INFLUENCE OF PROCESS PARAMETERS ON TORSIONAL STRENGTH, IMPACT TOUGHNESS AND HARDNESS OF DISSIMILAR AISI 304 AND AISI 1021 FRICTION WELDED STEELS

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Resume

In this present study an attempt was made to join austenitic stainless steel (AISI 304) with low alloy steel (AISI 1021) at different rotational speeds and at different axial pressures and then determining the strength of the joint by means of mechanical properties such as torsional strength, impact strength and micro hardness. The experimental results indicate that the rotational speed and the axial pressure have a significant effect on the mechanical properties of the joint and it is possible to improve the quality of the joint by selecting the optimum parameters.

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1. Introduction

Dissimilar joints between austenitic stainless steel and low alloy steel are extensively used in many high temperature applications in the energy conversion system. 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 [1]. Joining of the metals is one of the most essential need of the industry [2]. 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 [3]. Friction welding is one such solid state welding process widely employed in such situations [4, 5]. Main advantages of friction welding are high material saving, low production cost, and ability to weld dissimilar materials [6]. Friction welding is one of the versatile and well established welding processes [4] 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 [7]. 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. 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. In this process heat energy is produced by the interconvertion of mechanical energy into thermal energy at the interfaces of the rubbing components [8].

This study extends the work done in reference [1]. In this present study different rotational speeds were used to evaluate the torsion strength, impact strength and hardness whereas in the previous work [1] tensile strength was evaluated under constant rotational speeds.

2. Experimental Details

Austenitic stainless steel AISI 304 and low alloy steel AISI 1021 specimens having diameter of 20 mm and 100 mm length were joined together at different rotational speeds and axial pressures respectively. 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 [2] was fitted on the machine to measure axial pressure. Test samples with the specific dimensions were prepared for friction welding experiments. Prior to friction welding the contacting surfaces was faced on the lathe machine and then cleaned using acetone [9]. The rotational speeds selected for this study was 800, 1000, 1250, 1430 and 1600 rpm. The required rotational speeds were 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, and afterwards 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. The welded specimens at different combinations have been shown in Figure 1.

3. Approach of work

Friction welded parts were subjected to variety of mechanical tests such as torsion test, impact toughness and micro hardness along with the visual inspection 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.

4. Results and Discussion

The friction welded specimens of five different rotational speeds and five different axial pressure combinations were prepared; 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 as well as the rotational speeds. It has also been observed from the Figure 1 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

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. Friction welded specimens.
(full colour vesrion available online)

undergoes extensive deformation. This phenomenon may be attributed to the low strength of AISI 1021 steel [10].

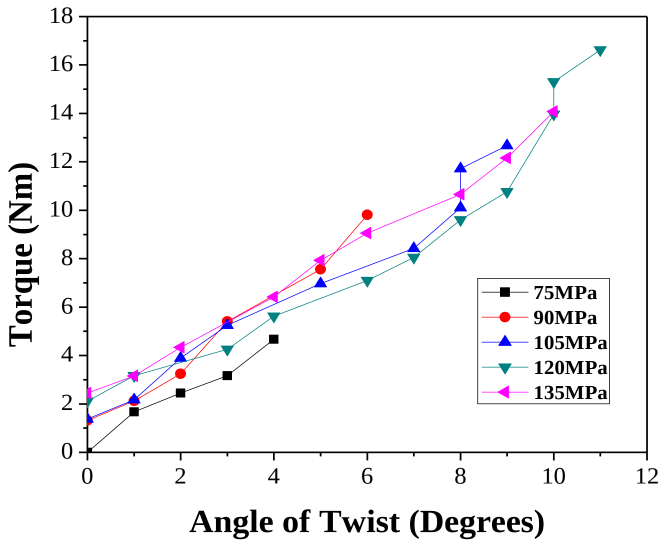
4.1 Torsion Test Result

Torsion testing machine was used for performing this test, the specimens for torsion test were prepared according to ASTM F779-12 standards keeping the weld interface at the center of the gauge length. In this test the specimens were loaded tangentially until its fracture occurs. The graphs were plotted on the basis of the results obtained from this test. Torsion 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 maximum torsion strength obtained from the tests varied from 4.67 Nm to 36.77 Nm and the maximum angle of twist in terms of degrees varied from 4° to 28°. Similar results have been reported by Shribman at el [11, 12]. It has also been observed during testing that the entire specimens fail at the weld interfaces. Fig. 2 (a to e) 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. It has also been noticed that with the increase in rotational speed the torque and angle of twist increases as well. This might be the effect of the diffusion of alloying elements from austenitic stainless steel to low alloy steel at the joint interface [11, 12]. When the rotational speed increases beyond 1430 rpm there is little bit decline in the torque but this difference is very marginal.

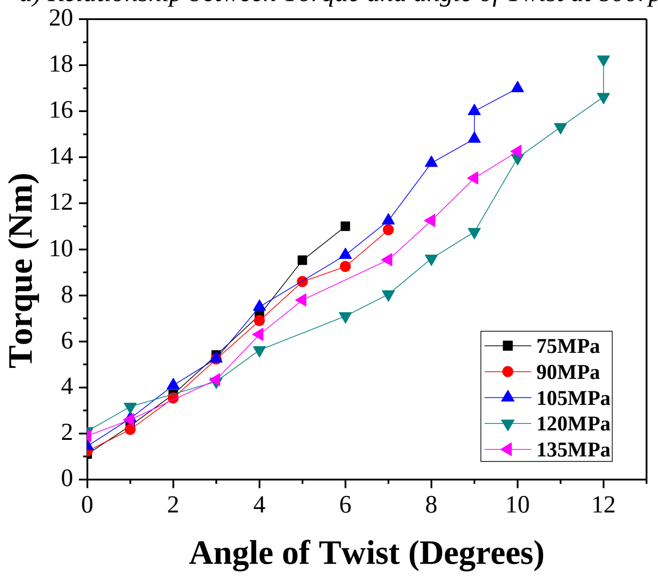
Table 2

Reports maximum values of Torque and Angle of Twist.

Specimen	Axial Pressure (MPa)	Max.Torque(Nm) 800rpm	Max. Angle 800rpm	Max.Torque(Nm) 1000rpm	Max. Angle 1000rpm	Max.Torque(Nm) 1250rpm	Max. Angle 1250rpm	Max.Torque(Nm) 1430rpm	Max. Angle 1430rpm	Max.Torque(Nm) 1600rpm	Max. Angle 1600rpm
A 1	75	4.67	4	11	6	14.6	8	18.14	9	16.26	8
A 2	90	9.81	6	10.85	7	14	8	23.53	12	20.5	11
A 3	105	12.67	9	17	10	18.45	11	24.51	12	26.71	14
A 4	120	16.62	11	18.25	12	22	14	36.77	28	22.94	14
A 5	135	14.08	10	14.25	10	19.9	13	34.32	21	22.32	10



a) Relationship between Torque and angle of Twist at 800rpm



b) Relationship between Torque and angle of Twist at 1000rpm

Fig. 2. Shows the relationship between Torque and angle of Twist at various rotational speeds.

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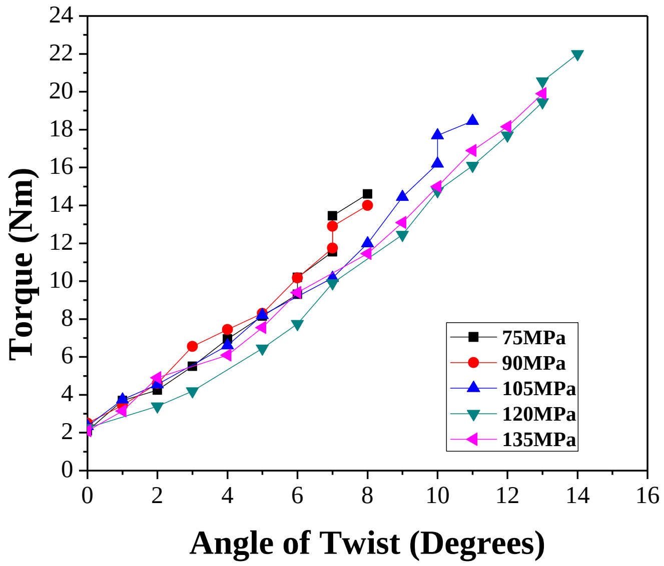
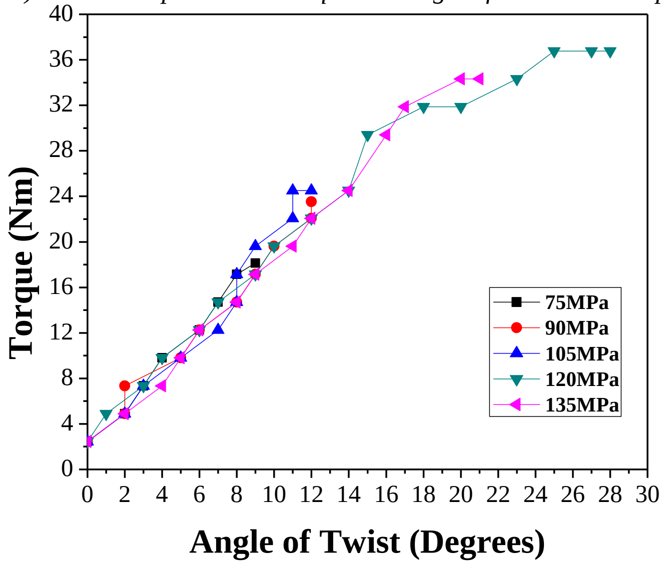
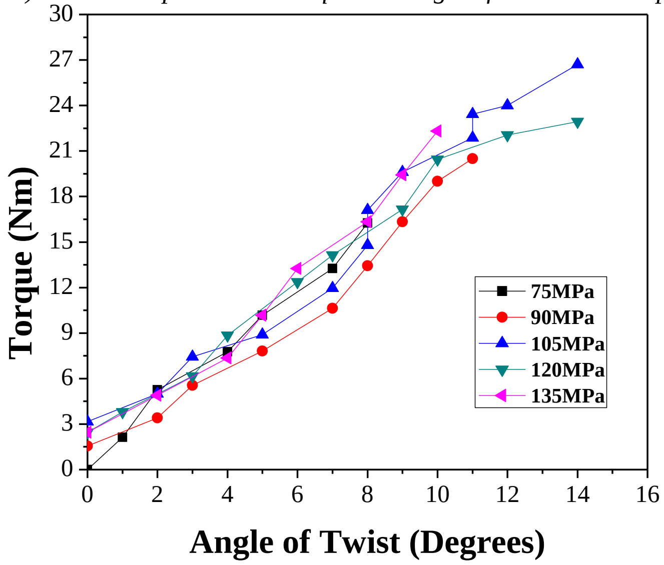


c) Relationship between Torque and angle of Twist at 1250rpm



d) Relationship between Torque and angle of Twist at 1430rpm



e) Relationship between Torque and angle of Twist at 1600rpm

Continuing of Fig. 2. Shows the relationship between Torque and angle of Twist at various rotational speeds.

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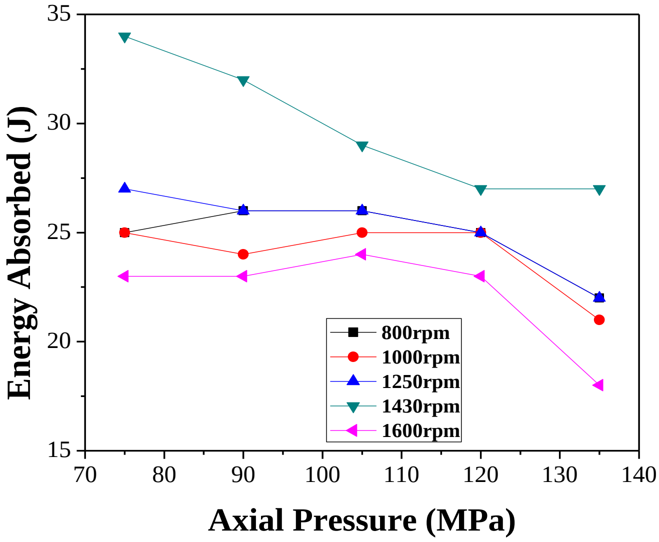
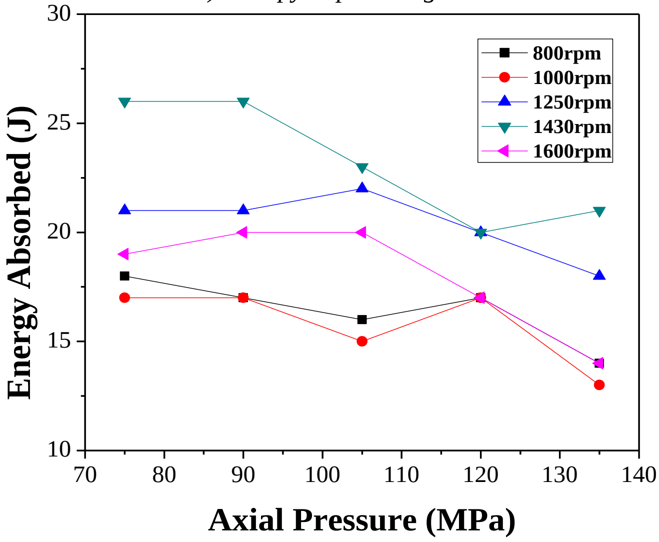
The maximum torque available was 36.77 Nm and the maximum angle of twist was 28° and these results were obtained at 120 MPa axial pressure and at 1430 rpm.

4.2 Impact Test Result

The notch impact toughness tests were carried out to find amount of energy absorbed during fracture. For impact testing the samples were prepared according to the ASTM A370-12 standards maintaining the notch at the centre of the weld interface. 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. As can be seen from the Fig. 3 (a & b), the Charpy toughness of the welded parts is slightly larger than the Izod impact toughness for every rotational speed and axial pressure. It has been noticed from the obtained results that with the increase in axial pressure the impact strength increases, it was found to be maximum at 1430 rpm and then with the further increase in rotational speed, it starts declining.



a) Charpy impact toughness



b) Izod impact toughness

Fig. 3. Impact toughness at different rotational speeds and axial pressures.

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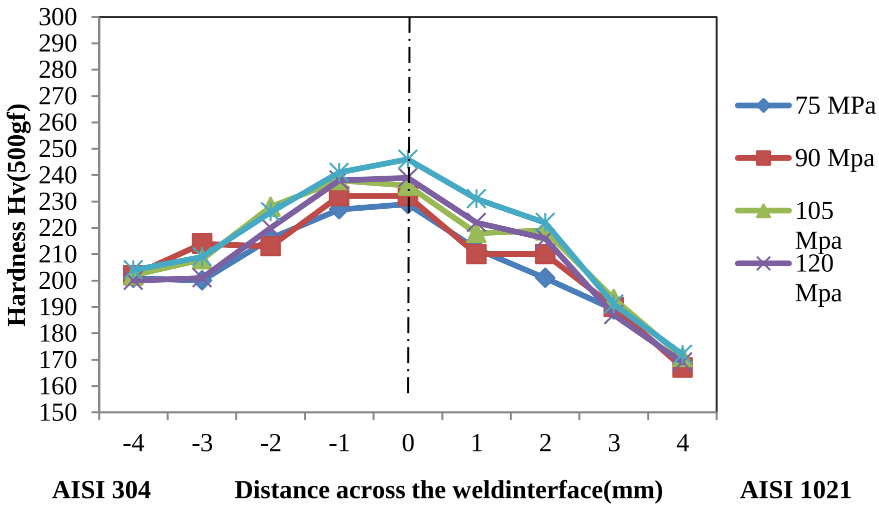
It has also been observed that with the increase in axial pressure, keeping the rotational speed constant, the impact toughness either remains constant or decreases. The results obtained from the test are quite comparable with the literature [10]. The maximum impact strength both for Izod as well as Charpy was obtained at 1430 rpm. Almost similar results were obtained at all the rotational speeds and axial pressures, but when the rotational speed exceeds 1430 rpm, the impact values both for Izod as well as Charpy decreases.

4.3 Micro Hardness Test Result

The micro hardness variations were obtained on Vickers Hardness Testing Machine, The hardness variations across the weld interface and along the weld interface were obtained by applying a constant load of 500 gf as shown in Fig. 4 (a to e). The hardness was measured at the weld interface and on the either side of the parent materials. AISI 1021 indicates 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 joint interface for all the joints [14]. The peak hardness of friction welded joints increases with the increase in burn-off length [15]. 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. This may be occurred by the presence of heat as the thermal conductivity of the material is relatively low [10]. In addition to that the higher values of hardness at the joint interface were probably due to the oxidation process which takes place during friction welding [16]. The higher hardness values were found to be at austenitic stainless steel side for all the samples. For every sample with the increase in either the axial pressure or the rotational speed, the value of hardness increases. The maximum hardness was found at 1600 rpm and at 135 MPa axial pressure where it crosses the 290 HV value, this might be the reason that the specimen fails at this parameter without giving any deformation.



a)Hardness at 800rpm
Fig. 4. Variation in hardness under different rpm's and axial pressures.
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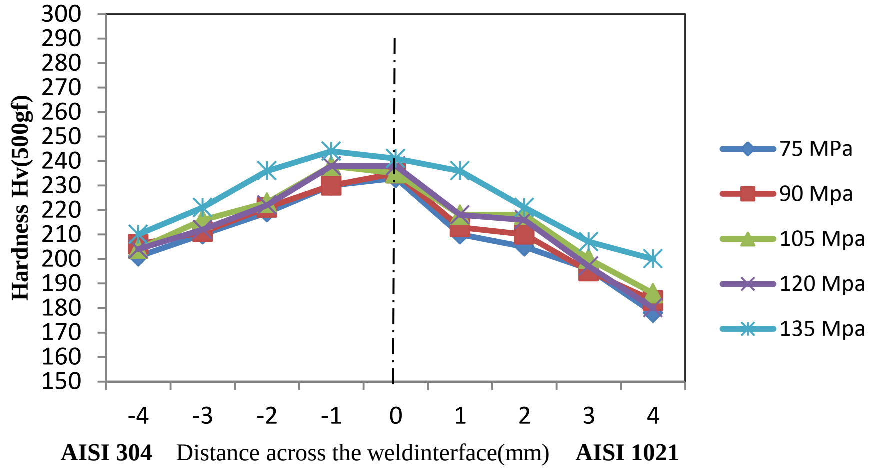
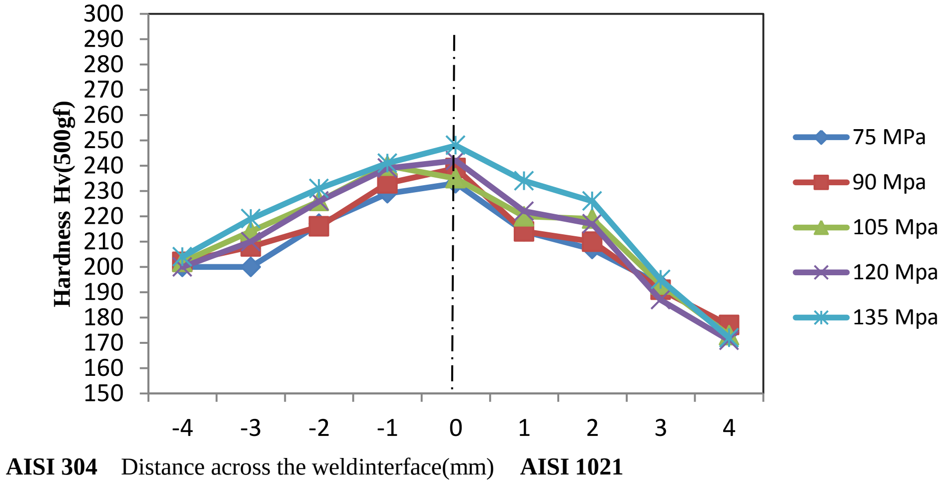
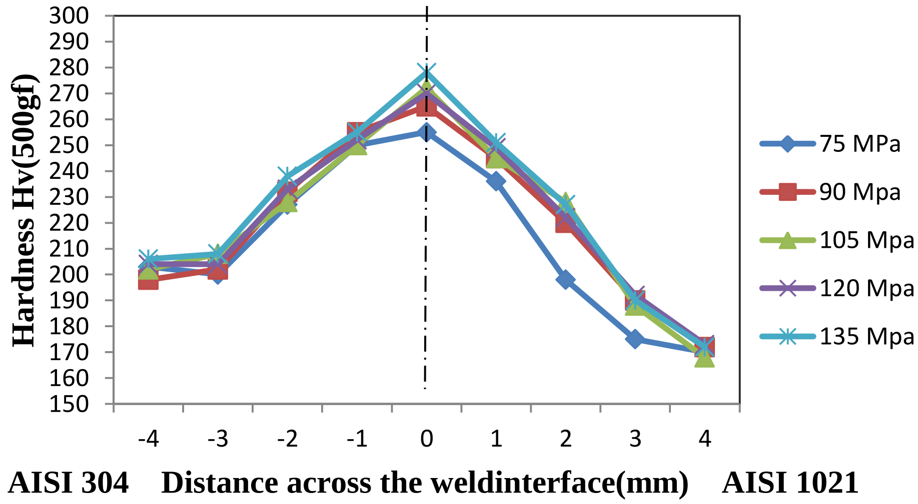


b)Hardness at 1000rpm



c)Hardness at 1250rpm



d)Hardness at 1430rpm

Continuing of Fig. 4. Variation in hardness under different rpm's and axial pressures.

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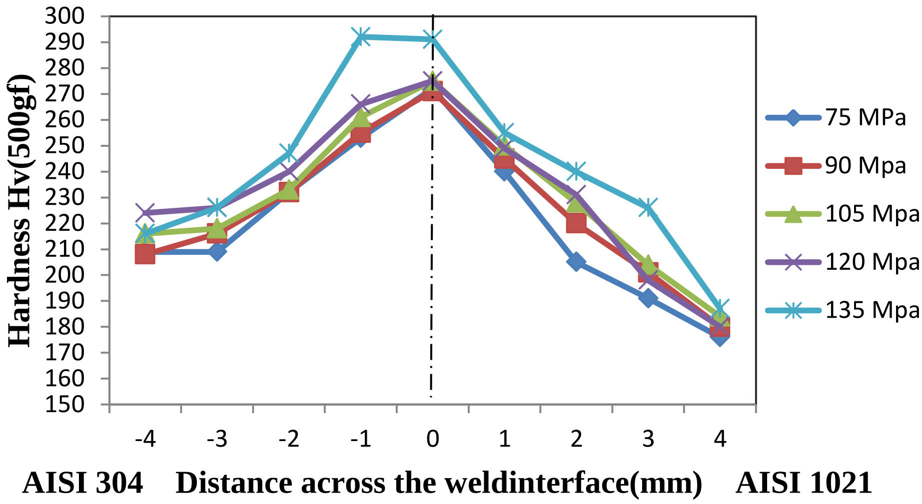

e)Hardness at 1600rpm

Continuing of Fig. 4. Variation in hardness under different rpm's and axial pressures.

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5. Conclusion

It has been concluded from the above study that with the increase in the axial pressure the strength increases, the torsional strength also increases with the increases in the rotational speed as well. The torsional strength starts declining when the rotational speed increased to 1600 rpm. This argument is also supported by Chander et al [3] that higher heat input rates at higher friction force conditions and low weld times results in rapid cooling of the material, which leads to the formation acicular martensite on low alloy steel side. This acicular martensite is hard and very brittle, hence giving low strength. Furthermore the value of hardness at 1600 rpm and at 135 MPa axial pressure crosses the value of 290 HV which is not acceptable. The maximum torsion strength was available at 1430 rpm and at 120 MPa axial pressure, maximum angle of twist was also found at these parameters, showing the signs of little bit ductility, even though the specimen at this parameter fails at the joint interface. The impact toughness and hardness values were also found to be satisfactory at these parameters.

References

[1] A. Handa, V. Chawla: Mater. Eng. – Mater. Inž. 20(3) (2013), pp. 102-111.

[2] A. Handa, V. Chawla: Sadhana - Academy Proc. in Engin. Sci. 38(6) (2013) 1407-1419.

[3] G. S. Chander, G. M. Reddy, G. R. N. Tagore: Int. J. Adv. Manuf. Technol. 64(9-12) (2012) 1445-1457.

[4] S. D. Meshram, T. Mohandas, G. M. Reddy: J. Mater. Process. Technol. 184(1-3) (2007) 330-337.

[5] P. Sathiya, S. Aravindan, N. A. Haq: Mater. and Design, 29(6) (2008) 1099-1109.

[6] M. Sahin: J. Mater. Process. Technol. 153-154 (2004) 1011-1018.

[7] P. Sathiya, S. Aravindan, A. N. Haq, K. Paneerselvam: J. Mater. Process. Technol. 209(5) (2009) 2576-2584.

[8] M. Sahin, H. E. Akata, T. Gulmez: Mater. Charact. 58(10) (2007) 1033-1038.

[9] P. Sathiya, S. Aravindan, A. N. Haq: Int. J. Adv. Manuf. Technol. 26(5-6) (2005) 505-511.

[10] V. V. Satyanarayana, G. M. Reddy, T. Mohandas: J. Mater. Process. Technol. 160(1) (2005) 128-137.

[11] V. Shribman, A. Stern, Y. Livshitz, O. Gafri: AWS Welding J. 81(4) (2002) 33-37

[12] V. Shribman: In: 3rd international conference on high speed forming, Ed: M. Kleiner, Dortmund, 2008, pp. 13-22.

[13] D. Ananthapadmanadan, V. S. Rao, N. Abraham, K. P. Rao: Mater. and Design 30(7) (2009) 2642-2646.

[14] N. Ozdemir, N. Orhan: J. Mater. Process. Technol. 166(1) (2005) 63-70.

[15] N. Arivazhagan, S. Singh, S. Prakash, G. M. Reddy: Mater. and Design 32(5) (2011) 3036-3050.

[16] H. Ates, M. Turker, A. Kurt: Mater. and Design 28(3) (2007) 948-953.