MECHANICAL CHARACTERIZATION OF FRICTION WELDED DISSIMILAR STEELS AT 1000 rpm

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Resume

Joining of dissimilar metals is one of the most essential needs of industries. There are various welding methods that have been developed to obtain suitable joints in various applications. However, friction welding is a joining process that allows more materials and material combinations to be joined than with any other welding process. Continuous drive friction welding studies on austenitic stainless steel and ferritic steel combinations has been attempted in this investigation. Friction welding process parameter optimization, mechanical characterization and fracture behavior is the major contribution of the study. The microhardness across the weld interface was measured and the strength of the joint was determined with tensile tests and impact tests. Also the tensile fractured specimens were examined by scanning electron microscopy so as to study its fracture behavior. The experimental results indicate that axial pressure has a significant effect on the mechanical properties of the joint and it is possible to increase the quality of the welded joint by selecting the optimum axial pressures.

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1. Introduction

Welding is one of the fast growing principal technologies used for joining materials which is almost used by all the fabricating industries. There are many situations arises in the industries where dissimilar metals needs to be welded. The joining of dissimilar metals is generally more challenging than that of similar metals because of difference in physical, mechanical and metallurgical properties of the parent metals to be joined. The growing availability of new materials and higher requirement being placed on materials creates a greater need for joints of dissimilar metals [1]. The use of carbon steel electrode in the conventional fusion welding results in the formation of very hard, crack-susceptible bulk structure on the stainless steel side of the dissimilar metal welded joint and along the fusion line of ferrite side of the joint discontinuous brittle and hard zones gets formed. Such hard and brittle zones may render dissimilar metal welding susceptible to localized pitting corrosion attack, hydrogen embrittlement, sulphide stress cracking, and stress rupture, which often occurs in the weakened structure heat affected zone of the ferrite material of the dissimilar metal welding [2]. Thus conventional fusion welding of many dissimilar metal combinations is not feasible owing to the formation of brittle and low-melting inter-metallic due to metallurgical incompatibility, wide difference in melting point, thermal mismatch [3]. Friction Welding is a class of solid-state welding process that generates heat through mechanical friction between two components where metallic bonding is produced at temperatures lower than the melting point of the base metals with a relative velocity, a load, normal to the welding plane, is applied to plastically displace and join the materials. In friction welding two work pieces are brought together under load with one part rapidly revolving. Frictional heat is developed at the interface until the material becomes plastic, at which time the rotation is stopped and the load is increased to consolidate the joint. A strong welded joint is formed by metallic bonds that arise between the contacting surfaces. The surface films and inclusions are broken up by friction and removed from the weld area, in radial direction, such that they don’t interfere in the formation of bonds so that a marked plastic deformation takes place on the surface. Mechanical energy is directly converted into heat which is liberated on the rubbing surfaces and rapidly arise the metal to a temperature necessary to produce a welded joint.

2. Description of approach

The parent materials employed in this work are AISI 1021 ferritic steel and AISI 304 austenitic stainless steel. The material available was in the form of rods of 20 mm diameter. The chemical composition of the materials is given in Table 1. A continuous drive [4] lathe machine was used for the experimentation. The machine was then modified to suit the friction welding requirements. A load cell was designed and fitted on the machine to measure axial pressure.Test samples with 20 mm diameter and 100 mm length were prepared for friction welding experiments.Prior to friction welding the contacting surfaces was faced on the lathe machine and then cleaned using Acetone [5].

Table 1

Chemical composition of the parent materials.

Metal	Cr	Ni	C	Mn	Si	P	S	Fe
AISI 304	17-20	9-13	0.08	2	0.75	----	----	Remaining
AISI 1021	----	----	0.15-0.25	0.6-0.9	----	----	----	Remaining

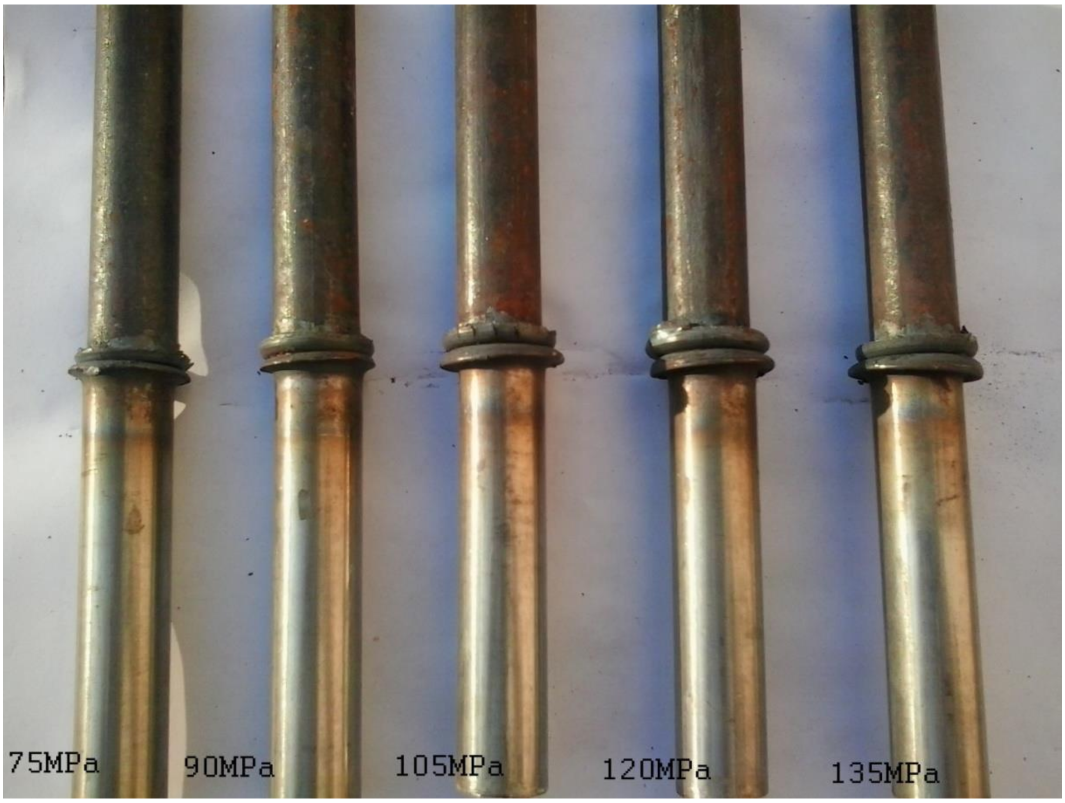


Fig. 1. Macrograph of the friction welded specimens at different axial pressures.

Prior to friction welding the contacting surfaces was faced on the lathe machine and then cleaned using Acetone [5]. The rotational speed for this study selected was 1000 rotational speed [5]. The required rotational speed was set by the levers attached on this machine. Within a fraction of seconds, the constant speed was achieved; subsequently the axial alignment of the specimens was checked. Then the axial pressure was applied. The welds were prepared at different axial pressures in the steps of 15 MPa starting from 75 MPa to 135 MPa to form different welds for the study. The welding joint so formed was allowed to cool down for 4-5 minutes. In this way, necessary number of weldments were prepared and subjected to various tests for evaluation of their mechanical characterization. Fig. 1 shows the welded specimens at different axial pressures.

2.1. Work Methodology

Friction welded parts were subjected to variety of mechanical tests to determine their suitability for the anticipated service applications. They were necessary to carry out so as to ensure the quality, reliability and strength of the welded joints.

2.1.1.Tensile Test

Tensile test carried for this study was performed on the Universal Testing Machine of make HIECO make having the capacity 60 tons. Firstly the standard specimens were prepared for this and for that ASTM standards were followed for making the sample. The gauge lengths of the specimens were maintained according to the ASTM A370-12 standards keeping the weld interface at the centre of the gauge length. The sample was then fitted firmly between the jaws of the machine and load was applied. This test was carried out on the friction welded samples of AISI 304 with AISI 1021 materials to measure their strength in tension. In this test the specimen was subjected to axial tensile load till its failure occurs.

2.1.2. Scanning Electron Microscope (SEM) Test

For supporting the type of failure that has been occurred in tensile test, the SEM analysis was done. For that scanning electron microscope (SEM) of make JEOL model no. JSM-6610LV was used. The SEM analysis was carried out to show the fracture behavior of tensile test which justifies the visual inspection results of brittle and ductile failures. The magnified images were captured at the fractured locations taken at 1 500 magnification.

2.1.3. Impact Test

This test was carried out on the pendulum type single blow impact testing machine so as to measure their notch impact toughness. Again the samples were prepared according to the ASTM standards maintaining the notch at the centre of the weld interface. The specimens were supported at both ends as a simple supported beam and was broken by a falling pendulum on the face opposite to the notch and the energy absorbed by the specimen was noted down. Side by side Izod test was also performed in this test the specimens were vertically placed and the notch was facing towards the falling pendulum. For Charpy impact test the size of the specimen was kept 55 mm x 10 mm x 10 mm and the depth of the notch was kept 5mm deep and for Izod test the specimen dimensions were kept 75 mm x 10 mm x 10 mm and the V notch was made 2mm deep not in the centre but 28 mm away from the striking end.

2.1.4. Micro Hardness

For micro hardness testing Vickers hardness testing machine was used. In this test asquare based pyramid type diamond indenter was used and the hardness variation on the weldinterface as well as along with it, across the weld interface on both the parent materials was obtained by applying a constant load of 500 gf. The indentations were made at the weld interface and on both the sides along the axis of the shaft at the regular intervals of 1 mm apart so as to find out the effect of heat on the hardness values.

3. Description of achieved results

The friction welded specimens of five different welding combinations were prepared by varying the axial pressures at constant speed of 1000 rpm; it was observed that with the flash has been produced during friction welding process and the amount of flash increases with the increase in axial pressure. The formation of flash has been presented in Fig. 1. It has also been observed from the figure that the formation of flash is higher towards the low alloy steel than the austenitic stainless steel for all the cases. This might be attributed due to the presence of Cr in austenitic stainless steel; as AISI 304 having lower thermal conductivity as compared to low alloy steel, for this reason the formation of flash is higher on the AISI 1021 side than the AISI 304 side, also austenitic stainless steel having greater hardness at higher temperatures as compared to low alloy steels. For this reason austenitic stainless steel does not undergo extensive deformation while the low alloy steel undergoes extensive deformation. This phenomenon may be attributed to the low strength of AISI 1021 steel [1].

3.1. Tensile test results

Universal testing machine of HEICO make having the maximum capacity of 600 KN load with load accuracy of 1 % and displacement accuracy of 1 % was used. In this test the specimens were loaded gradually until its fracture. The graphs were plotted on the basis of the results obtained from this test. Tensile test results of friction welded specimens are reported in Table 2, it has been observed experimentally that all the specimens were failed at the joint interface. The specimens welded at axial pressures 75 MPa, 90 MPa and 105 MPa were failed at the interface, though the specimens welded at 120 MPa and 135 MPa were also failed at the weld interface but they show necking behavior before getting failed at the interface.Also it has been noted that these specimens took more time before fracture than the others. The maximum time taken by the specimen was 23 seconds and was welded at 135 MPa axial pressure. The maximum stress available was at 105 MPa but the difference is very marginal as available at 120 MPa and 135 MPa.The maximum strain available was at 120 MPa axial pressure

Table 2

Results of tensile test.

Sample No.	Axial Pr. (MPa)	Peak Load (KN)	Peak Displacement (mm)	Peak Strain	Peak Stress (MPa)	Time (Sec)	Fracture Location
S1-S2	75	46.5	7.84	0.1568	378.913	16	weldinterface
S1-S2	90	49.85	8.64	0.1728	406.211	16	weldinterface
S1-S2	105	52.65	8.58	0.1716	429.027	20	weldinterface
S1-S2	120	52.05	8.67	0.1734	424.138	21	weldinterface
S1-S2	135	52.34	8.4	0.168	426.501	23	weldinterface

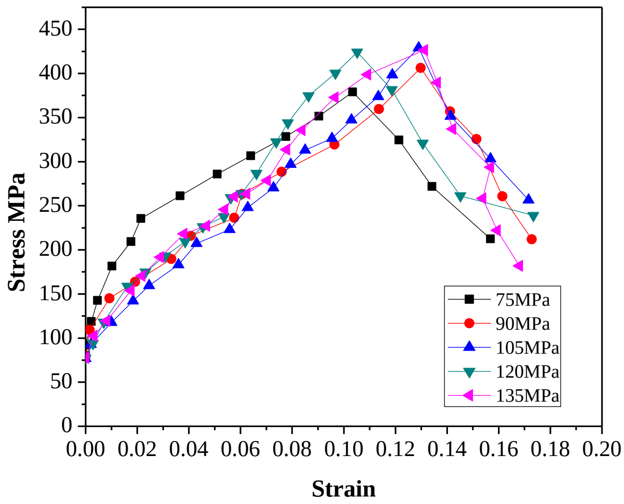


Fig. 2. Stress vs. Strain behavior of friction welded specimens at different axial pressures.
(full colour version available online)

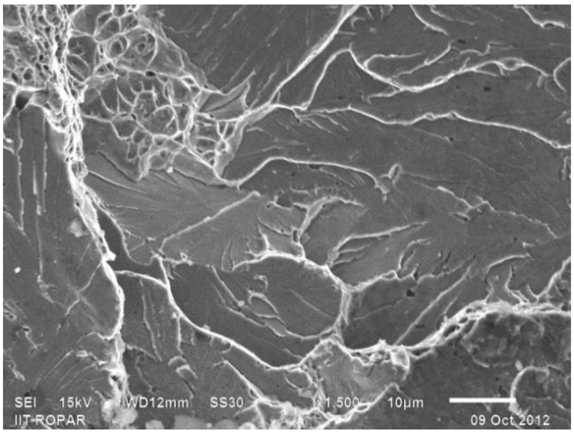
In general it has been observed that with the increase in axial pressure the value of tensile strength increases, this might be attributed that with the increase in axial pressure more mass is thought to be transferred at the interfaces [6].

3.2. SEM test results

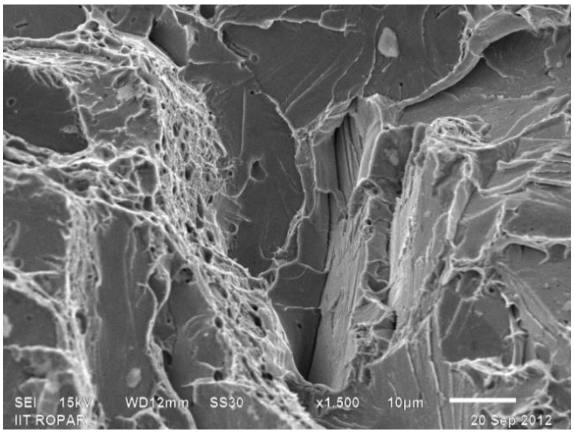
For supporting the visual inspection of failure, the fracture analysis was done. For that scanning electron microscope (SEM) of make JEOL model no. JSM-6610LV was used. The SEM analysis was carried out to show the fracture behavior of tensile test which justifies the visual inspection results of brittle and ductile failures. The magnified images were captured at the fractured locations taken at 1 500 magnification. The effect of tensile strength has been observed on the fractured surface appearance. In the fig. 3 (a), the fractograph indicates river like pattern which shows the pure brittle failure. This may be due to the formation of martensite at the interface of the joints [6], also has been observed from the tensile test that minimum time has been taken by the specimen before getting failed. Fig. 3 (b) indicates again the sign of river like pattern, which depicts the brittleness of the joint. Fig. 3 (c) reveals cleavage pattern as well as small amount of dimples at various locations; this indicates the fracture may have occurred by the mixed phenomenon i.e. quasi cleavage fracture mechanism [7]. Fig. 3 (d) represents dimpled pattern showing ductile fracture. Fig. 3 (e) also depicts dimples at various locations but the dimples are deep at Fig 3 (d) as compared to Fig. 3 (e) indicating more ductility.

3.3. Impact test results

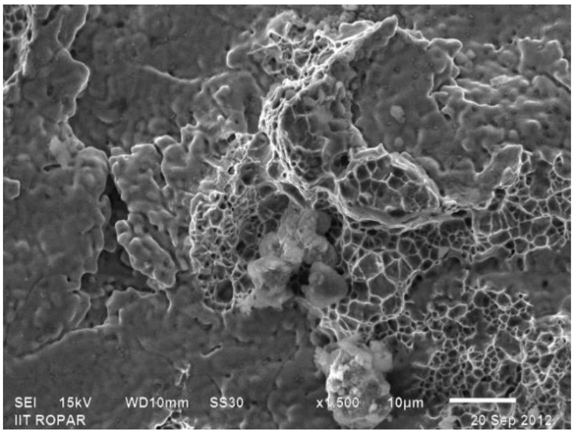
The notch impact toughness tests were carried out to find amount of energy absorbed during fracture. Two types of tests were carried out namely the Charpy impact and Izod impact strength. The samples prepared for impact testing were according to ASTM standards A370-12.The results of both Charpy and Izod impact results in terms of fracture energies have been reported in the Table 3.As it can be seen from the table that the Charpy toughness of the welded parts is slightly larger than the Izod impact toughness, this may be the reason of the placement of the impact samples towards the impact load.



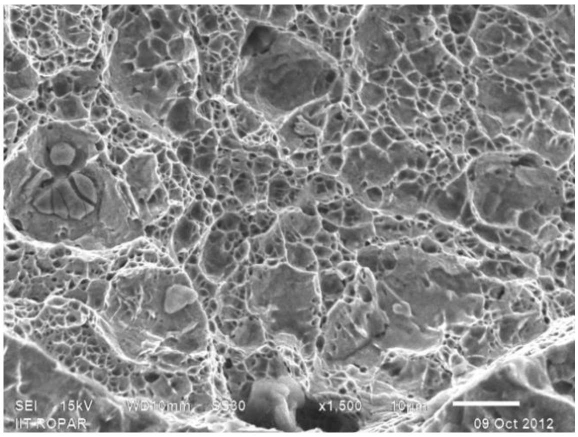
a) 75MPa Axial Pressure



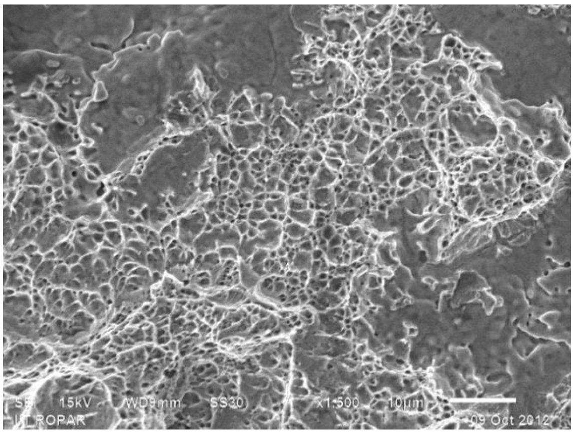
b) 90MPa Axial Pressure



c) 105MPa Axial Pressure



d) 120MPa Axial Pressure



e) 135MPa Axial Pressure

Fig. 3. SEM images at fractured interface during tensile testing.

Fig. 4 shows the variation of impact strength with axial pressure, it reveals that the impact strength in case of Charpy impact strength, firstly decreases with the increase in axial pressure, then rises a little bit and then remains constant up to 120 MPa pressure and after that with the increase in axial pressure declines sharply. Fig. 4 also shows that the impact strength in case of izod strength, it remains constant up to 90 MPa afterwards little bit decline in strength were observed. It raises little bit at 120 MPa and then with the further increase in axial pressure it shows steep decline. In general it has been observed that the impact strength goes on decreasing with the increase in the axial pressures and if the axial pressure increased beyond 120 MPa there was immediate decline in strength was observed. The similar results have been reported in the literature [1]. It has also been observed that with the increase in the axial pressure the flash increases, and experimentally it has been found that with the increase in the flash the impact strength decreases [2, 8].

3.4. Micro Hardness test results

The micro hardness variations were obtained on Vickers Hardness Testing Machine. The hardness variations at the weld interface and across the weld interface were obtained by applying a constant load of 500gf and have been reported in the Table 4. The hardness was measured at the weld interface and on the either side of the parent materials. Fig. 5 shows the hardness variations on both the sides at a distance of 1 mm apart as well as the hardness was also measured at the weld interface. It has been observed from the plot that AISI 1021shows less hardness than the AISI 304. This decrease in hardness may be attributed to recrystallization process taking place at the heat affected zone towards the low alloy steel [9]. It has also been observed that the maximum hardness was obtained at the weld interface for all the joints [6]. The peak hardness of friction welded joints increases with the increase in burn-off length [8]. It was observed that with the increase in burn-off length a soft region appears on the austenitic stainless steel adjacent to the weld interface. The formation of soft region can be attributed to decarburization.

Table 3

Results of impact test.

Sr. No.	Specimen	Axial Pressure (MPa)	Energy Absorbed Charpy (J)	Energy Absorbed Izod (J)
1	S1-S2	75	25	17
2	S1-S2	90	24	17
3	S1-S2	105	25	15
4	S1-S2	120	25	17
5	S1-S2	135	21	13

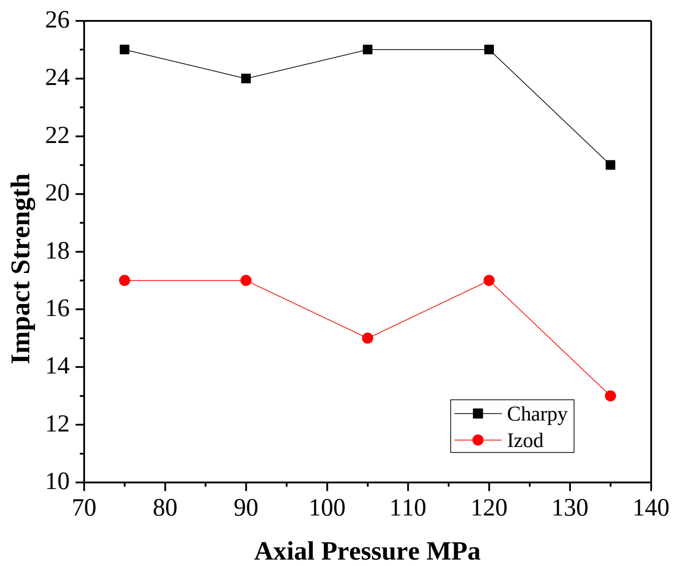


Fig. 4. Impact strength vs. Axial Pressure at 1000 rpm

This may be occurred by the presence of heat as the thermal conductivity of the material is relatively low [1].In addition to that the higher values of hardness at the weld interface were probably due to the oxidation process which takes place during friction welding [10].

3.5. Micro Structure at weld interface

The microstructure of the parent metal as well as the weld zone is shown in Fig. 6. Different etching reagents were used for the parent metals; for low alloy steel nital solution was used and for austenitic stainless steel it was ferric chloride and hydrochloric acid. In case of dissimilar materials joined by friction welding, the formation of flash depends upon the mechanical properties of two parent materials [11]. It was observed that the flashes were formed around the weld interface on sides of both the parent materials and the amount of flash increased with increasing the axial pressure [11] as shown in Fig 2. In the optical microscope observation of the welded specimen it is observed that there are no cracks or blank spaces and the transition of materials between AISI 304 and AISI 1021 steel in the weld zone, similar results have been reported in the literature [11].

Table 4

Results of micro hardness test.

Specimen	Axial Pressure (MPa)	Microhardness at a distance(mm) from weld interface towards AISI 304 material				Microhardness at the weld interface	Microhardness at a distance(mm) from weld interface towards AISI 1021 material			
		4	3	2	1	Weld Interface	1	2	3	4
S1-S2	75	201	210	219	230	233	210	205	196	178
S1-S2	90	206	211	221	230	235	213	210	195	183
S1-S2	105	204	216	223	238	235	218	218	200	186
S1-S2	120	204	212	222	238	238	218	216	197	180
S1-S2	135	210	221	236	244	241	236	221	207	200

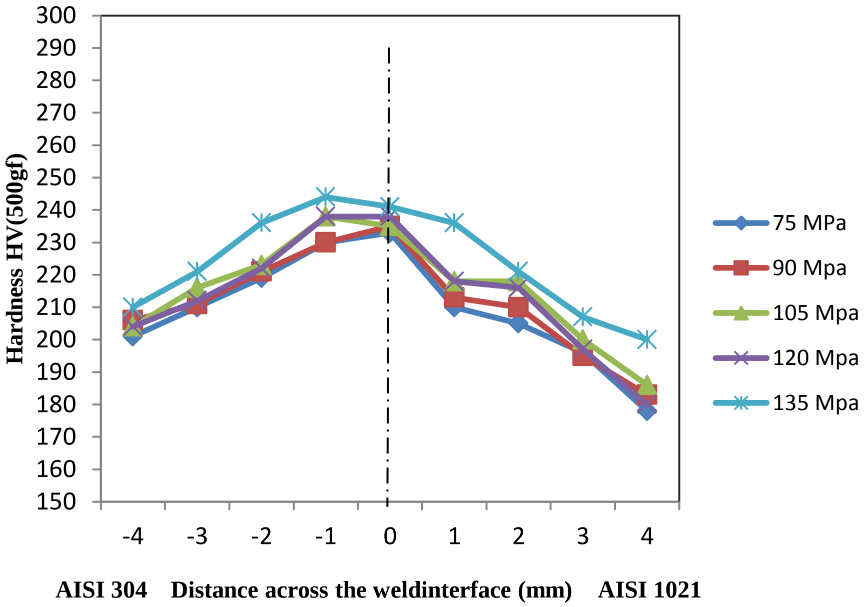
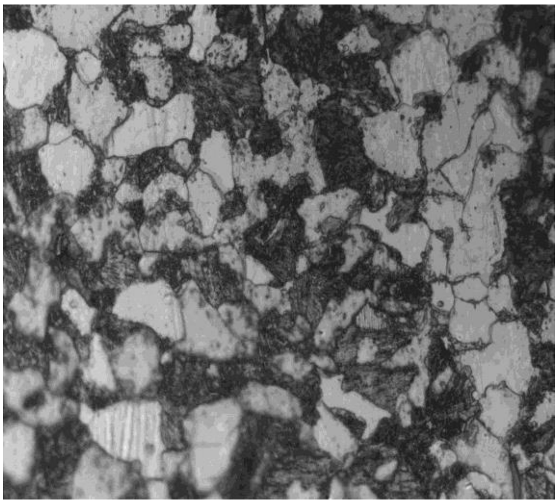
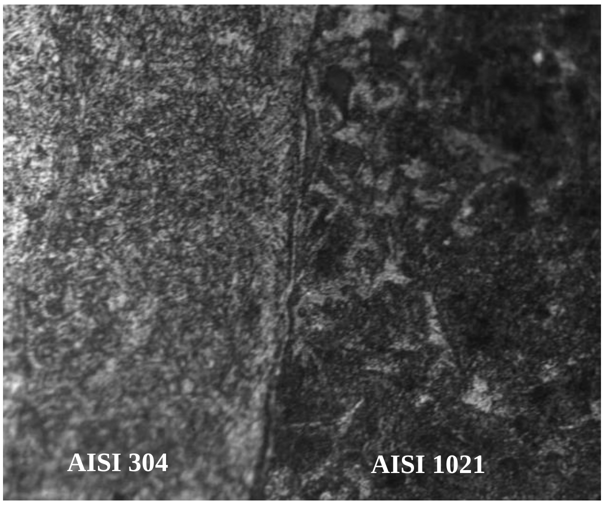


Fig. 5. Micro hardness at the weldinterface.

a) Optical microstructure AISI 304, etch. Ferric Chloride and Hydrochloric Acid



b) Optical microstructure AISI 1021, etch. Nital



c) Optical microstructure of the joint

Fig. 6. The microstructure of weld joint interface.

4. Conclusions

Following conclusions have been made from the study:

- The laboratory built friction welding setup was found to be successful for the production of friction welds.
- The axial pressure has been found to be an influential parameter for the friction welding process, which has been optimized for the process based up on the results of the present study. The mechanical properties of the friction welds were found to vary with the applied axial pressure, which indicates that axial pressure is an important welding parameter. The axial pressure could be successfully optimized for the friction welding process on the basis of the results of the current investigation.
- The maximum tensile strength for welded bars was achieved with an applied axial pressure of 105MPa, but the specimen fails in a brittle manner, whereas small amount of necking appears on the specimens which were prepared at an axial pressure of 120 MPa and 135 MPa axial pressures and the difference between the load carrying capacity with 105 MPa is very marginal.

- It has also been found that maximum time which was 23 seconds before failure was observed at 135 Mpa.
- It has also been observed that the impact strength both for charpy and izod were found to be maximum at 120MPa axial pressure.
- The hardness of all the samples was found to me maximum on the austenitic stainless steel side than that of low alloy steel. With the increase in the axial pressure the hardness at the centre of weld cross section increases.

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