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Effect of Friction Time on Mechanical Properties of Two Dissimilar Welded Joints of Austenitic Stainless Steel AISI304 and Low Carbon Steel ST-37 Using Rotary Friction Welding Techniques

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***Abstract* - The current study focusing on investigating the mechanical properties of joining two dissimilar pieces of Austenitic stainless steel AISI304 and Low carbon steel ST-37 using rotary friction welding techniques. The metals were welded under different rotational speeds 560, 1030 and 1800(RPM) with varying friction time at each rotational speed.The tensile test, impact test, micro hardness distribution and microstructure examination of the welded specimen were carried out. At rotational speed 560(RPM) with forging pressure 65(Mpa), the tensile strength increasing when the friction time increased until reach to value 567(Mpa) at friction times 15, 20 (sec) then decreasing in tensile strength with increasing friction time.While at rotational speed 1030(RPM) with forging pressure 45(Mpa), the tensile strength increasing when friction time increased. While at rotational speed 1800(RPM) with forging pressure 80(Mpa), the tensile strength decreasing when friction time increased, until reach 551.5(Mpa) at friction time 9(sec) then increasing in tensile strength with increasing friction time. The maximum tensile strength was 596.3(Mpa) achieved at a rotational speed of 1030(RPM) with joint efficiency 93.8%. The hardness increases with increasing friction time at the weld zone.The impact energy decreasing when the friction time increased.**

Keywords: Friction Time, Welded Joints, Austenitic Stainless Steel, AISI304, Low Carbon Steel, ST-37, Rotary Friction, Welding Techniques.

I. INTRODUCTION

Friction welding (FW) is classified as a solid state welding process, because pieces to be welded do not reach the melting point, but the layers of joining between the two pieces occurs as a result of the heat generated by friction. "Friction welding is a solid state joining process that produces coalescence of materials under compressive forces contact of work pieces rotating or moving relative to one another to produce heat and plastically displace material from the faying surfaces. Under normal conditions, the faying surfaces do not melt. Filler metal, flux, and shielding gas are not required with this process"[1].

The process can be performed on similar and dissimilar materials, ferrous and non-ferrous materials which have wide variation in mechanical and thermal properties such as copper to aluminum, steel to copper, stainless steel to carbon steel, etc. The main advantages of friction welding are low production cost, material saving, and ability to weld dissimilar materials [2]. Friction welding has much number of applications in nuclear, aerospace, automobile, electrical, chemical, marine, cryogenic, etc. [3].

There are many type of friction welding are: rotary friction welding (RFW),linear friction welding (LFW), friction stir welding (FSW), friction stir spot welding (FSSW), inertia friction welding (IFW), etc.

In the (RFW), one part is fixed and rotates by electric motor to a predetermined speed, and the other part is positioned, aligned and moved to touch the part that is spinning. After that, friction pressure (P1) is applied for a given time (T1), heat is generated between two surfaces, the temperature rises below the melting point of the base metals, Thus the surfaces of the parts becomes plastic and flash material was produce, the machine brakes until it reaches zero speed (RPM=0), the forging pressure P2 is applied during a forging time (T2) to fabricate the joint, finishing the welding. Figure (1) shows the process [4].

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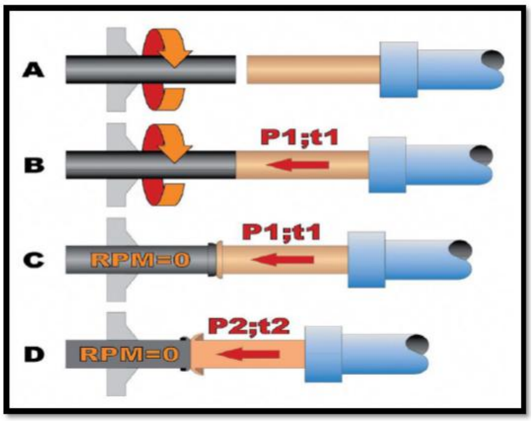

Figure (1): phases of conventional friction welding process. (A) Two parts one is rotating and the other is stationary. (B) applied friction pressure (P1)for a friction time(T1). (C) Braking the machine (RPM=0) flash begin formed. (D) Applied forging pressure (P2) during forging time (T2) and finish welding

There are many scientific researchers focus on developing this type of welding.

Ho Thi My Nu, Nguyen Huu Loc, and Luu Phuong Minh. (2020). Studied rotary friction welding to joint Ti6AI4V alloys rods, the results showed that the tensile strength and hardness decreases radially, therefore the radius of the welded part by rotary friction welding must be limited, because the poor quality of weld at the edges. An increased forging force produces fine, equiaxed, and recrystallized grain structures in the weld zone, results increasing tensile strength and hardness. Neglecting the effect of a small changes in rotational speed on the quality of the weld when the parts diameter is less than 15mm . the optimal parameters are: rotation speed of 1200 (RPM), and forging pressure of 62.5 (Mpa) [5].

Eder Paduan Alves, Francisco Piorino Neto, Chen Ying An, (2010). Also studied rotary friction welding of dissimilar parts of AA1050 aluminum to AISI 304 austenitic stainless steel, they found that it was not possible to weld dissimilar materials which have different thermal and mechanical properties with high quality, the maximum tensile strength is 80.08(Mpa). Obtained at friction pressure of 2.1(Mpa), friction time of 32(sec), forging pressure of 1.4(Mpa), forging time of 2(sec), and at fixed speed of 3200(RPM), the fracture occurred away from interface in AA1050 side, the hardness values are high in the interface and near the bonding interface on both side of materials, and decrease until reach the base materials [4].

CH. Muralimohan, S.Haribabu, Y. Hariprasada Reddy, V. Muthupandi, K. Sivaprasad,(2014).Studied continuous drive friction welding of 6082-T6 aluminum to pure copper rods. they reported that the tensile strength of the weld joint is 3.8% higher than the base meta of aluminum, the higher hardness observed at diffusion layer in the interface, with optimal parameters such as friction pressure of 110(Mpa), friction time of 6(sec), forging pressure of 160(Mpa), forging time of 4(sec),and rotation speed of 1500(RPM) [6].

M.Jafarzadegan, A. Abdollah-zadeh, A.H. Feng, T. Saeid, J.Shen, H. Assadi.(2013). Studied friction stir welding of Austenitic stainless steel to ST-37 low carbon steel. They showed that a sound weld with small recrystallized grains of austenite(which transform to ferrite and pearlite after cooling) have higher hardness, strength, and ductility at the stir zone(SZ) .the fracture occurred in ST-37 side [7].

R. KUMAR, M. BALASUBRAMANIAN. (2015). Studied rotary friction welding of Ti-6A1-4V to SS304L rods using interlayer techniques. It was shown that using copper interlayer in the weld joint has a significant role to obtaining excellent bonding of the parts without cracks and reduced heat affected zone. The effect of brittle intermetallic on mechanical properties reduced because formation of intermetallic compounds Cu3Ti and Fe30CuMn20 in alloy and SS side respectively. Also observed that with low interlayer thickness produce better mechanical properties [8].

Abdul Ghani Khan and S. Rajakumar.(2018) . Investigated rotary friction welding of Aluminum matrix composites LM25 with added 10% SiC. It was demonstrated that the Fully deformed zone (FDZ)has finer grains than Partially deformed zone(PDZ , while coarser grain was found at HAZ, as the rotational speed increasing,the grains get finer.Also the tensile and yield strength was increased with increase in rotational speed, and the highest value was181,162(Mpa) respectively at 2400(RPM) .the peak hardness was found at FDZ in all joints which highest value recorded was 72 HV [9] .

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Peng Li , Jinglong Li ,Muhammad Salman , Li Liang , Jiangtao Xiong , Fusheng Zhang . (2013).Studied the effect of friction time on mechanical properties for dissimilar materials of Ti6A14V to SUS321 welded by continuous drive friction welding. It was shown that the tensile strength increased with friction time, and maximum strength 560(Mpa),which is 90.3% of the SUS321 base metal, was obtained at a 4(sec)friction time. the fracture occurred along the joint interface where intermetallic compounds and other phases were formed in the both base metals. the optimized friction time was range of 2-4(sec) [10] .

M. Deepak Kumar , P.K. Palani ,V. Karthik (2020). Studied the effect of welding parameters on the weld joint strength of Duplex stainless steel UNS S31803 tubes welded by rotary friction welding. They concluded that a maximum tensile strength of 610(Mpa) obtained at heating load 1200(kg), heating time of 20(sec), upset load1200(kg),and upset time of 4(sec). and increasing in upset time and upset load leads to rapidly increasing in tensile strength. and the heating time have the greater effect on tensile strength. the ductile fracture of the highest tensile strength and brittle fracture of the lowest tensile strength [11].

The aim of the present work is to investigate the mechanical and microstructural properties of welding two dissimilar materials are AISI304 austenitic stainless steel to ST-37 low carbon steel using rotary fiction welding techniques conducting the following tests: tensile test, impact test, hardness test, and microstructure test. And attempted to obtaining the optimal welding parameters of the weld joints.

II. MATERIALS AND METHODS

The materials used in the present work are AISI304 Austenitic stainless steel and ST-37 Low carbon steel rods with 100(mm)length and 12(mm)diameter welded together by rotary friction welding process, the two materials have chemical compositions and mechanical properties that differ from each other, as show in table(1), and(2)respectively.

Table (1): Chemical composition of the parent materials (wt.%)

Material elements	AISI304	ST-37
C	0.0183	0.076
Si	0.235	0.155
Mn	1.78	0.42
P	0.0045	<0.0005
S	0.0157	0.0037
Cr	18.73	0.09
Ni	8.02	0.063
Mo	0.348	0.0085
Al	0.0024	0.0021
Cu	0.56	0.299
Fe	Balance	Balance

Table (2): Mechanical properties of AISI 304 Austenitic stainless steel and ST-37 Low carbon steel

Base materials	Tensile strength (Mpa.)	Elongation %	Impact energy (J)	Hardness (Hv)
AISI 304 Austenitic stainless steel	691.5	50	146	270
ST-37 Low carbon steel	635.8	22	125	215

The surfaces of the specimens were flatted on the lathe machine to obtain flat, smooth faces free aliasing and oxides, after that, the surfaces was polished and cleaned with acetone to remove the layer of grease or carbohydrates and impurities for the purpose of preparing it for the welding process in order to obtain high quality of joint. A lathe machine type (TAKISAWA)was used to perform the welding processes. One of the pieces was fixed on the chuck, which represents the rotating part, while the other pieces was fixed on the tail stock and attached to the(load-cell)device in order to read the friction and forging pressures during welding process, which represents the stationary part as shown in Figure(2). The welded parts were completed, after that the welding parts were removed from the lathe machine and the flash removed from the surfaces of the welding area was visually inspect in order to ensure its safety from any defects Figure (3) shows some of the welded pieces with the flash formed at the

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welding area, also the Heat affected zone (HAZ) of the two pieces is shown. The main parameters of rotary friction welding which have significant influences on the welding quality are; rotational speed, frictional pressure, friction time, forging pressure, and forging time. The experiments had using many specimens at a three levels of rotational speeds: 560(RPM), 1030(RPM) and 1800(RPM) with a friction pressure of 24(Mpa) and forging time exceed 10(sec) with changing friction time, and their effect on the mechanical properties which are tensile strength, hardness, impact strength and microstructure.

Figure (2): (TAKISAWA) lathe machine that used for rotary friction welding and (load-cell) tying on the tail stock

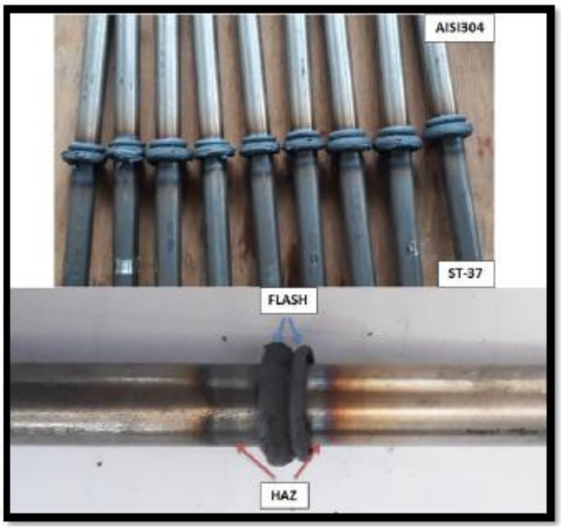

Figure (3): Some of the welded pieces and the flash formed in the welding area and (HAZ)

The tensile strength test was carried out using a computerized universal tensile testing machine type(Qualitest USA)with a capacity of(100 T0N).The tensile samples were prepared on the lathe machine according to the standards ASTM E-8, keeping the weld interface at the center of the gauge length. The configuration and the size of the specimen illustrated in Figure (4).

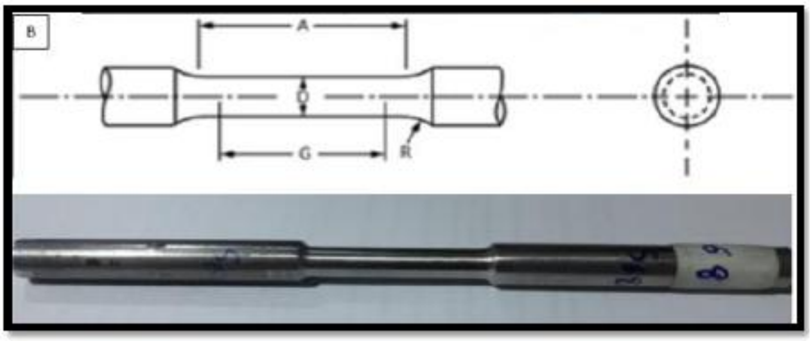

Figure (4): A; Tensile testing machine. B; Tensile test specimen geometry, where: D=9mm, G= 36mm, A=45 mm

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The micro hardness test was carried out using a hardness tester device type (wolpert)/Germany.The specimens of the hardness test were cut to a suitable pieces and then the surfaces horizontally machined using milling machine, Then grinding process was conducted on the faces by using silicon carbides(SiC)abrasive emery paper, with different grades starting from the coarse to finer size (120,220,400, 600,800,1000,1200)then polishing, to obtain a suitable flat surface of the specimen for Vickers hardness test across the weld interface, thermo mechanically affected zone(TMAZ)and heat affected zone(HAZ)to base metal, conducted as per ASTM E92-17 ready for Vickers hardness testing. Vickers micro hardness HV1 was used for hardness test across welded centerline horizontally, the indenter having a diamond pyramid with a load1(kg), the distance between points is 0.5(mm).

The impact test was carried using a Charpy type impact tester. Initially, the welded samples were cut into a suitable piece, and then operations were carried out using the milling machine, in order to obtain dimensions of the test model 55(mm) length, 10(mm) width and 5(mm) depth, while keeping the weld interface at the center of the samples. In addition, a "V" notch was made at the weld interface with 2(mm) depth having an angle 45° according to the standard ASTM E23. As shown in Figure (5).

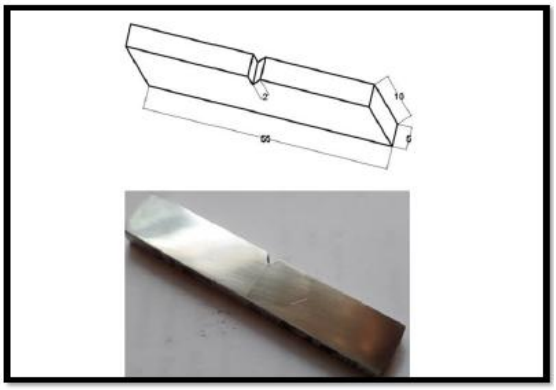

Figure (5): Impact test specimen with sub size dimensions

The microscopic examination was carried out using microscope type(BEAM ENGINEERS)with magnification of(160) megapixel. The samples were cut into a suitable pieces and then placed on the milling machine to remove approximately(3 mm)from both sides then a grinding process was performed using emery paper from coarse to fine(200, 400, 600, 800 and 1200). Since the two materials having different in chemical composition, two type of etchant solutions were used are: a- Nital: 2(cm^3) nitric acid, 98(cm^3) ethanol, this etchant using for low carbon steel ST-37. b- Viella´s :5(cm^3)HCl, 2(gr)Picric acid,100(cm^3)Methyl alcohol, this etchant using for austenitic stainless steel AISI304.[ASTM 407].

Several points were taken under the microscope, in a horizontal direction, passing through the Thermo mechanically affected zone (TMAZ), Heat affected zone (HAZ) and reaching the base metal. The distance between one point and the next point is 0.5(mm). Figure (6) shows the microstructures of base metals.

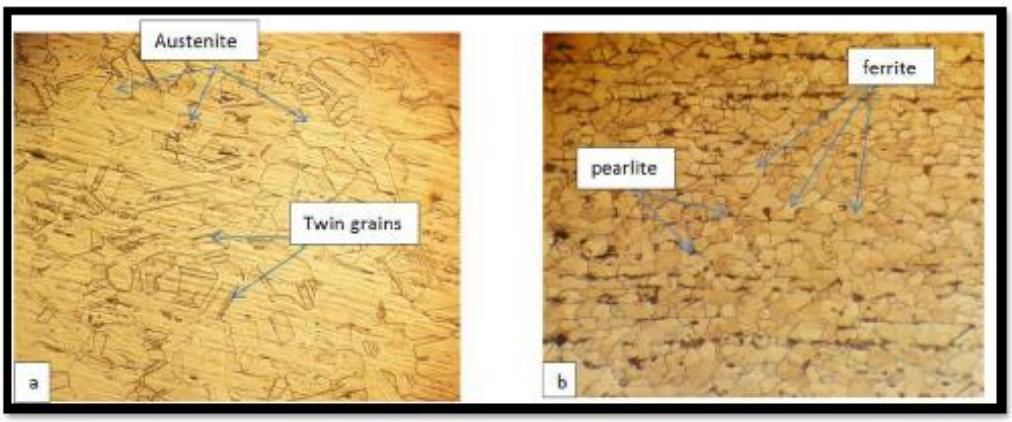

Figure (6): Optical micrographs of base metal: (a); Austenitic stainless steel (AISI304) showing Twin grains, (b); Low carbon steel (ST-37) showing ferrite and pearlite grains

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III. RESULTS AND DISCUSSION

3.1 Effect of friction time on flash formed in welded zone and length of the welded parts

Figure (7) shows dissimilar joints of ST-37 and AISI304 were welded by rotary friction welding processes with different friction time keeping other parameters as constant .The flash formation on the weld joint is unsymmetrical because the difference in mechanical properties of the two materials .The flash diameter on the ST-37 side is larger than on the AISI304 side due to lower thermal conductivity of AISI304, also AISI304 steel having strength and hardness greater than ST-37 steel at high temperature. The friction time have a significant effect on the morphology of the flash and length of the welded parts, which indicates an increase the friction time, the flash width increase and the length of the welded parts will decreases, as shown in table 3. This is agreed with a similar statement was reported by [10].

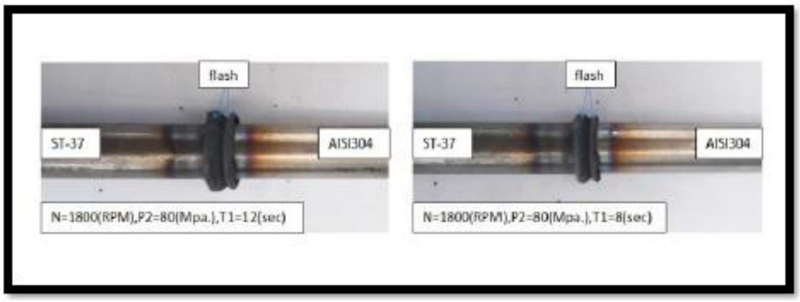

Figure (7): The flash formation on the welded area at different friction times

Table (3): Shows the effect of friction time on the reduce in the length (mm) of the welded pieces

N(RPM)	Forging pressure (Mpa)	Friction time (sec)	Reduce in length (mm)
1800	80	8	2.5
1800	80	12	4.5

3.2 The effect of friction time on weld zone width

Friction time has affecting the width of the welding zone, in order to study the influence of the friction time on the weld width, two welded samples were investigated and analyzed ,the samples have the same parameters of rotation speed N=560(RPM), friction pressure P1=24(Mpa), and forging pressure P2=45(Mpa). One of the two samples welded with a friction time T1=30(sec) while the other sample welded with a friction time T1=15(sec). Figure(8) illustrate the weld width of two samples with different friction time .The results shown in Figure(8)proves that the welded sample with a friction time of 30(sec) have a weld width greater than the welded sample by15 (sec). This leads to the fact that: when the friction time increased, the heat transmitted to the pieces increasing and thus leads to an expansion of the welding width and the area adjacent to it.This statement was also supported by[5].

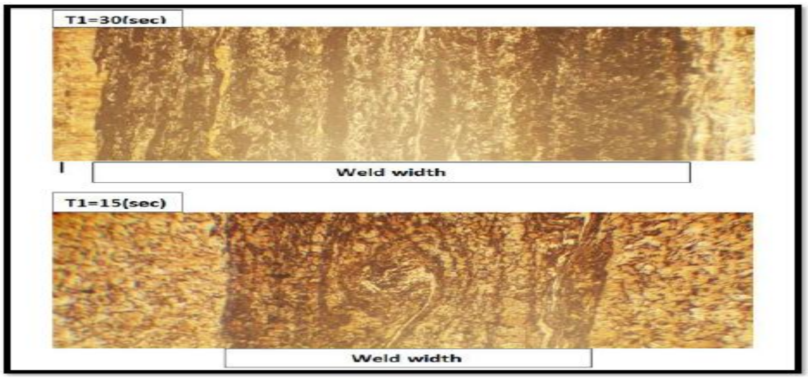

Figure (8): Illustrate the weld width of two samples with different friction time

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3.3 Effect of friction time on tensile strength of welded parts

To study the effect of friction time on tensile strength at three rotational speed 560, 1030 and 1800(RPM). Several welded samples were taken at different friction time as listed in table (4).

Table 4: Welding parameters with ultimate tensile strength, elongation %, fracture location and joint efficiency % of the welded parts

N(RPM)	Friction time (sec)	Forging pressure (Mpa)	Uts (Mpa)	Elongation %	Fracture location	Joint efficiency %
560	10	65	548	15	HAZ	86
560	15	65	566	15.5	HAZ	89
560	20	65	567	16.5	HAZ	89
560	25	65	512	7	WZ	80.5
560	30	65	451	4.2	WZ	71
1030	6	45	542	4	WZ	85
1030	8	45	547	11	HAZ	89.3
1030	12	45	596.3	19.5	HAZ	93.8
1800	7	80	585.4	14	HAZ	92
1800	8	80	558.5	16	HAZ	87.8
1800	9	80	551.5	13.8	HAZ	86.7
1800	10	80	558.5	16	HAZ	87.8
1800	12	80	563.3	10.5	HAZ	88.6

3.3.1 At rotational speed N=560 (RPM)

From Table (4) and Figure (9), We observed that, when friction time increased, the tensile strength increases until reach to value 567(Mpa) at friction time T1=15 and 20(sec), then decreasing in a tensile strength with increasing a friction time. The reason for the decrease in tensile strength may be attributed to the excessive heat generated in the welding area resulting to the high friction time, which led to the large size of the particles.The same phenomenon has been reported during friction welding of dissimilar materials obtained by[12,10].

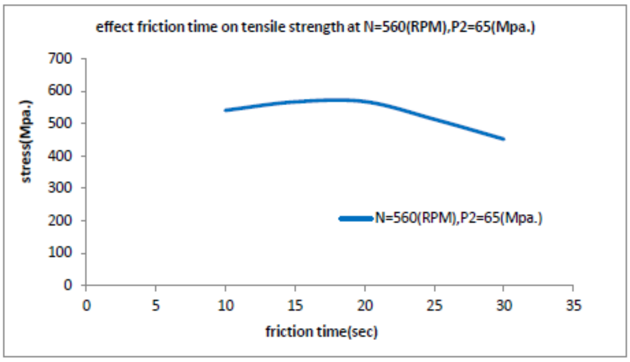

Figure (9): Effect of friction time on tensile strength at rotational speed 560(RPM) and forging pressure 65(Mpa)

3.3.2 At rotational speed of N=1030 (RPM)

From Table (4) and Figure (10), It is evident that the sample with less friction time T1=6(sec) has a lower tensile strength 541(Mpa) , elongation 4% with brittle fracture occurred in the weld zone (WZ), This is because there is not enough heat in the weld interface generated to make the metal soft due to a short friction time. While the sample with high friction time T1=12(sec) has an upper tensile strength 596.3(Mpa), elongation 19.5% with a shear cut fracture with angle of 45° in the HAZ of ST-37 side and efficiency 93.8%, as shown in Figure(10). The reason for this increased in tensile strength may be attributed to the increase in the friction time, which leads to the formation of sufficient heat in the welding interface to a soften the metal, and eventually when the forging pressure is applied, it will lead to a homogeneous compaction of the grains and a fine size. A similar statement has been reported during friction welding of dissimilar material [5,10].

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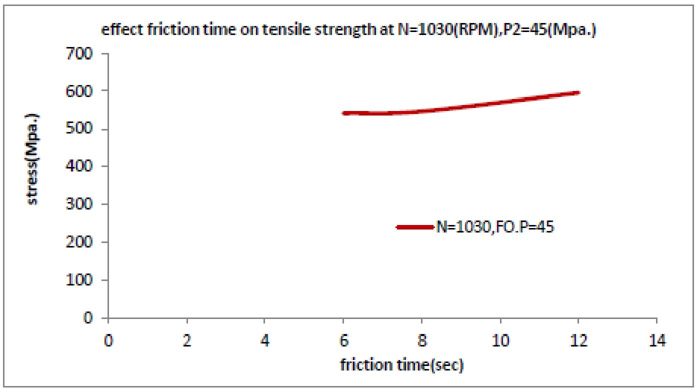

Figure (10): Effect of friction time on tensile strength at rotational speed 1030 (RPM) and forging pressure 45(Mpa)

3.3.3 At rotational speed of N=1800 (RPM)

From Table (4) and Figure (11) .It is observed that the tensile strength decreases when the friction time increased and reaching its lowest value of 551.8(Mpa.) when the friction time equals to 9 (sec) and then begins to rise gradually by a small amount, and that all samples have been successfully welded and that the failure was in the HAZ on the ST-37 side. The same phenomenon has been reported during friction welding of dissimilar materials by [11,12].

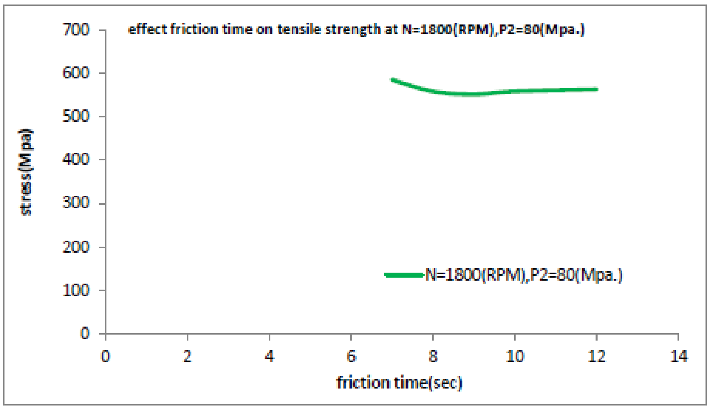

Figure (11): Effect of friction time on tensile strength at rotational speed 1800 (RPM) and forging pressure 80 (Mpa)

3.4 The effect of friction time on values and distribution of micro hardness in the weld zone

To investigate the effect of friction time on the weld interface hardness, it was taken welding parameters at rotational speed N= 560 (RPM), with different other parameters as listed in Table (5) and showed in Figure (12).

The values indicated in Table (5) and Figure (12), an increase in hardness at the weld area was observed when the friction time was increased at different forging pressures, The reason for this increasing may be attributed to a high heat generated at the welding interface as a result of increasing of the friction time and a rapid cooling rate. The same statement has reported by [10,13].

Table (5): Welding interface hardness at N=560(RPM) with different friction time

Forging pressure (Mpa.)	Friction time (sec)	WZ hardness(Hv1)
45	10	313
45	13	340
45	15	350
45	30	440
65	8	305
65	9	321
65	15	372

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65	20	407
65	30	460
80	8	321
80	12	368
80	15	395
80	25	467

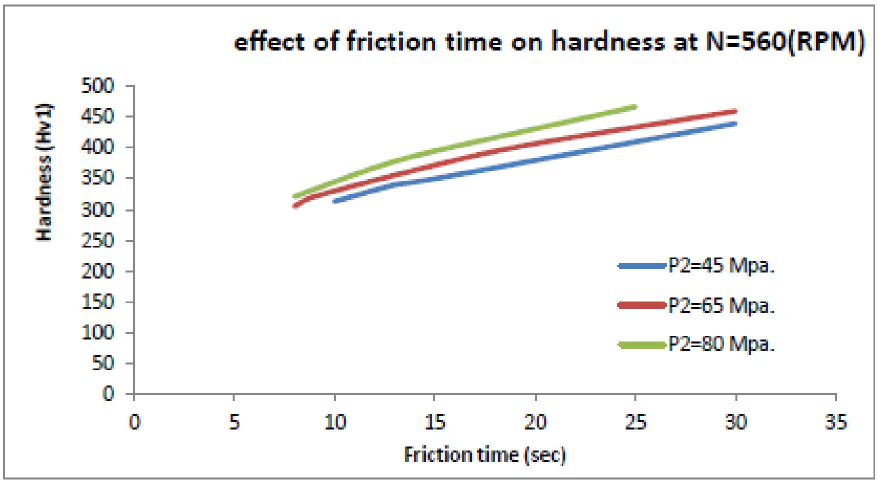

Figure (12): Effect of friction time on weld zone hardness at N= 560 (RPM) with different forging pressures

3.5 The effect of the friction time on impact strength

To study the effect of friction time on impact strength, three samples were taken at rotational speed N=560(RPM) with forging pressure P2=65(Mpa) and keeping other parameters constant as listed in Table (6) and shown in Figure (13).

Table (6): Impact strength with varying friction time

N (RPM)	Forging pressure (Mpa.)	Friction time (sec)	Impact strength (J)	Joint efficiency %
560	65	8	98	78.4
560	65	15	87	69.6
560	65	30	78	62.4

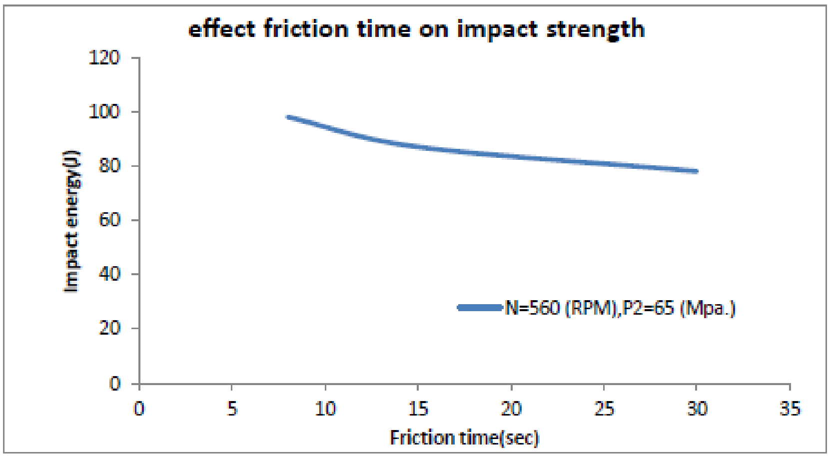

Figure (13): Effect of friction time on impact strength at speed N= 560 (RPM)

The reason for the decreasing in the impact strength can be attributed to the fact that when the friction time increases, high heat will be generated in the welding area and as a result of a rapid cooling rate the metal will be more brittle.

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IV. CONCLUSIONS

It was found from this experimental research that the welding process of two dissimilar joints of Austenitic stainless steel AISI304 and Low carbon steel ST-37can be successfully carried out using rotary friction welding. And approach the ideal welding parameters at each rotational speed. As well as explaining the effect of each of the friction time on the mechanical properties:

1. The flash formed on each side of two welded parts is unsymmetrical due to the difference in thermal conductivity and mechanical properties of AISI304 and ST-37. Also the amount of the formed flash and the reduce in length of the welded parts increased when friction time increased.

2. When the friction time increase, the width of the welding zone increase.

3.1 The tensile strength at rotational speed 560(RPM) increase when the friction time increase until reach to value 567(Mpa) at friction time15 and 20(sec), then decreasing with increasing a friction time.

3.2 The tensile strength at rotational speed 1030(RPM) increased, when increasing in friction time, the highest tensile strength was 596.3(Mpa), with elongation of 19.5% and a joint efficiency 93.8% at friction time 12(sec) and forging pressure 45(Mpa).

3.3 The tensile strength at rotational speed 1800(RPM) decreasing when friction time increased, until reach 551.5(Mpa) at friction time 9(sec) then increasing in tensile strength with increasing friction time. The maximum tensile strength at a rotational speed of 1800 (rpm) reached to 585.4(MPa) with elongation of 14 % and joint efficiency of 92 %, at a friction time of 7(sec), and forging pressure of 80 (MPa).

4. The greatest hardness of the welded parts was in the welding interface of all samples and then gradually decreased towards the adjacent area of the welding zone. In addition, the hardness increases with increasing rotational speed, friction time, or forging pressure. The highest value of hardness was recorded as 467(Hv1) at a rotational speed of 560(RPM), a friction time of 25(sec) and a forging pressure of 80(MPa).

5. The impact energy decrease when the friction time increase.

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