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# Friction Welding of AISI 304 and AISI 1021 Dissimilar Steels at 1600RPM

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*Abstract* – **Friction welding is a solid state joining process which is extensively used due to its advantages such as low heat input, ability to join dissimilar materials and environment friendliness. Friction welding can be used to join different kinds of materials which cannot be welded by conventional fusion welding processes. The rotational speed and the axial pressures are the important parameters that play the major role in determining the strength of the joint. In this study an attempt was made to join austenitic stainless steel (AISI 304) with low alloy steel (AISI 1021) at 1600 rpm and at different axial pressures and then determining the strength of the joint by means of mechanical properties such as tensile strength, torsional strength, impact strength and micro hardness. The tensile tested specimens were also subjected to SEM analysis to determine the failure pattern of the specimens**

*Keywords:* **Friction Welding; Dissimilar Materials; Mechanical testing; SEM analysis.**

## I. Introduction

Dissimilar joints between austenitic stainless steel and low alloy steel are extensively used in many high temperature applications in the energy conversion system [1]. There is an extensive need for dissimilar metal joints in power plant components, due to the severe gradients in mechanical and thermal loading. In central power stations, the parts of the boiler that are subjected to lower temperatures, are made of low alloy steel for economic reasons. The other parts, operating at higher temperatures, are constructed with austenitic stainless steel. Therefore, transition welds are needed between these two materials. The joining of dissimilar materials is generally more challenging than those of the similar materials due to difference in thermal, metallurgical and physical properties of the parent materials. The specific problems associated with welding of austenitic stainless steel are formation of delta ferrite, sigma phase, stress corrosion cracking, and sensitization at the interface [1]. Friction welding is one such solid state welding process widely employed in such situations [2, 3]. Main advantages of friction welding are high material saving, low production cost, and ability to weld dissimilar materials [4]. Friction welding is one of the versatile and well established welding processes [2] that are capable of giving good quality welds; it gives solid state joining of the materials through the controlled rubbing of the interfaces. Due to thus produced heat softens the material and brought the localized faces into the plasticized form which results in good quality welds [5]. In this process heat energy is produced by the interconvertion of mechanical energy into thermal energy at the interfaces of the rubbing components[6].

## II. Experimental Details

Austenitic stainless steel AISI 304 and low alloy steel AISI 1021 specimens having diameter of 20mm and 100mm length were joined together. The chemical composition of austenitic stainless steel and low alloy steel is presented in table 1.A continuous drive lathe machine was used for the experimentation. A designed load cell [7]was fitted on the machine to measure axial pressure. Test samples with 20mm 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 [8]. The rotational speed for this study selected was 1600rpm. 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 pressurewas applied. The welds were prepared at different axial pressures in the steps of 15MPa starting from 75MPa to 135MPa 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. Figure 1 shows the welded specimens at different axial pressures.

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 |

## III. APPROACH OF WORK

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.

### *A. 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.

### *B. 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 X magnification.

### *C. Torsion Test*

Torsion test was performed on the torsion testing machine of make scientific instruments limited. In this test torque was applied on the specimens till its fracture occurs. The specimen was fitted in the jaws of machine with one jaw is kept fixed and other rotates when the torque is applied. During the application of twisting moment the specimen a start twisting at an angle called angle of twist and this angle was measured during the application of torque.

### *D. 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.

### *E. Micro Hardness*

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

## IV. Results and Discussion

The friction welded specimens of five different welding combinations were prepared by varying the axial pressures at constant speed of 1600rpm; 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 [9].

Fig. 1 Shows friction welded samples

### *A. Tensile Test Result*

Universal testing machine of HEICO make having the maximum capacity of 600KN 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 II, it has been observed experimentally that all the specimens were failed at the joint interface. The specimens welded at axial pressures 75MPa, 90MPa, 105MPa and 120 showed certain amount of displacement before failure, but the specimen welded at 135MPa axial pressure failed without showing any displacement. It has also been observed that the specimen welded at this pressure took minimum time before tensile failure. 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 [10].

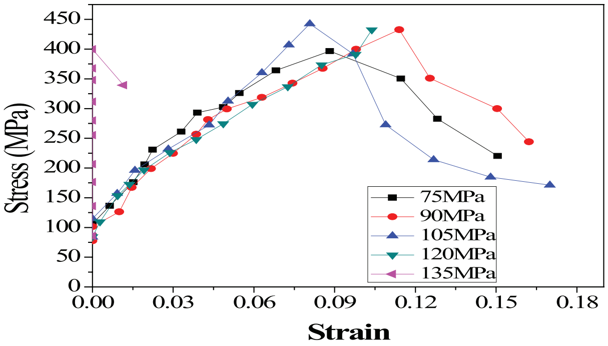


Fig. 2 Shows the stress Vs Strain behaviour

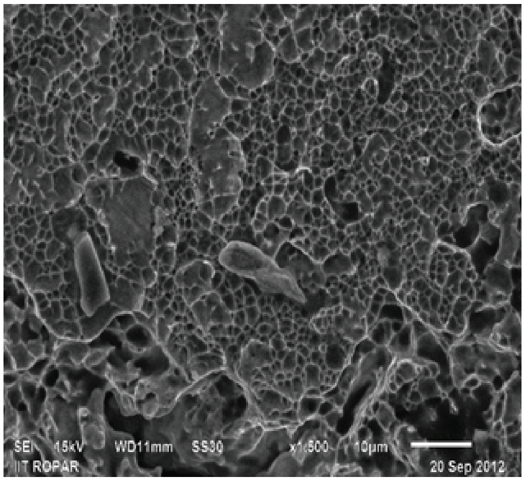
Figure 2 shows the stress versus strain behavior at different axial pressures and it has been depicted that the value of stress as well as the value of strain both goes on increases up to 105MPa axial pressure and then values start declining with the further increase in axial pressure.

Table II Results of Tensile Test

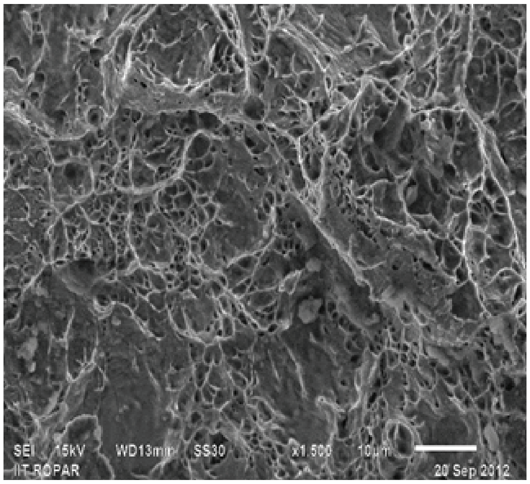
| Sample No. | Axial Pr. (MPa) | Peak Load (KN) | Peak Displacement (mm) | Peak Strain | Peak Stress (MPa) | Time (Sec) | Fracture Location |
|---|---|---|---|---|---|---|---|
| S1-S2 | 75 | 48.67 | 7.53 | 0.1506 | 396.5955 | 15 | weldinterface |
| S1-S2 | 90 | 53.11 | 8.11 | 0.1622 | 432.7756 | 17 | weldinterface |
| S1-S2 | 105 | 54.3 | 8.5 | 0.17 | 442.4725 | 15 | weldinterface |
| S1-S2 | 120 | 53.06 | 5.19 | 0.1038 | 432.3681 | 13 | weldinterface |
| S1-S2 | 135 | 49.05 | 0.58 | 0.0116 | 399.692 | 11 | weldinterface |

### B. SEM Test Result

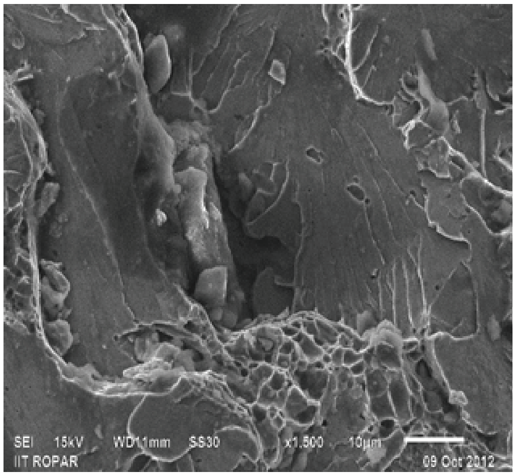
For validating the fracture behavior of tensile tested specimens, fractography analysis was carried out. For this the specimens were cut from the fractured locations keeping the height of the specimen 15mm for the ease in the adjustment in specimen holder for SEM analysis. The SEM images of every sample were captured at 1500X magnifications and are shown in figures no 3. . Fig 3 (a) depicts very small size voids and fig 3 (b) shows river like patterns depicting the brittle failure. Fig 3 (c) and (d) shows brittle cleavage fracture. Fig 3 (e) also shows the brittle failure, in tensile test this specimen takes minimum time to failure without showing any deformation.



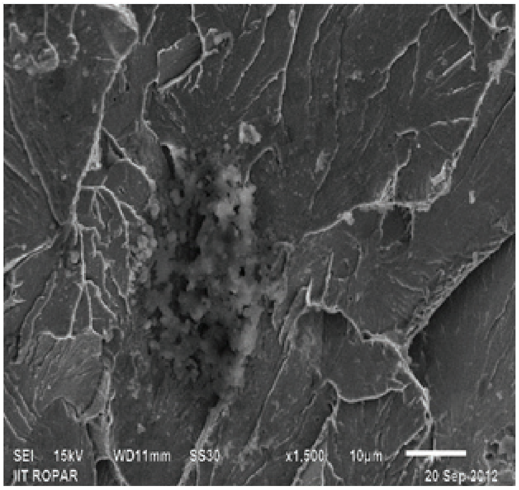
(a) 90MPa



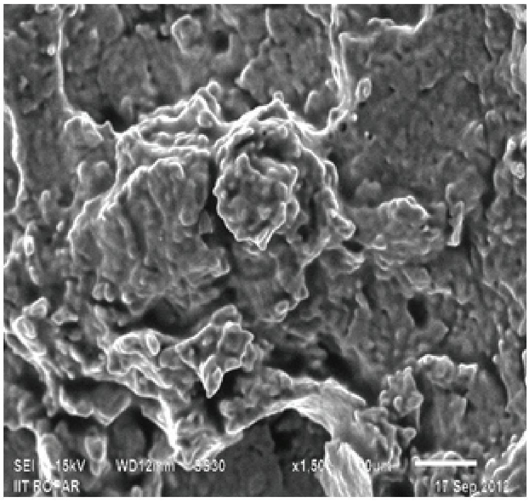
(b)105MPa



(c)105MPa



(d)120MPa



(e)135MPa

Fig.3 Shows SEM images at 1600rpm

### *C. Torsion Test Result*

The maximum torsion strength obtained from the tests varied from 16.26Nm to 26.71Nm and the maximum angle of twist in terms of degrees varied from 8 to 14. Similar results have been reported by Shribman at el [11, 12]. It has also been observed during testing that the entire specimen fails at the weld interfaces. Fig. 4 shows the variation of the torque with respect to angle of twist. With the increase in torque the angle of twist increases; it has also been noticed from the experiment that with the increase in axial pressure the torque as well as the angle of twist increases. This might be the effect of the diffusion of alloying elements from austenitic stainless steel to low alloy steel at the joint interface. When the axial pressure increases beyond 105MPa there is little bit decline in the torque but this difference is very marginal. The maximum torque available was 26.71Nm and the maximum angle of twist was 14 and these results were obtained at 105MPa axial pressure.

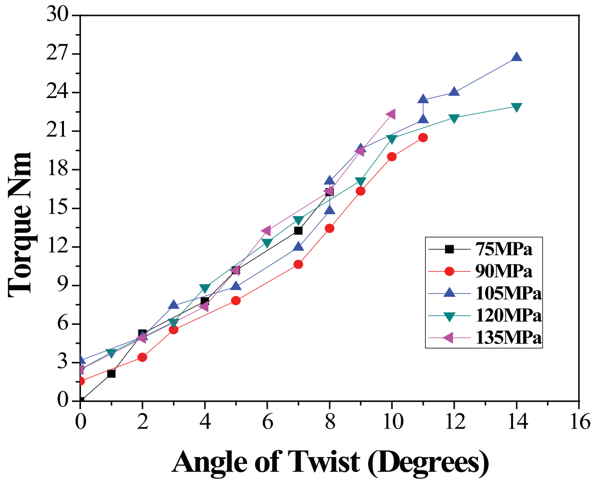


Fig. 4 Shows the relationship between torque and angle of twist

### *D. Impact Test Result*

The notch impact toughness tests were carried out to find amount of energy absorbed during fracture. . As can be seen from the Fig. 5, the charpy toughness of the welded parts is slightly larger than the izod impact toughness. The results obtained from the test are quite comparable with the literature [9].The maximum impact strength both for Izod as well as Charpy was obtained at 105MPa axial pressure. Almost similar results were obtained at all the axial pressures, but when the pressure exceeds 120MPa, the impact values both for Izod as well as Charpy decreases little bit.

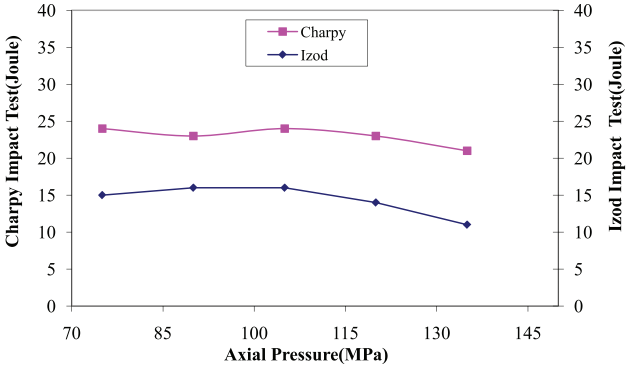


Fig. 5 Shows the impact test results

### *E. Micro Hardness Test Result*

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. The hardness was measured at the weld interface and on the either side of the parent materials. Fig. 6 shows the hardness variations on both the sides at a distance of 1mm apart as well as the hardness was also measured at the weld interface. It has been observed from the plot that AISI 1021 shows 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 [13]. It has also been observed that the maximum hardness was obtained at the weldinterface for all the joints [14]. When the axial pressure increases beyond the 120MPa axial pressure, the value of hardness at the weld interface crosses 290Hv.

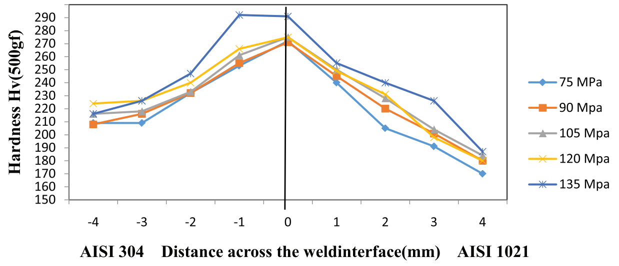


Fig. 6 Shows the variation in hardness at different axial pressures

## V. CONCLUSIONS

The axial pressure has been found to be an influential parameter for the friction welding process, which has been optimized for the process based upon 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. The maximum displacement was also available at this axial pressure. With the further increase in axial pressure the strength starts declining. It has also been observed that the impact strength both for charpy and izodwas found to be maximum at 105MPa 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. The torsional strength was also found to be maximum at 105MPa axial pressure.

## References

[1] Ghander, G.S., Reddy, G.M.,Tagore, G.R.N., (2012), "Influence of process parameters on impact toughness and hardness of dissimilar AISI 4140 and AISI 304 continuous drive friction welds", *Int J AdvManufTechnol*ogy, Vol. 64,pp. 1445-1457.

[2] Meshram, S.D., Mohandas, T., Reddy, G.M., (2008), "Friction welding of dissimilar pure metals", *J Mater Process Technology,* Vol. 184, pp. 330-337.

[3] Sathiya, P., Aravindan, S., Haq, N.A., (2007), "Some experimental investigations on friction welded stainless steel joints", Material and Design, Vol. 153, pp. 1099-1109.

[4] Sahin, M., (2004), "Simulation of friction welding using a developed computer program", *Journal of Material Processing and Technology,* Vol. 153, pp. 1011-1018.

[5] Sathiya, P., Aravindan, S., Haq, A.N., Paneerselvam, K., (2009), "Optimization of friction welding parameter using evolutionary computational techniques", *Journal of Materials Processing Technology,* Vol. 209, pp. 2576-2584.

[6] Sahin, M., Akata, H.E., Gulmez, T., (2007), "Characterization of mechanical properties in AISI 1040 parts welded by friction welding", *Materials characterization*, Vol. 58, pp. 1033-1038.

[7] Handa, A., Chawla, V., (2013), "Experimental study of mechanical properties of friction welded AISI 1021 steels", Sadhana - Academy Proceedings in Engineering Sciences, Accepted for publication.

[8] Sathiya, P., Aravindan, S., Haq, A.N., (2005), "Mechanical and metallurgical properties of friction welded AISI 304 austenitic stainless steel", *Int J AdvManufTechnol,* Vol. 26, pp. 505-511.

[9] Satyanarayana, V. V., Reddy, G. M., Mohandas, T., (2005), "Dissimilar metal friction welding of austenitic-ferritic stainless steel", *Journal of Materials Processing Technology*, Vol. 160, pp. 128-137

[10] Ozdemir, N. and Orhan, N., (2005) "Microstructure and mechanical properties of friction welded joints of a fine-grained hypereutectoid steel with 4% Al" *Journal of Materials Processing Technology,* Vol. 166, pp. 63-70.

[11] Shribman V, Stern A, Livshitz Y and Gafri O. Magnetic pulse welding produces high strength aluminium welds. AWS Welding Journal April 2002.

[12] Shribman V. Magnetic pulse welding for dissimilar and similar materials: *3rd international conference on high speed forming* 2008: 13-22.

[13] Ananthapadmanadan, D., Rao, V. S., Abraham, N, Rao, K. P., (2009) " A study of mechanical properties of friction welded mild steel to stainless steel joints", *Materials and Design*, Vol. 30, pp. 2642-2646

[14] Ozdemir, N. and Orhan, N., (2005) "Microstructure and mechanical properties of friction welded joints of a fine-grained hypereutectoid steel with 4% Al" *Journal of Materials Processing Technology,* Vol. 166, pp. 63-70.