd.uomustansiriyah.edu.iq/index.php/jeasd
https://doi.org/10.31272/jeasd.27.3.8

Vol. 27, No. 03, May 2023
ISSN 2520-0917

Original Research

INVESTIGATION OF FRICTION PRESSURE EFFECT ON WELDING QUALITY IN FRICTION STUD WELDING PROCESS

Mustafa S. Kadhim*, Kadhim K. Resan

Material Engineering Department, College of Engineering, Mustansiriyah University, College of Engineering, Baghdad Iraq

Received 13/7/2022 ***Accepted in revised form 20/9/2022*** ***Published 1/5/2023***

Abstract: The influence of friction pressure on welding quality when friction stud welding 1017 low carbon steel with AISI 304 austenitic stainless steel is investigated in this study. friction stud welding is employed in industrial applications instead of conventional welding processes Due to the friction welding process didn't need to reach the melting point of welded metals. Welding is performed on these dissimilar metals by utilizing a lathe machine with a load cell connected to a weight indicator and a manufacturing grip to fasten the plate at a rotating speed of 1600 RPM, a friction time of 20 seconds, and a friction pressure of (15, 20, and 25) MPa. After the welding procedure is completed, the specimens are subjected to tensile, torque, and hardness tests to evaluate the welding quality. In addition, optical microscope research was carried out to determine the microstructural aspects. The effect of friction pressure on welding quality was investigated based on the information generated from the results. The increase of friction pressure during the process from 15 MPa to 25 MPa leads to an increasing ultimate tensile strength from 203 MPa to 210 MPa approximately. Also, the torque values raised from 179 N.m to 198 N.m in the same case.

Keywords: *Friction stud welding; welding quality; friction pressure; dissimilar welding; AISI304; AISI1017*

1. Introduction

In the stud welding procedure, a metal fastener (stud) is welded onto a metal workpiece, meaning that at any time during the processing, the material is in a solid state [1]. Stud welding is a common welding technique in the construction industry [2]. Arc stud welding items can be used in a variety of mechanical applications, including manufacturing, mechanical structures, and the automobile industry [3]. However, when underwater welding is required, arc stud welding is not suited. In regions where arc welding is prohibited due to the risk of causing a fire or explosion, friction stud welding has been used to attach grating to offshore oil platforms. Anodes were previously installed in some of the tanks using a friction stud welding process to avoid damage to the painted surfaces during commissioning. When properly tested, friction stud welding can even be performed in zones with potentially explosive atmospheres [4-5].

Friction stud welding is a solid-phase welding process that uses a high-speed stud that is pressed against a substrate and generates heat through friction [6]. Friction stud welding is an excellent choice for deep-water naval applications, short-term emergency repairs, and submarine rescue [7]. Metals have substantially greater melting points than the highest temperatures reached. It's

**Corresponding Author*:
ebma013@uomustansiriyah.edu.iq

a one-of-a-kind friction welding technology. Friction stud welding equipment is provided for usage on construction sites, offshore, underwater, and in workshops [8]. Friction welding can be used to join various ferrous and non-ferrous metals that cannot be welded by using conventional fusion welding techniques [9]. Friction welding allows two dissimilar materials to be joined in a full-strength weld without affecting the quality or strength of the weld. Friction welding creates a full-surface weld formed of a completely new substance that combines the two original components [10].

For joining two components, friction welding uses the conversion of mechanical energy into thermal energy. Solid-phase metallurgical bonding is achieved because the source material does not melt during the performing process. This is in marked contrast to fusion welding procedures, which often require the creation of a melt pool [11-12]. Friction welding has several advantages, including considerable material savings, short production times, and the ability to join dissimilar metals or alloys [13]. Because of variations in the physical, metallurgical, and mechanical properties of the metals to be joined, combining dissimilar metals is more difficult than joining similar metals, resulting in the production of brittle phases that degrade the mechanical properties of the weldment. Welding austenitic stainless steel to low alloy steel results in alloying element segregation at grain boundaries, lowering the weld's mechanical characteristics and corrosion resistance. As a result, while welding stainless steel, precautions must be taken, such as selecting the correct welding conditions [14]. Friction stud welding parameters are friction pressure, forging pressure, friction time, forging time, and rotational speed [15-17].

Many studies were performed on the effect of these parameters on the quality of weldments when connecting objects by using a mill and friction machine such as:

Verma et al [18] compared the effects of 730 and 1133 rpm rotational speeds on connection strengths of connected specimens by friction stud welding process and found that the effect was positive where the joints had higher strength at the larger rotational speeds. After that, the friction time influence was discovered by an experimental study by Serkan et al [19], where they found that raising the friction time resulted in a significant increase in hardness. The forging pressure parameter effect on mechanical properties was investigated by Gawhar et al [20]. They found that the hardness values and the welding strength increased with increasing the forging pressure.

The current study dealt with the friction pressure parameter applied by using a lathe machine and a set of a load cell, manufacturing grip, manufacturing adapter, and weight indicator to investigate the welding quality of stud-plate joints welded by friction stud welding to evaluate the effect of friction pressure on the quality of welding.

2. Materials and Method

An austenitic stainless-steel stud (ASS 304) and low-carbon steel plate (LCS 1017) were used in the investigation, with chemical composition and mechanical properties shown in Tables 1 and 2. The dimensions of the stud were (16x75 mm), while the plate dimensions were (6x50x50 mm). The tools used in this study are the load cell, weight indicator, and manufacturing grip for fixing the plate. The parameters of the process are a rotational speed of 1600 RPM, friction time of 20 seconds, and friction pressure of (15, 20, and 25) MPa as shown in Table 3.

Table 1. Materials Chemical Composition

	Fe	C	Mn	Si	Cr	Ni
1017LCS	Balanced	0.170	0.432	0.284	0.0312	0.124
ASS 304	Balanced	0.964	0.934	0.693	16.6	10.3

Table 2. Materials Mechanical Properties

The Materials	Tensile strength (MPa)	Yield strength (MPa)
1017 LCS	405	340
ASS 304	700	450

Table 3. Process Parameters

Specimen No.	Rotational speed (RPM)	Friction time (Sec)	Friction pressure (MPa)
S1	1600	20	15
S2	1600	20	20
S3	1600	20	25

3. Experimental Procedure

3.1. The Procedure of the Process

The materials LCS 1017 and ASS 304 that whose chemical composition was mentioned in Table 1were used in this procedure. The procedure is as the following:

1. first, the plates and studs must be clear of any contaminants.
2. The assembly of the set as the stud fixed in the rotated chuck of the lathe while the plate is fixed in the manufacturing grip which is regard attached to the load cell settled on the tool post, the weight indicator is electrically turned on and connected with the load cell as the Fig. 1.
3. The lathe is turned on and keeps going at the 1600 RPM rotational speed.
4. The two parts are brought together for rubbing by axial force to obtain the heat produced from the friction.
5. After 20 seconds of time of applying the friction pressure, the pressure applied and the heat generated contribute to the plastic deformation of rubbing surfaces.
6. The next step is breaking the speed and giving a forging pressure for a while so that the joints cool and the welding completes. after the bond between the stud and the plate occurs, the welded specimen is removed. Fig. 2 shows 304 ASS stud -1017 LCS plate welded joint.

Figure 1. Complete set of Friction Stud Welding tools

Figure 2. 304ASS stud -1017 plate welded joint

3.2. Visual Inspection and Microstructure Test

The purpose of the visual examination is to check the flash uniformity of welded joints, and the magnitude of the heat-affected zone, in addition to detecting cracks and surface voids. While the microstructure test helps to understand the behaviour of the material after the process which affects the physical properties of the material such as strength, hardness, toughness, and corrosion resistance. The specimens were prepared for microstructure by cutting, coarse and fine grinding, and etching were used to prepare the joints according to ASTM E3. The microstructure of 1017 low carbon steel was revealed for 15 seconds in Nital solution, which is 98 percent water and 2% HNO3, whereas the microstructure of 304 ASS was revealed for 20 seconds in a solution consisting of (3 ml HCL + 2 ml HNO3 + 2 ml acetic acid) [21]. The optical microscopy MEIJI type with a magnitude of 200X was used for the microstructure test.

3.3 Tensile Test

The test was performed according to ASTM A370-14; standard test methods and definitions for mechanical testing of steel products. The purpose of the tensile test is to find out how strong a weldment joint is when welding dissimilar metals. For performing the test, there was a need to fix the plate while the stud was pulled vertically by the machine's jaws and that's why a fixture was made; Fig. 3 shows the fixture constructed for fixing the plate in the tensile test machine. The WDW 200E type Tensile test machine was used. The photo of the sample and the fixture in the tensile test machine is shown in Fig. 4.

Figure 3. The manufactured fixture according to ASTM A370-14

Figure 4. The sample and the fixture in the tensile test machine for testing

3.4 Torque Test

In the torque test, the stud should be torqued till the failure occurs. The torque tool assembly should be arranged according to ISO14555-2006, Fig. 5. The instrument used for performing the torque test is a digital torque wrench with the range (20-200 N.m) shown in Fig. 6. During the test, the nut is tightened with a torque wrench against a washer bearing on the sleeve by applying the load with some shear effect on the stud till fracture and then taking the value of fracture torque.

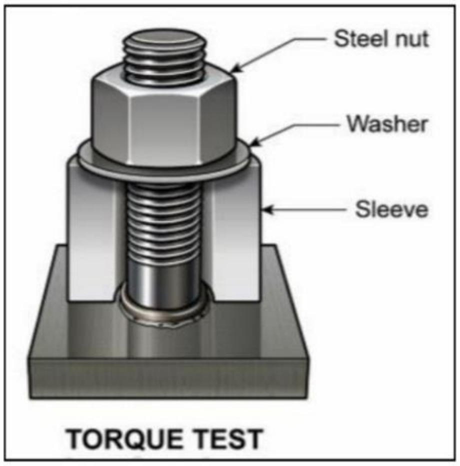


Figure 5. Torque Test Tools Assembly

Figure 6. Digital Torque Wrench

3.4 Hardness Test

The Rockwell B hardness (HRB) test of the welded samples was carried out in three lines (A, B, C), on the sectioned specimens, each line has five points {low carbon steel (LCS), low carbon steel heat affected zone (LCS HAZ), welding zone (WZ), Austenitic stainless steel heat affected zone (ASS HAZ) and austenitic stainless steel zone (ASS)} as shown in Fig. 7. This test to evaluate the wear resistance of the material and to determine whether the joints are suitable for the purpose. The hardness test machine used in this test was INNOVA-Nexus 700 as shown in Fig. 8.

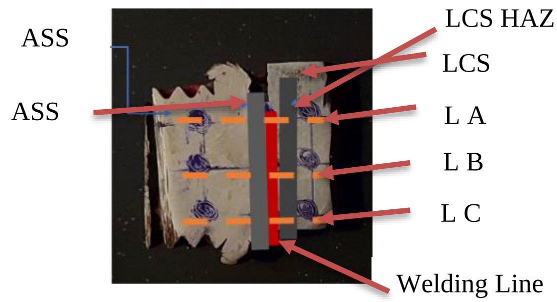


Figure 7. Specimen Divided to 15 Points for HRB Test

Figure 8. INNOVA, Nexus700 Hardness device

4. Results and Discussion

4.1 Visual Inspection and Microstructure Test Results

In all three specimens, the flash around the stud shows uniformity and continuity and there are no cracks or surface voids. The amount of flash increases with increasing the friction pressure applied. The formation of flash almost from the 304 ASS. Due to that 1017 carbon steel is cold worked (rolling) so the surface barrier should expose to high energy to overcome and that needs for certain pressure a more period, this leads to softening of stainless steel before overcoming the carbon steel barrier and hence the flash is formed mostly from austenitic stainless steel [22].

The microstructure of three specimens revealed that there are three zones; the welding zone (WZ) has a very fine grain structure due to the full recrystallization, and the size of grains starts to be bigger in the heat-affected zone (HAZ) due to partial deformation and the associated reduction in strain and strain rate. The third zone is the base metal (BM) which has a coarser grain structure and maybe grain growth occurs depending on the peak temperature of the welding process [13]. Fig. 9 shows the welding zone (WZ) and heat-affected zone (HAZ).

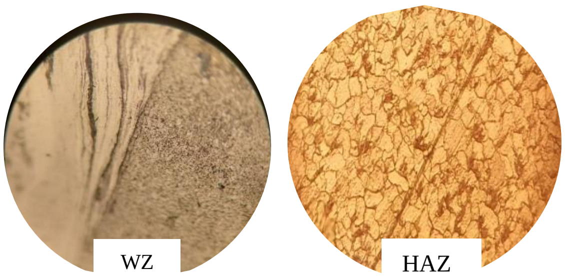


Figure 9. Microstructure of welding and heat-affected zones

4.2 Tensile Test Results

The results of the tensile test of the three specimens (S1, S2 &S3) were in Table 4 and Fig. 10.

In Fig. 10, the Bar charts show the results of the S1, S2, and S3 Specimens Ultimate Tensile strength. The highest value was (210.45 MPa) of S3 of friction pressure 25MPa while the lowest value was (203.52) MPa of the specimen S1 of 15 MPa of friction pressure. The value recorded of S2 with the 20 MPa is (208.94 MPa).

Table 4. Tensile Test Results

Specimen No.	Ultimate Tensile Strength (MPa)
S1	203.52
S2	208.94
S3	210.45

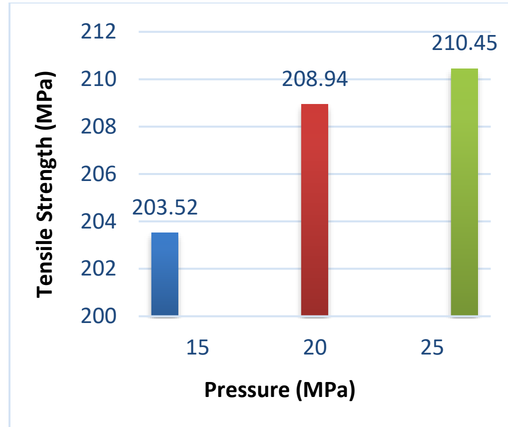


Figure 10. Tensile Test Results

4.3 Torque Test Results

The torque test of welded samples is shown in Table 5 and Fig. 11. The torque results obtained in Fig. 11 of S3 measured a maximum torque of 198.4 N.m when the friction pressure was bigger (25MPa), while S1 had a minimum torque of 179.2 N.m with (15 MPa) friction pressure. S2 also recorded 195 N.m when its friction pressure was (20MPa). That means the increase in friction pressure leads to an increase in both tensile and torque values.

Table 5. Torque Test Results

Specimen No.	Torque (MPa)
S1	179.2
S2	195
S3	198.4

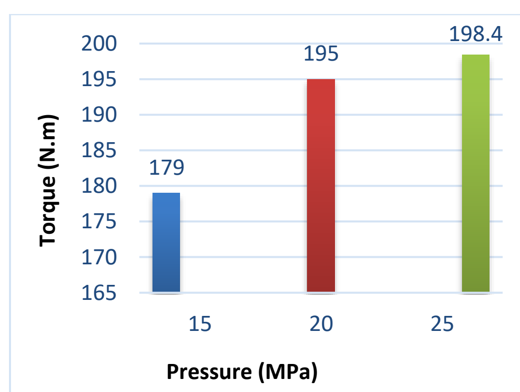


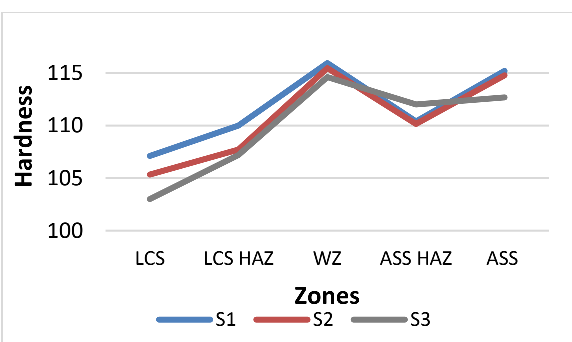
Figure 11. Torque Test Results

4.4 Hardness Test Results

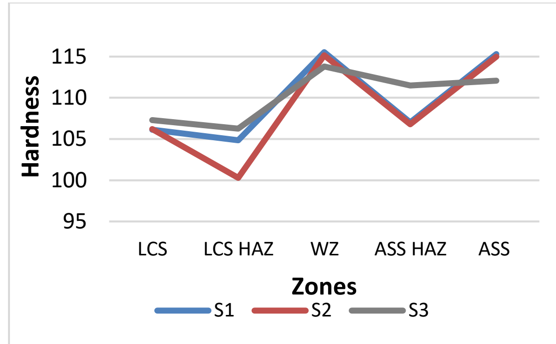
The Hardness results of inspected specimens showed in Table 6 and Fig. 12. The obtained values showed that the highest hardness region was the welding zone. Line A and C have bigger results than Line B due to the linear distance traveled at the edges of the sample is greater than the distance traveled in the center, and this means greater friction, and therefore a greater temperature that finally leads to a greater temperature gradient with the surrounding environment resulting in higher hardness values [23].

Table 6. Hardness Test Results

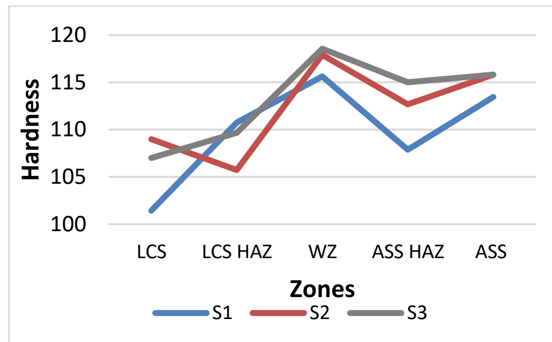
No.		LCS zone	LCS HAZ	WZ	ASS HAZ	ASS zone
S1	L A	107.1	110	115.93	110.39	115.2
	L B	106.12	104.85	115.54	107.04	115.29
	L C	101.43	110.76	115.63	107.86	113.45
S2	L A	105.33	107.72	115.45	110.15	114.78
	L B	106.22	100.29	115.16	106.8	115
	L C	108.98	105.73	117.91	112.67	115.83
S3	L A	103	107.18	114.6	111.99	112.67
	L B	107.31	106.26	113.8	111.51	112.09
	L C	107	109.66	118.56	115	115.82



a. Line A



b. Line b



c. Line C

Figure 12. a, b, and c Shows the Lines Drawn by Hardness Test on The Specimens

4. Conclusions

Low carbon steel and austenitic stainless steel metals were welded by friction stud welding process and the effect of friction pressure parameter was studied. The results were as the following:

1. There are three zones recognized in the welded joints which are the welding zone (WZ), heat affected zone (HAZ), and base metal zone (BM), where the welding zone (WZ) has the smaller grain size. The grain size grows when the distance increased away from the welding zone.
2. The most flash formed during the process is in the austenitic stainless steel side and its quantity increased with increasing the friction pressure.
3. The increase in friction pressure led to an increase in the values of tensile strength due

to the rising bond strength at higher compressive forces.

4. The torque values significantly rose when friction pressure increased.
5. The highest hardness value was in the welding zone, however, even in the welding zone, the hardness value of the edges increased when compared to the center because the heat generated on the edges was higher.

Acknowledgments

The authors would like to acknowledge the Journal of Mustansiriyah University-College of Engineering, as well as the Materials Engineering Department staff, for their unlimited support.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Author Contribution Statement

Kadhim K. proposed the research problem and supervised the work.

Mustafa S. performed the measurements, manufactured the samples, processed the experimental data, performed the analysis, drafted the manuscript, and designed the figures.

Both authors discussed the results and commented on the manuscript.

5. References

1. Resan K., Takhakh A., and Salman A., (2014). *Effect of Friction Stir Processing (FSP) to the Mechanical Properties of 7075-T73 Aluminum Allys Plates Welded by Friction Stir Welding*. Jorurnal of Engineering and Development, Vol.18, No.5.
2. Behrend K., Marqués J., Forster G. Jenicek A., Müller M., Cramer H, Jilg A., Soyer H., and Schein J., (2014). *Stud arc welding in a magnetic field – Investigation of the influences on the arc motion.* Journal of Physics: Conference Series. 550. 012003. https://doi.org/10.1088/1742-6596/550/1/012003.
3. Firas H. H., Sami A. N., and Muzher T. M., (2021). *Study the Effect of Welding Current and Time on The Microstructure and Strength of Dissimilar Weld Joint AISI 303/AISI 1008.* Diyala Journal of Engineering Sciences, Vol. 14, Issue 1, PP.67-75. https://doi.org/10.24237/djes.2021.14106.
4. Jones D. J. J., and Sankaranarayanan R., (2020). Friction Stud Welding –An Overview, AIP Conference Proceedings 2220, pp. 140037, India, https://doi.org/10.1063/5.0001232.
5. Chandima R. M., Ytterhaug H. O., Bogwald P. and Nilsen S. T. R., (2015). *Underwater friction stud welding optimal parameter estimation: Engineering robust design-based approach*. Journal of Offshore Mechanics and Arctic Engineering. Vol. 137, Issue 1. https://doi.org/10.1115/1.4028466.
6. Rajesh N., Nagaraj P., and Angela J., (2014). *Ultrasonic evaluation of friction stud welded AA6063/AISI 1030 steel joints*. Mater Des, Vol. 62, PP.118–123. https://doi.org/10.1016/j.matdes.2014.05.017.
7. Samuvel D. S., Pravin R., S. Kavin S. R., Benita B., Samuel N. D., and Nagarajan R., (2020). Process Capability & Fascinating Applications of Friction Stud

welding. Materials Science and Engineering, Vol. 923, International Conference on Technological Advancements in Materials, Design, Manufacturing and Energy Sectors (ICTAMDMES'20) 20-21 February 2020, Chennai, India. https://doi.org/10.1088/1757-899X/923/1/012029.

8. Rajesh N., Nagaraj P., and Angela J., (2014). *Investigation on joining of aluminium & mild steel by friction stud welding*. Material Manufacturing Process. Vol. 27, Issue 12, PP. 1409-1413. https://doi.org/10.1080/10426914.2012.667894.
9. Ananthapadmanaban D., Seshagiri Rao V., Nikhil A., and Prasad K. R., (2009). *A study of mechanical properties of friction welded mild steel to stainless steel joints*. Materials and Design, Vol. 30, PP. 2642–2646. https://doi.org/10.1016/j.matdes.2008.10.030.
10. Maalekian M., (2007). *Friction welding – critical assessment of literature*. Science and Technology of Welding and Joining, Vol. 12, Issue 8, PP. 738-759. https://doi.org/10.1179/174329307X249333.
11. Sandeep R., Manu S., Sachin M., Kundra T. K., and Arshad N. S., (2018) *Friction Based Additive Manufacturing Technologies. Principles for Building in Solid State, Benefits, Limitations, and Applications*. USA, Ch. 3. ISBN: 9781351190862
12. Ihsan K., Edip C., Musa K., and Zülküf B., (2019).*Investigating Microstructural Properties of 5140 Steel with 316 Stainless Steel Joined by Friction Stud Welding*. 4th International Science Symposium, Kiev-Ukraine, pp. 19-24.
13. Jaykumar J. V., and Vishvesh J. B., (2019). *Advances in Welding Technologies for Process Development*. New York, Ch. 10.
14. Ehab N. A., Salman O., Muhaed A Mohammed ., H. A., and Abood N. A, (2018). *Dissimilar Welding of AISI 309 Stainless Steel to AISI 1020 Carbon Steel Using Arc Stud Welding*. ICOASE, Iraq. https://doi.org/10.1109/ICOASE.2018.8548844.
15. Tharmaraj R., Rajesh N. J. H., and Shenbaga P., (2020). *Investigation on friction stud welded AMC/AISI 304 steel joints with ceramic intercoating.* Journal of the Brazilian Society of Mechanical Sciences and Engineering, Vol. 42, Issue 538. PP. 8. https://doi.org/10.1007/s40430-020-02621.
16. Annette B. and Carlos G., (2007) *Welding Handbook*. 9th ed. 2007. Miami. Vol.3, Part 2.
17. G. Kapil., (2020). *Surface Engineering of Modern Materials*. South Africa, 1st ed. 2020. Ch2..
18. Verma G., Sandeep K., and Bharat R. B., *A Research Paper on The Comparison of Weld Strength of Friction Welding of Different Materials at Two Different RPM. 2016*, International Journal of Mechanical Engineering and Technology, Vol. 7, Issue 6, pp. 123–127. ISSN: 0976-6359
19. Serkan B, Musa K, and Ihsan K., (2016). *Friction welding of dissimilar AISI 304 and AISI 8640 steels*. European Journal of Technic, vol. 6, Issue 2, pp. 79-86.
20. Gawhar, I. K. and Sherko A. B., (2019). *Efficiency of dissimilar friction welded*

1045 medium carbon steel and 316L austenitic stainless steel joints. Journal of Materials Research and Technology, Vol. 8, Issue 2, pp. 568. https://doi.org/10.1016/j.jmrt.2018.01.002.

21. Mohammed H. A., (2016). *Microstructural and Mechanical Properties of Stud Arc Welding of Austenitic Stainless Steel Studs AISI 304 and AISI 316L to Carbon Steel AISI 1020.* Thesis, The Engineering Technical College-Baghdad, Iraq. https://doi.org/10.1007/s13632-021-00744-8.
22. Niyanth. S., (2016). *Fundamental Understanding of Bond Formation During Solid State Welding of Dissimilar Metals*. Ph.D. Thesis, the University of Tennessee, Knoxville.
23. Anitha P., Manik C., Saravanan V. and Rajakumar S., (2018). *Effects of Friction Pressure and Friction Time on the Mechanical and Microstructure Properties of Friction Welded Inconel 718 and SS410 Dissimilar Joints*. Journal of Advanced Microscopy Research. Vol. 13, Issue 2, pp.211-216. https://doi.org/10.1166/jamr.2018.1381.