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Metallurgical and Mechanical Behavior of AISI 316- AISI 304 during Friction Welding Process

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ABSTRACT

Present study focuses on the micro-structural and mechanical behavior effect of friction time for similar (AISI 316-AISI 316 and AISI 304-AISI 304) and dissimilar (AISI 304-AISI 316) joint during continuous drive friction welding. The welding carried out with different friction time: 6.5, 8.5 and 10 s while kept all other conditions constant. The effect of that time on the strength, structural and behavior of welded metals was investigated by Energy Dispersive Spectroscopy (EDAX), Scanning Electron Microscope (SEM), micro-hardness and tensile test. The obtained results illustrated that the friction time extended was responsible on some harmful mechanical and micro-structural properties of the welded joint. Therefore, increasing in friction time is led to reduce of Ultimate Tensile Strength (UTS), reduce of ductility, increasing in level of micro-hardness and larger HPDZ, that was clearly observed in similar joint (AISI 316-AISI 316 and AISI 304-AISI 304).

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1. INTRODUCTION

Friction welding has been used in several industrial applications such as manufacturing, transportation, aerospace and nuclear field. Among the friction welding techniques, friction stir [1-3] and continuous drive [4-7] are the most popular. During continuous drive, one of the parts is held stationary while the other rotates and the two are being brought into contact of each other. The friction between the contact parts produced by a combination of rotation and compression force applied, which is resulting energy transformed into heat. This technique has some practical features, for example, low temperature, short time, reproducibility, low heat input and allows assembly of similar or dissimilar materials [4-6]. Various works considerd the effect of friction welding conditions on the micro-structural and mechanical properties of welding joint [4-8]. Currently, short friction time and high rotation speed obtained high tensile strength [7-8]. Thus, this effect revealed at high welding speed in friction stir welding [2], also obtained low heat input and better corrosion resistance [9].

There are two periods of time during friction welding cycle, one for friction phase and the other for forging phase [4-8]. Therefore, to illustrate the friction time effect, Hassan et al. [10] separated friction phase time into two steps and eliminate forging phase. High micro-hardness values found at first step while very low values were obtained at the second step. Consequently, present study focused on the effect of friction time at high rotation speed (3000 rpm) with joining of AISI 316 and AISI 304, that time has responsibility on the amount of heat diffusion [6], which is carrying the great blaming on behavior of metallurgical and mechanical properties of the welding joint. However, the industrial necessitates and because of several applications of AISI 316 and AISI 304, the present study focuses on these types of austenitic stainless steel

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2. MATERIALS AND METHOD

2. 1. Parent Metals When the parent metals received, presently, measured the chemical compositions of elements by spectrometer and mechanical properties by mechanical tests as respectively shown in Tables 1 and 2. For optical microstructures were electrolyte etched by 10 g oxalic acid hydrate and 90 ml water at 15 V for period of 300 s as showing in Figure 1. The figure illustrates the austenitic equiaxed grains of AISI 304 are finer than grains of AISI 316.

2. 2. Friction Welding Friction welding machine used in this work was designed and fabricated as a continuous friction welding machine (Figure 2). Whereas, selected welding conditions related to the metals nature, samples cross-section and previous articles [6, 8, 10]. Table 3 shows different friction time and the following conditions were considered constant: rotation speed 3000 rpm; friction pressure 130 MPa; forging pressure 260 MPa and forging time 5 s.

For dissimilar welding joint according to their mechanical properties, AISI 316 chucked in rotating part while AISI 304 clamped in stationary once to obtain uniform flash metal formation.

2. 3. Temperature Measurement For each welding operations, the generated temperature was measured at the interface on the surface of the fixed part of the welded joint, cause of the temperature of the peripheral region would be higher [11]. The thermal curve as illustrate in Figure 3 presents average temperatures versus time, it can be seen the friction welding phases and their steps.

TABLE 1. Alloying elements of base metals (% wt)

Metals	C	Mn	Si	P	S	Mo	Cr	Ni
AISI 316	0.040	1.500	0.670	0.030	0.021	2.93	17.93	9.95
AISI 304	0.070	1.650	0.750	0.045	0.030	0.80	19.00	8.00

TABLE 2. Mechanical properties of base metals (as received; Ref. No. 4401 for AISI 316 and Ref. No.4301 for AISI 304)

Metals	Yield stress 0.1% (MPa)	UTS (MPa)	Young's modulus (MPa)	Elongation (%)	Average micro-hardness ($Hv_{0.1}$)
AISI 316	≥ 550	670 - 680	≈ $1.93\ 10^5$	≈ 45	260 - 265
AISI 304	≥ 600	760 - 780	≈ $1.93\ 10^5$	≈ 47	280 - 286

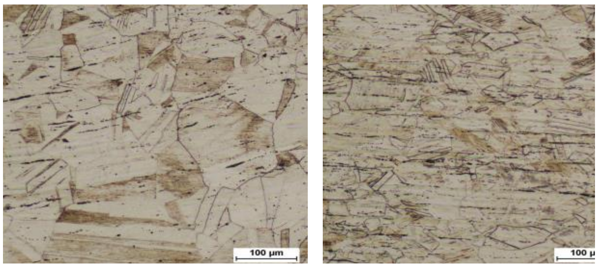

Figure 1. Optical microstructures of base metals, [left: AISI 316]; [right: AISI 304]

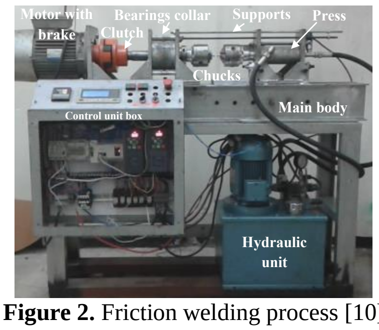

Figure 2. Friction welding process [10]

TABLE 3. Different friction time for similar and dissimilar joint

Metals	Friction time (s)
	6.5
AISI 316-AISI 316	8.5
	10
	6.5
AISI 304-AISI 304	8.5
	10
	6.5
AISI 304-AISI 316	8.5
	10

The friction between two parts increases the interface temperature until maximum, while the metal still in solid state until that point, the produced heat convert the metal from solid to plastic state, which is lead to deceases in temperature where the high compression force extrudes metal from central to the peripheral to form flash metal.

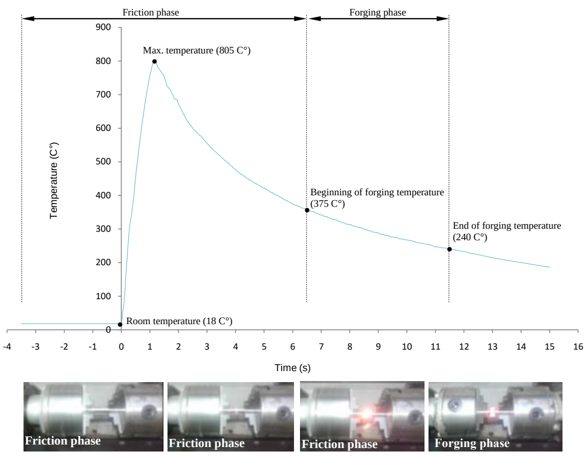

Figure 3. Thermal curve seems friction and forging phase time [AISI 304-AISI 316, 10 s]

When sufficient energy is developed, the rotation stopped and compression force increased, to forge the parts together and obtained post-forge friction welding joint. Noticed, the temperature reading was verified by thermocouple type K with dia. 0.5 mm and range of temperature between -50 to 1370 °C (± 50 °C, at high temperature).

2. 4. Metallography Macroscopic observations were carried out by optical macroscopic from type NIKON SMZ 745T. On the other side, the microstructure observations were achieved by optical microscopy NIKON ECLIPSE LV100ND. Hence, the test pieces were electrolyte etched by 10 g oxalic acid hydrate and 90 ml water (STRUERS LECTROPOL-5) at 15 V for period of 300 s.

2. 5 Mechanical Tests Micro-hardness measurements $Hv_{0.1}$ analyzed by SHIMADZU HMV included micro-hardness survey along the axis of rotation. While, tensile tests were performed by using INSTRAN 5500 and carried out on the standardized test piece ISO 6892-1: 2009 (F), machined in the direction of rotation axis (Figure 4). Tensile fracture surface and EDAX were observed by SEM JEOL JSM-6360 (EDAX).

3. RESULTS AND DISCUSSION

3. 1 Macro-Microstructure of Welding Joints Macroscopic views and the axial shortening for the three friction times for similar and dissimilar joint are demonstrating respectively in Figures 5 and 6. Large amount of flash formation and high axial shortening have seen at friction time increased, because of amount of heat diffusive. Whereas, mechanical and thermo-physical properties of two welded metals are

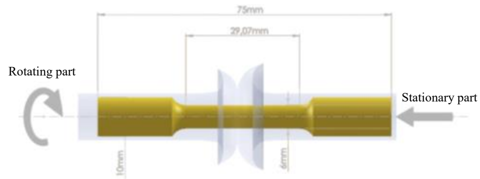

Figure 4. Tensile test piece

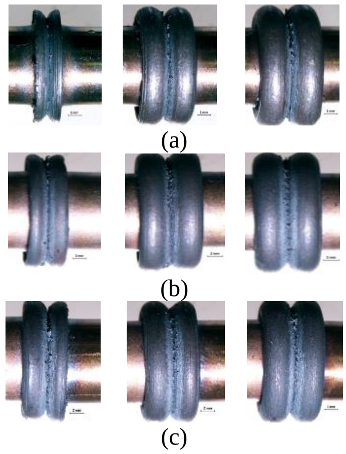

Figure 5. Flash formation (a) (AISI 316-AISI 316), (b) (AISI 304-AISI 304) and (C) (AISI 316-AISI 304)

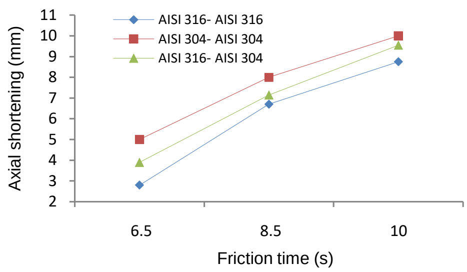

Figure 6. Effect of friction time on the axial shortening

responsible on non-symmetrical flash formation for dissimilar joint [11].

Friction welding generally improves the microstructure grains; it's indicated by good friction welding joint for AISI 316 and AISI 304, also no cavities or cracks are being in the welding region. For similar and dissimilar welding joints, the central region (high plastically deformed zone HPDZ) consists of fine black equiaxed grains (Figure 7), while the adjacent regions (deformed zone DZ and partially deformed zone PDZ) contain bent, elongated and parallel banded grains (Figure 8). Average wide of HPDZ, DZ, PDZ for different friction time: [HPDZ: 130 µm, DZ: 350 µm,, PDZ: 550 µm for 6.5 s (AISI 316-AISI 316)]; [HPDZ: 210 µm, DZ: 600 µm,, PDZ: 920 µm for 10 s (AISI 316-AISI 316)]; [HPDZ: 80 µm, DZ: 500 µm, PDZ: 900 µm for 6.5 s (AISI 304-AISI 304)]; [HPDZ: 100 µm, DZ: 380 µm, PDZ: 910 µm for 10 s (AISI 304-AISI

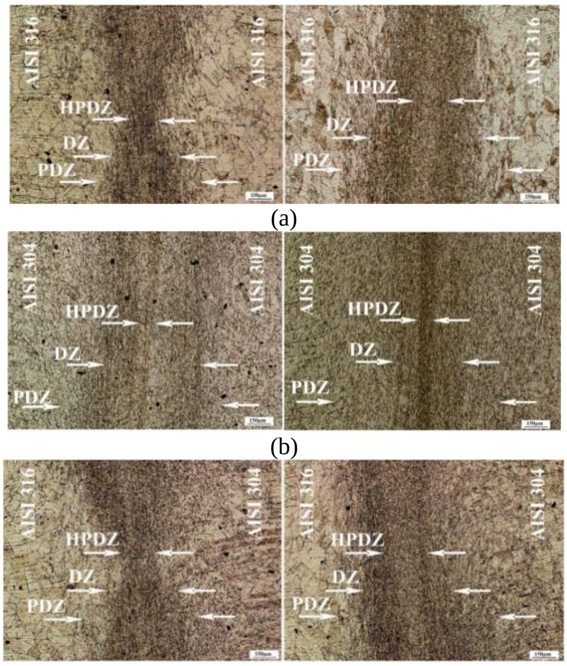

Figure 7. Optical microstructure of (a) (AISI 316-AISI 316), [left: 6.5 s]; [right: 10 s], (b) (AISI 304-AISI 304), [left: 6.5 s]; [right: 10 s] and (C) (AISI 316-AISI 304), [left: 6.5 s]; [right: 10 s]

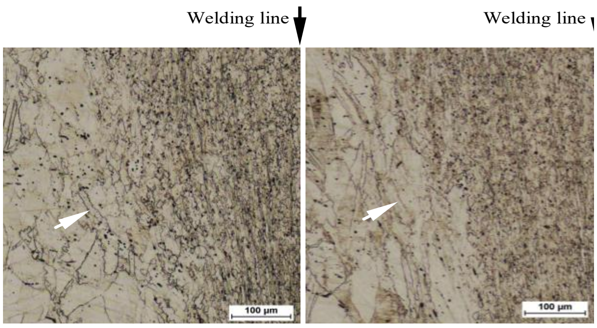

Figure 8. Bent, elongated and parallel banded grains for DZ and PDZ (AISI 316- AISI 316), [left: 6.5 s]; [right: 10 s]

304)]; [HPDZ: 160 µm, DZ: 380 µm, PDZ: 610 µm for 6.5 s (AISI 316-AISI 304)]; [HPDZ: 250 µm, DZ: 600 µm, PDZ: 880 µm for 10 s (AISI 316-AISI 304)].

Amount of thermo-plastic deformation can dictates the dimension of HPDZ. Therefore, if the friction time is shorter the dimension of HPDZ is narrow (Figures 7A, 7B and 7C left), as well as at longer friction time (Figures 7A, 7B and 7C right) the HPDZ is large. However, longer friction time led for widen of heat diffusion toward the axis of rotation and permit to lower cooling rate and larger heat affected zone [6]. Although, HPDZ doesn't extend to the peripheral [11]; because of temperature, dynamic recrystallization and thermo-plastic deformation have not the same effect from central to the peripheral. Grains refinement and narrow size occurred at central region due to dynamic recrystallization [11, 12] and thermo-mechanical-deformation effect, consequently the welding quality [7]. Dynamic recrystallization often occurs when the metal experiences hard plastic deformation under high temperatures, the post-forge interface joint will be obtain with densely recrystallized grains forms. Furthermore, the recrystallization phenomena affected by several coefficients, such as deformation conditions, initial grain size, metal chemical composition and crystal structure [13].

3. 2. Mechanical Properties

3. 2. 1. Micro-hardness Profile The profiles of micro-hardness along the axis of rotation are illustrated in Figure 9 reveals the values of micro-hardness increase clearly with increasing friction time around the center on the two axes [14]. The micro-hardness profiles for AISI 304-AISI 304 joint have an average value reach about 280 $Hv_{0.1}$. While, for AISI 316-AISI 316 joint the friction time is shorter (6.5 s) shows there is a hardening in rotating part and softening in stationary part because it has little influence of mechanical action related to rotating part (Figure 9). However, at longer friction time (10 s) find symmetrical form of micro-hardness profile for both sides (Figure 9). In the same method, can be obviously in AISI 304-AISI 316 joint a general softening of micro-hardness profiles is also obtained for both sides. If the friction time is shorter (6.5 s) the average values of micro-hardness at HPDZ are in the level of AISI 316. Hence, at longer friction time (8.5) the HPDZ has average value of micro-hardness in level of AISI 304.

The values of micro-hardness are dictated by forging application [6, 10, 11] and an interactive effect between friction and forging [11]. Thus, the increasing in micro-hardness at welding interface may be explained by high plastic deformation and heating diffusion of material at that region [14]. Consequently, the refinement of grains size in welding center as shown in Figure 7 gives that increase in micro-hardness level. The effect of friction time can be confirmed the evolution of post- forging mechanical properties, which are the aim of this work. If longer friction time is obtained, more heat diffuses [4]. The latter under effect of axial pressure is responsible for hardening of post-forging joint, where HPDZ is large and the area of refinement grains is wide. Conversely, if the friction time is shorter the heat diffusion is very low [5] and the post- forging joint will be formed with a little values of micro-hardness, where HPDZ is thin and the area of refinement grains is contracted. The micro-hardness profiles for dissimilar welding because of AISI 316 is more refractory than AISI 304 (according to the amount of Mo, and Cr) as shown in Figure 10, therefore, it has ability to keep more amount of heat, that is leading to low speed of cooling rate and resulting of softening at AISI 316 side because of grain growth (Figure 7).

3. 2. 2. Tensile Tests From tensile tests curves as shown in Figures 11A and 11B it is observed that for similar joint, longer friction time achieved low tensile strength, low ductility, high level of micro-hardness and larger HPDZ, while shorter friction time exhibited a reverse trend cause of no enough time for heat diffusion. Consequently, use of higher rotational speed and shorter friction time increases UTS of welded joint [7].

On the other hand, for dissimilar joint (Figure 11c) high ductility recorded for 6.5 s while high tensile strength for 8.5 s, because of the mechanical and thermo-physical properties of dissimilar joint have mainly influence on the mechanical behavior of that joint because the temperature achieved by every joint depends on the thermo-physical properties of the two metals being welded and on the selected period of friction time. Therefore, the relations between stress-temperature for each joint will effect on the joint properties resulted through welding operation [11]. Moreover, metals have different thermo-physical properties can be joining successful by friction welding; thus, they have tensile strengths and ductility closest to those from similar alloy.

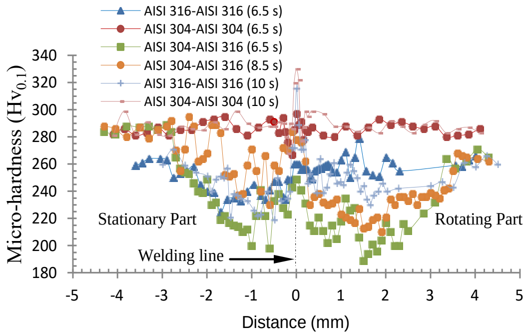

Figure 9. Micro-hardness profile for axis of rotation vs. friction time

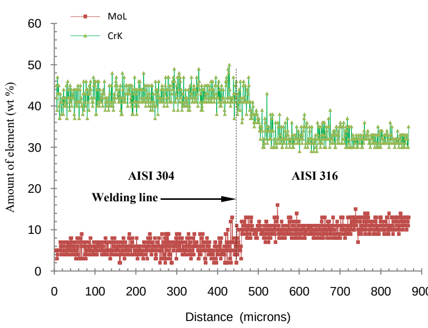

Figure 10. EDAX analysis for [AISI 304-AISI 316, 8.5 s]

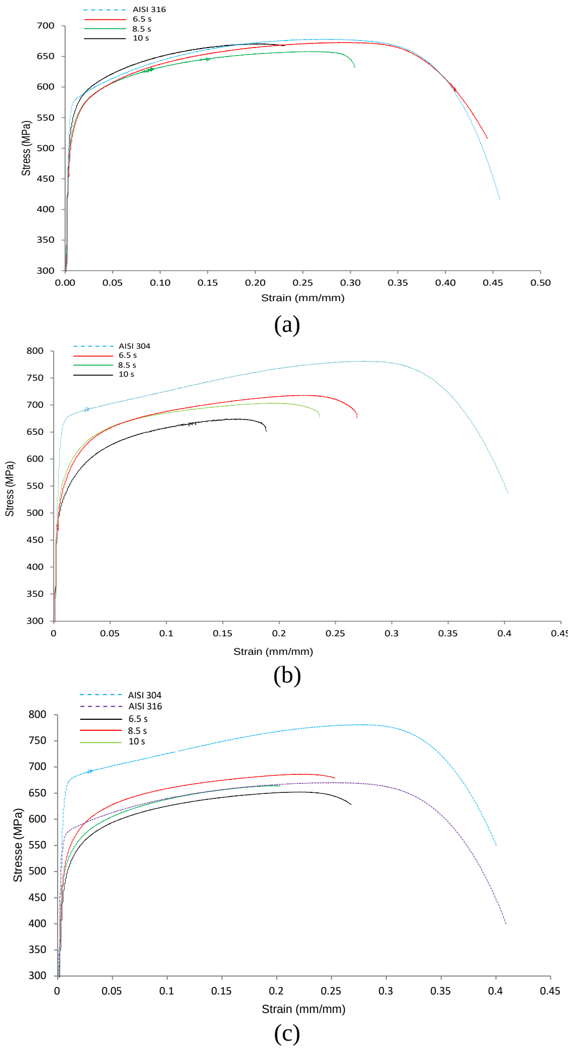

Figure 11. Stress strain curves for (a) AISI316-AISI 316, (b) AISI304-AISI 304 and (c) AISI 316-AISI 304

The macro-graphic of tensile test pieces reveals more elongation in gauge length and reduction in the welding zone for 6.5 s for similar welding joints Figures 12A and 12B and reduction in the welding zone were clearly for all specimens in dissimilar welding joints Figure 12c. Thus, for AISI 304-AISI 316 joint specimens, the breaking occurred principally on the AISI 316 part or precisely in the zone beside the welding line.

3. 3. Fracture Surface Observation Fracture surface observation by SEM is shown in Figure 13 illustrates amount of dimples formation, which is fractured surface proves that the fracture is mostly ductile mode [12]. It showed also the dimples with a few cleavage facets. Moreover, observed that the AISI 304-AISI 304 joint (Figure 13 b) has more ability to thermo-plastic deformation than AISI 316-AISI 316 and

Figure 12. Macro-graphic of tensile test pieces

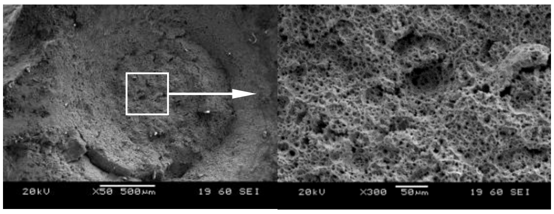

Figure 13 A. SEM observation, AISI316-AISI 316 [6.5 s]

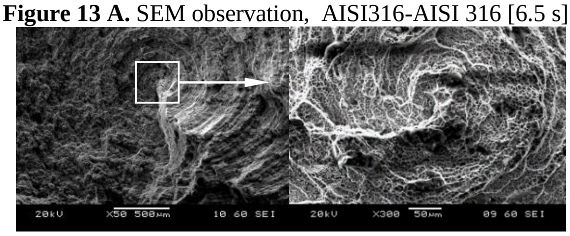

Figure 13 B. SEM observation, AISI 304-AISI 304 [6.5 s]

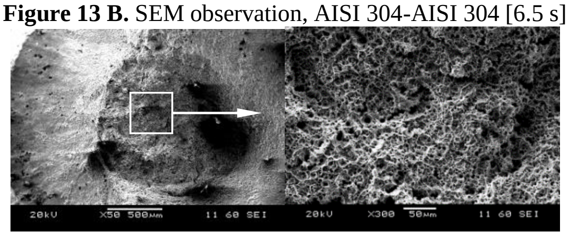

Figure 13 C. SEM observation, AISI 304-AISI 316 [8.5 s]

AISI 304-AISI 316 joint, demonstrated by the absence of the spirals shape on the fracture surface, resulted from metal flow that occurs near the plane of the weld cause of the rotating part against the stationary part.

4. CONCLUSION

According to present study the friction time controls the amount of heat diffusion, which is responsible on the behavior of the mechanical and micro-structural properties of the welded joint. Therefore, when friction time increased:

- Obtained large amount of flash formation and axial shortening,
- Large dimension of HPDZ at the interface of welding joint,
- Hard zone around the interface illusterted clearly for similar welding joint of AISI 316-AISI 316 and AISI 304-AISI 304,
- AISI 316 is more refractory than AISI 304, therefore, it has ability to keep more amount of heat, which is leading to low speed of cooling rate, and resulting softening at side of AISI 316 because of grain growth,
- Reducing of UTS and ductility at similar welding joint, which seems clearly at AISI 304-AISI 304 joint,
- Metals have different thermo-physical properties can be joining successful by friction welding; furthermore, they have tensile strengths and ductility closest to those from similar alloy.
- AISI 304-AISI 304 joint has more ability to thermo-plastic deformation than AISI 316-AISI 316 and AISI 304 –AISI 316 joint, verified by absence of spirals shape on the fracture surface.

5. REFERENCES

1. Hasanzadeh, R., Azdast, T., Doniavi, A., Babazadeh, S., Lee, R. E., Daryadel, M., Shishavan, S. M., Welding properties of polymeric nanocomposite parts containing alumina nanoparticles in friction stir welding proces, ***International Journal of Engineering Transactions A: Basics***, (2017), Vol. 30, No. 1, 143-151.
2. Singh, R., Rizvi, S. A., Tewari, S. P., Effect of friction stir welding on the tensile properties of aa6063 under different conditions, ***International Journal of Engineering. Transactions A: Basics***, (2017), Vol. 30, No. 4, 597-603.
3. Shishavan, S. M., Azdast, T., Aghdam, K. M., Hasanzadeh R., Moradian M., Daryadel M., Effect of different nanoparticles and friction stir process parameters on surface hardness and morphology of acrylonitrile butadiene styrene, ***International Journal of Engineering Transactions A: Basics***, (2018), Vol. 31, No. 7 , 1117-1122.
4. Kimura M., Kusaka M., Kaizu K., Nakata K., Nagatsuka K., Friction welding technique and joint properties of thin-walled pipe friction welded joint between type 6063 aluminium alloy and aisi 304 austenitic stainless steel, ***International Journal of Advanced Manufacturing Technology***, (2016), 82,489-499.
5. Çelik S., Güneş D., Continuous drive friction welding of al/sic composite and AISI 1030, ***Welding Journal***, (2012), 91, 222s-228s.
6. Hazra M., Rao K.S., Reddy G.M., Friction welding of a nickel free high nitrogen steel: influence of forge force on microstructure, mechanical properties and pitting corrosion resistance, ***Journal of Material Research and Technology***, (2014), 3, 1, 90-100.
7. Özdemir N., Investigation of the mechanical properties of friction welded joints between aisi 304l and aisi 4340 steel as a function rotational speed, ***Materials Letters***, (2005), 59, 2504-2509.
8. Bouarroudj, E., Chikh, S., Abdi, S., Miroud, D., Thermal analysis during rotational friction welding, ***Applied Thermal Engineering***, (2017), 110, 1543-1553.
9. Chen, Y.C., Gholinia, A., Prangnell, P.B., Interface structure and bonding in abrasion circle friction stir spot welding: A novel

approach for rapid welding aluminium alloy to steel automotive sheet, ***Materials Chemistry and Physics***, (2012), 134, 459-463.

10. Hassan, A. J., Lechelah, R., Boukharouba, T., Miroud, D., Titouche, N., Ouali, N., History of microstructure evolution and its effect on the mechanical behavior during friction welding for AISI 316, Edts. T. Boukharouba; et al., ***Springer International Publishing Switzerland***, (2017), 51-65.
11. Satyanarayana, V.V., Madhusudhan R. G., and Mohandas, T., Dissimilar metal friction welding of austenitic–ferritic stainless steels, ***Journal of Material Processing Technology***, (2005), 160, 128-137.
12. Uzkut, M., Ünlü, B. S., Akdağ, M., Determination of optimum welding parameters in connecting high alloyed x53crmnnin219 and x45crsi93 steels by friction welding, ***Bulletin of Material Science***, Indian Academy of Sciences, (2011), 34, 4, 815-823.
13. Liu, F.C., and Nelson, T.W., Twining and dynamic recrystallization in austenitic alloy 718 during friction welding, ***Material Characterization***, (2018), 140, 39-44.
14. Mitelea, I., Budau, V., Craciunescu, C., Dissimilar friction welding of induction surface hardened steels and thermo-chemically treated steels, ***Journal of Material Processing Technology***, (2012), 212, 1892-1899.

Metallurgical and Mechanical Behavior of AISI 316- AISI 304 during Friction Welding Process

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چکیده

در حال حاضر مطالعه بر روی رفتار اصطکاکی میکرو سازه و مکانیکی برای مشابه (AISI 316-AISI 316 و AISI 304-AISI 304) و غیر متقابل (AISI 304-AISI 316) در طی جوشکاری اصطکاک مداوم درایو تمرکز دارد. جوشکاری انجام شده با زمان اصطکاک مختلف: ٦,٥، ٨,٥ و ١٠ ثانیه در حالی که تمام شرایط دیگر را ثابت بوده است. اثر آن زمان بر قدرت، ساختار و رفتار فلزات جوش داده شده توسط اسپکتروسکوپ پراکندگی انرژی (EDAX)، میکروسکوپ الکترونی اسکن (SEM)، میکرو سختی و آزمون کشش مورد بررسی قرار گرفت. نتایج به دست آمده بیانگر آن است که زمان اصطکاک طولی بر برخی خواص مکانیکی و میکرو سازه جوش داده شده است. بنابراین، افزایش زمان اصطکاک باعث کاهش شدت مقاومت کششی (UTS)، کاهش قابلیت انعطاف پذیری، افزایش سطح میکرو سختی و افزایش HPDZ می شود که به طور واضح در مفصل مشابه دیده می شود (AISI 316-AISI 316 و AISI 304- AISI 304).

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