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Effect of Rotation Speed Parameter on Mechanical Properties of Similar AISI 1040 Parts Joined By Friction Welding

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Friction welding is one of the important joining methods widely used, especially for welding cylindrical parts, in many industries. In this study, friction welding of similar material steel AISI 1040 cylindrical parts having 12 mm diameter is successfully realised at different welding parameters. In order to determine mechanical properties of welds, the tensile strength and microhardness tests as well as microstructural analysis are carried out and discussed. In addition, the comparison between parts welded at different revolutions per minute (rpm) is made in terms of mechanical properties. Experimental results show that the highest tensile strength is nearly 400 MPa, which is obtained at the parts welded through 1500 rpm.

Key words: friction welding, AISI 1040 steel, mechanical properties, rotation speed.

Зварювання тертям є одним з важливих способів з’єднання, який широко використовується, зокрема, для зварювання циліндричних деталів, у багатьох галузях промисловости. В даній роботі було виконано зварювання тертям циліндричних деталів діяметром у 12 мм зі сталі AISI 1040 за різних параметрів зварювання. Для характеризації механічних властивостей зварних швів визначено міцність на розтяг і мікротвердість, а також виконано мікроструктурну аналізу. Крім того, проведено порівняльну аналізу механічних властивостей деталів, зварених за різних швидкостей обертання. Результати експериментів по-

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казують, що максимальна міцність становить близько 400 МПа і досягається при 1500 об/хв.

Ключові слова: зварювання тертям, сталь AISI 1040, механічні властивості, швидкість обертання.

Сварка трением является одним из важных способов соединения, который широко используется, в частности, для сварки цилиндрических деталей, во многих отраслях промышленности. В данной работе была проведена сварка трением цилиндрических деталей диаметром 12 мм из стали AISI 1040 при разных параметрах сварки. Для характеризации механических свойств сварных швов определены прочность на растяжение и микротвёрдость, а также выполнен микроструктурный анализ. Кроме того, проведён сравнительный анализ механических свойств деталей, сваренных при различных скоростях вращения. Результаты экспериментов показывают, что максимальная прочность составляет около 400 МПа и достигается при 1500 об/мин.

Ключевые слова: сварка трением, сталь AISI 1040, механические свойства, скорость вращения.

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1. INTRODUCTION

In friction welding process, joining is made by generating heat through transformation of mechanical energy into thermal energy at the interfaces of the parts while one part is rotating and the other one is pressing on the rotating part. In friction welding process, the most important parameters are friction time, friction pressure, upset time, upset pressure and rotation speed to attain strong joinings. Friction welding is a solid state welding method that has many benefits, for instance, similar and dissimilar metals or alloys can be successfully joined with low material consumption, low distortion, and high mechanical properties (Celik and Ersozlu, 2009; Caligulu *et al.*, 2015). AISI 1040 steel can be easily welded by appropriate procedure. Welding of AISI 1040 steel parts in the through-hardened or flame or induction-hardened circumstances is not suggested. AISI 1040 steel is utilized for forged components having suitable strength and toughness. AISI 1040 steel is used for manufacturing of forged crankshafts and couplings.

Many studies on friction welding have been done. Ellis (1977) investigated the relationships between ‘friction time–workpiece diameter’, ‘shortening–upsetting pressure’ and ‘carbon equivalent–hardness variation’. Dunkerton (1986) studied on the effects of rotation speed, friction pressure and upsetting pressure in the friction welding process for steel. Yılmaz *et al.* (2003) investigated interface properties of aluminium and steel friction welded parts. Akata and Sahin (2003) examined the effect of dimensional differences in friction welding of AISI 1040 components.

In this study, friction welding of similar AISI 1040 steel bars having 12 mm diameter was performed.

2. MATERIALS AND METHODS

Material used in this study was commercial AISI 1040 medium carbon steel bars having 12 mm diameter. Chemical composition of this material is illustrated in Table 1. Friction welding of the same material AISI 1040 medium carbon steel bars was made by using direct-drive friction welding machine. Friction welding operations were performed at constant forging pressure and at constant forging time for two different rotational speeds which given in Table 2.

Macrophotograph of the joints of welded specimens is presented in Fig. 1. After friction welding operations, the welded specimens were prepared in TSE 138 standard shown in Fig. 2 for tensile tests. So, as to assess mechanical properties of friction-welded joints, tensile tests were performed by Yuksel Kaya Machine and microhardness tests on the weld cross-section areas at 0.5 mm intervals were carried out.

Furthermore, in order to observe the microstructural variations in the weld areas, adhesive SiC paper for cleaning and 1 micron diamond paste for polishing were used. 3% nital for etching operation was employed by applying 2 s. Later, weld interfaces were examined *via* scanning electron microscopy (SEM) and optical microscopy (OM). Macrophotograph of the welded interfaces is presented

TABLE 1. Chemical compositions of AISI 1040 material.

Material	C, %	P, %	S, %	Mn, %	Si, %	Ni, %	Cr, %	Tensile strength of materials, MPa
AISI 1040	0.35 0.44	<0.04	<0.05	0.75	0.2	–	–	520

TABLE 2. The process parameters used in the friction welding.

Sample No.	Welding parameters				
	Friction time, s	Friction pressure, MPa	Rotation speed, rpm	Upset pressure, MPa	Upset time, s
S1	6	60	1500	120	12
S2	6	60	1700	120	12

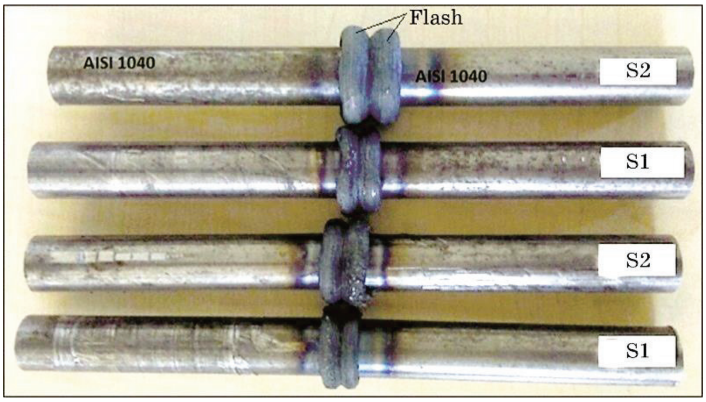

Fig. 1. Macrophotographic view of friction welded samples.

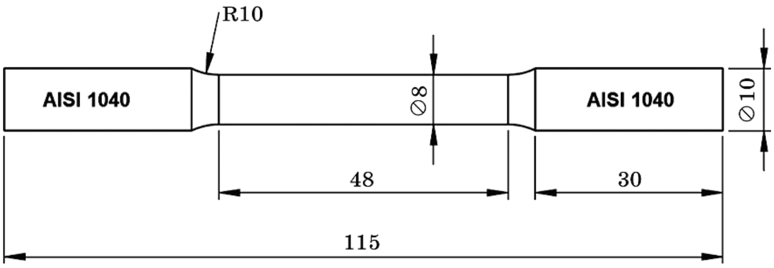

Fig. 2. Dimensions of tensile test specimens.

in Fig. 3.

3. RESULTS AND DISCUSSION

3.1. Tensile Strength Analysis

Figure 4 shows the samples prepared for tensile test, and Fig. 5 shows samples after tensile test. Tensile strength of friction welded S1 and S2 is given in Fig. 6. It can be seen from Fig. 6 that tensile strength of S1 is about 400 MPa joined at 1500 rpm rotation speed while tensile strength of S2 is about 360 MPa joined at 1700 rpm rotation speed. Tensile strength of S2 is lower than tensile strength of S1. The reason for lower tensile strength in S2 is that higher rotation speed of S2 resulted in high temperatures, which caused melting and removed plastic deformation in interface. In friction welding process, since high temperatures and plastic deformations and hardness changes occur in the weld interfaces of parts, mechanical properties of parts change (Ozdemir *et al.*, 2007; Maweja and

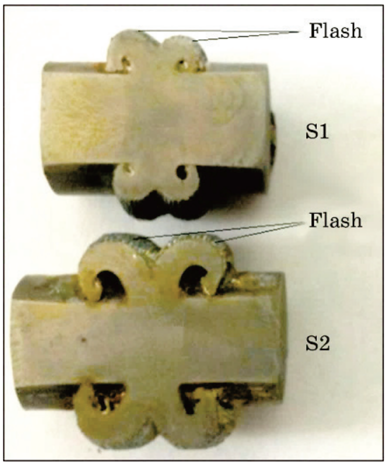

Fig. 3. The macrograph of the weld joint interface of samples S1 and S2.

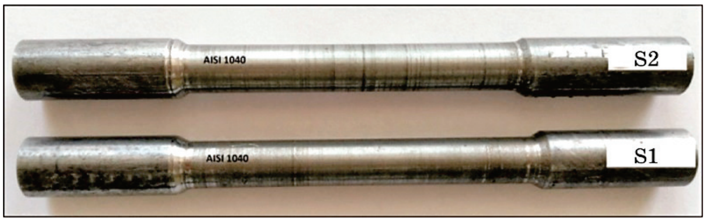

Fig. 4. Macrophotographic view of samples prepared for tensile test.

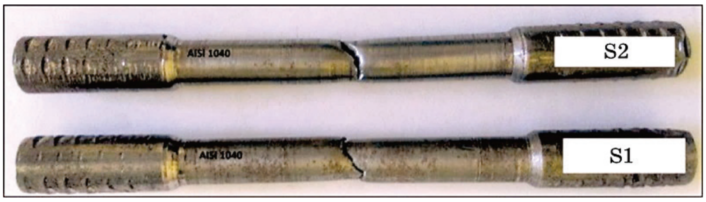

Fig. 5. Macrophotographic view of samples after tensile test.

Stumpf, 2006). Elongation of S1 is more than S2 and it is 9.52%.

3.2. Microhardness Analysis

Figure 7 indicates microhardness of friction welded joints. Microhardness tests were carried out under load of 300 g and at 0.5 mm intervals horizontally across the weld joint using Vickers Hardness technique. It was found that hardness of base material is higher

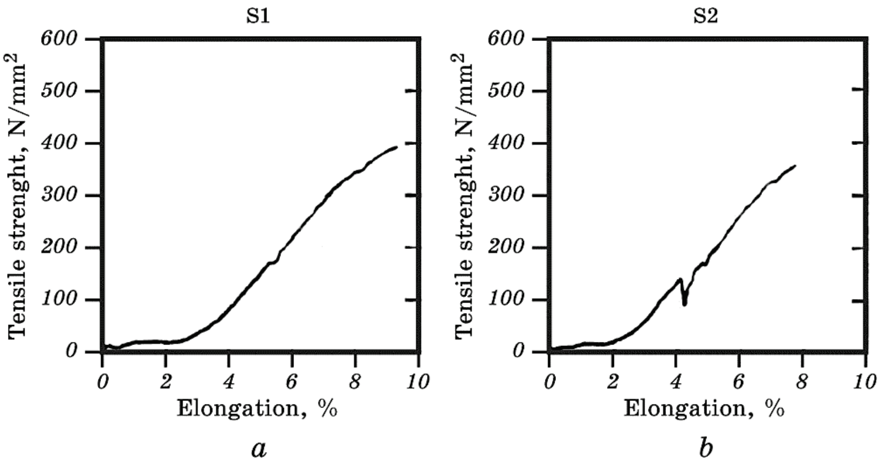

Fig. 6. Tensile tests results.

than the hardness of weld zone for both S1 and S2 that is approximately 255 HV.

It was determined that the hardness from base material to the weld zone decreases. When S1 and S2 compared in terms of hardness at the weld zone, S1 has a higher hardness value, which is at the average of 180 HV. In addition, it was found that the hardness

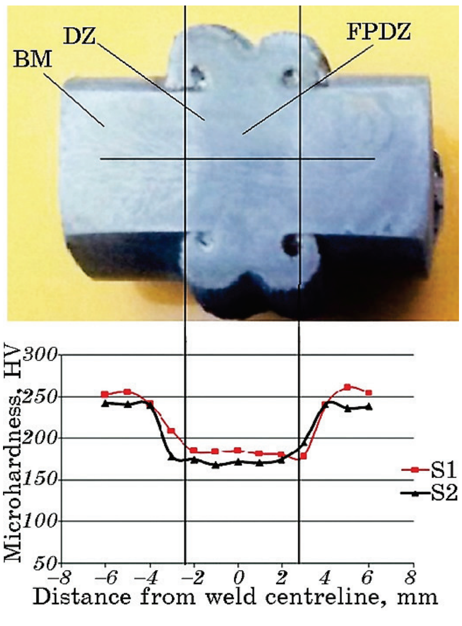

Fig. 7. Microhardness distribution.

at the deformation zone (DZ) is slightly greater than full plastic deformation zone (FPDZ). It was determined in all the experiments that the hardness of DZ is lower than the base material because of thermal effect dominating at the weld interface (Seli *et al.*, 2010).

3.3. Microstructure Analysis

The macrograph of the weld joint interface of samples S1 and S2 is demonstrated in Fig. 3. The micrograph of the weld samples S1 and S2 is presented in Fig. 8. Optical microscope photos of interface are given in Fig. 9. Crack, gap, and unbound regions were not observed at the joint surface of the components. Deformation flows revealed obviously that there are no defects at the weld joints for S1 and S2. Microstructure photos of base material (BM), DZ and FPDZ were taken and then these microstructure photos were inspected. Grains and grain boundaries can be seen clearly from microstructure photos. Both ferrite and austenite morphologies were observed at FPDZ as seen in Fig. 8, *b*. and Fig. 8, *c*.

It was observed that the grain sizes at the DZ are smaller than

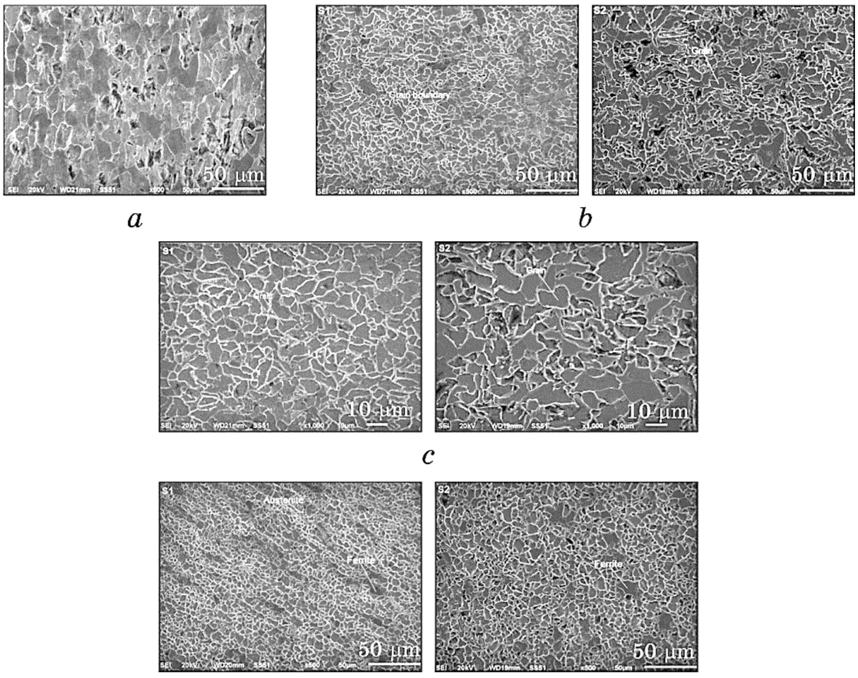

Fig. 8. SEM microstructure: BM (*a*), FPDZ (*b*, *c*), DZ (*d*).

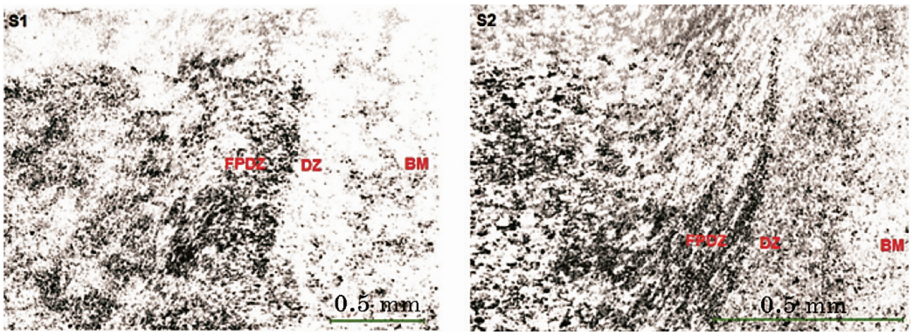

Fig. 9. OM photos.

those of FPDZ at both S1 and S2. Furthermore, the grain sizes at the FPDZ of S1 are smaller than S2; the reason for this is improving rotation speed. In other words, when rotation speed increased from 1500 rpm to 1700 rpm, the grain sizes at the DZ and FPDZ regions grew as it can been seen from Fig. 8, *c* and Fig. 8, *d*. In addition, as a result of increasing rotation speed causing an increase in heat and more deformation, flash size got larger as shown in Fig. 3 and width of FPDZ got larger demonstrated in Fig. 9. It was found by (Hazra *et al.*, 2014) that upset pressure determines each zone size and FPDZ microstructure has very fine grains owing to the repeated recrystallization and maximum deformation at FPDZ.

4. CONCLUSIONS

The effect of rotation speed on tensile strength, microhardness and microstructure in friction welding of similar material AISI 1040 were studied. AISI 1040 rods with a diameter of 12 mm were successfully joined *via* direct-drive friction welding method. The following conclusions were drawn.

The tensile strength decreased approximately by 12% with increasing rotation speed from 1500 rpm to 1700 rpm, and yield strength decreased by 18%.

With increasing rotation speed from 1500 rpm to 1700 rpm, microhardness at both DZ and FPDZ areas dropped.

The grain sizes at both DZ and FPDZ became larger as a result of increasing rotation speed resulting in more heat input. Also, FPDZ width improved.

Flash size increased due to an increase in rotation speed as seen clearly in Fig. 8.

When sample S1 is compared with S2 in terms of microstructure, S1 has a more fine-grained structure than S2. Therefore, microhardness and tensile strength value are higher in S1.

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