RESEARCH PAPER

Effect of Welding Parameters on the Microstructure and Mechanical Properties of Friction-Welded Joints of 100Cr6 Steel

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Received: August 2018 **Revised: May 2019** **Accepted: June 2019**

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DOI: 10.22068/ijmse.16.2.24

Abstract: *In this study, high-carbon, chromium alloy steel (100Cr6) having the initial spheroidized microstructure was welded using the rotary friction welding method. The effects of process parameters such as friction time and friction force were experimentally investigated. The friction welded joints were produced of two 100Cr6 steel rods. In order to examine the microstructure and mechanical properties of the friction welded 100cr6 steel joints, tensile and hardness tests were conducted. The microstructure of the weld zone was examined by optical microscopy. It was found that after cooling, martensitic structure is obtained at the core and periphery of the weld joint. It was found that the tensile strength of friction welded samples is increased with increasing time and force of friction up to a certain level and then decreases again. Hardness measurements show a higher hardness at the center of the weld joint in comparison with its periphery.*

Keywords: *Rotary friction welding, 100 Cr6 steel, Heat Affected Zone, mechanical properties, microstructure.*

1. INTRODUCTION

The 100Cr6 steel is a high-carbon, chromium alloy steel which has excellent characteristics needed for manufacturing bearings and precision components. These steels have high strength and good wear resistance [1]. However, when it is required to produce a continuous joint between different parts by conventional welding method, high carbon steels generally have poor weldability by fusion welding method. This technique has shown its ability to assemble materials when conventional techniques show their limits, appears promising to eliminate the melting problems which arise during fusion welding processes, because it does not reach the melting point of the material to be welded. Rotary friction welding (RFW) is a solid-state joining process. It is performed by rotating one part relative to another under a compressive axial force. The heat generated locally by friction at the interface plasticizes the material. This deformation process forms a flash and causes a shortening of parts in the direction of the compressive force. Once the required plastic state has been achieved, the rotation movement is ceased and the forging force is increased for a period of time to help consolidate the weld. In the literature, many researchers have conducted various investigations into the friction welding of carbon steels by combining several types of joints. Madhusudhan et al. [2] have applied the friction welding method to join low alloy steel to maraging steel with nickel as an interlayer. The study revealed that nickel can be employed as an effective barrier for diffusion of elements such as carbon and manganese to overcome the problem of carbon migration, retained austenite formation, and consequent premature failure. Mumin Sahin et al. [3] have characterized the mechanical properties in AISI 1040 friction welding joints. The optimization of the friction welding process parameters is investigated by using the response surface methodology (RSM) to achieve a good weld with maximum mechanical properties such as tensile strength [4,5,6]. Radoslaw have employed the RSM to develop empirical relationships between friction welding input parameters and output response such as tensile strength for ductile iron (ASTM A 536) with low carbon steel (AISI 1020) rods joints [7]. In another study [8], the optimum welding parameters, such as mechanical properties and microstructure of weld joint were experimentally determined in materials during the joining of X53CrMn NiN219 and X45CrSi93 steels by FW. Many types of research were carried out on the FW of high carbon steels, [9-12] where the properties of FW joints were studied and analyzed. In the literature, several studies were also done to characterize properties of weld joints in various metals processed by Friction stir welding (FSW). Gharibshahiyan et al. [13] have studied the heat transient generated in Al 7050 aluminum alloy joined by FSW. The authors developed a 3D model by using a finite element method to simulate weld heat distribution. Goodarzi et al. [14] have carried out a study on the FSW of 2024-T851 aluminum alloy. It was found that the A l6 (CuFeMn) particles are broken up during friction stir welding and the hardness in the stir zone increases with increasing rotational speed. Alvand et al. [15] have carried out an experimental investigation on the effect of FSW process on the grain structure and crystallographic texture in the stir zone of 0.8 mm thick AA 2024 aluminum alloy sheets using EBSD technique. Zamani et al. [16] performed friction stir lap welding between 3 mm thick 1100 aluminum alloy and commercial pure magnesium. Tehrani - Moghadam et al. [17] studied the effect of FSW parameters on microstructure and mechanical properties in Fe-24Ni-0.3C TRIP steel. It was observed that the microstructures from the base metal as well as the stir zones were fully composed of only austenite phase. Saman Karami et al. [18] evaluated the effects of FSW parameters on microstructure and mechanical properties of mild steel. The present work aims to investigate the effect of two process parameters such as friction time and friction force on the quality of the weld joints obtained by rotary friction welding process (RFW) of 100Cr6 steel having a spheroidized structure. For this purpose, the microstructures of weld metal, as well as tensile strength and hardness of the welded joints, were studied.

2. EXPERIMENTAL PROCEDURE

2.1 Material

In the present investigation, the friction welding was done on high carbon chromium alloyed steel (100Cr6). The chemical composition is given in Table 1. The microstructure of the 100cr6 steel showed a matrix of ferrite and spheroidized cementite (Fig.7a). The material called here base metal (BM) exhibits a hardness of about 280 HV.

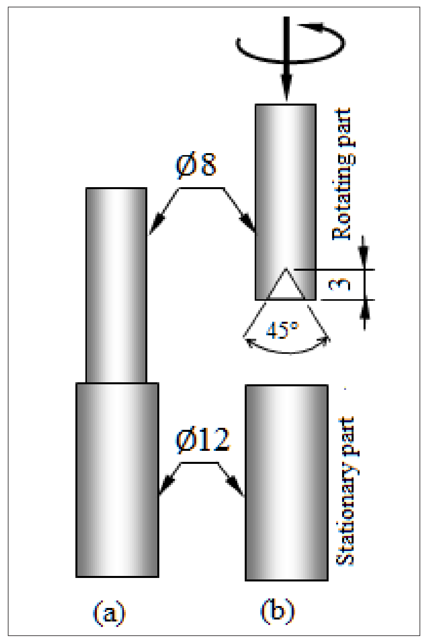

Fig.1 Test specimens dimensions
a - Reference tensile test specimen b - Workpieces used for friction welding experiments

The dimensions of base material rods and faying surface geometries considered inthis study are shown in Fig.1b. During friction welding, the 8 mm diameter rod with an internal taper was rotated and the 12 mm rod with square cut shape was kept stationary.

Table 1: Chemical composition of 100Cr6 steel

Elt	C	Si	Mn	S	Cr	Mo	Ni	Cu	Fe
Wt.%	1.01	0.19	0.37	0.013	1.55	0.04	0.11	0.39	Bal

[DOI: 10.22068/ijmse.16.3.24]

Table 2. Friction welding parameters

Séries N°	Samples N°	Friction time (sec)	Friction force (KN)	Constant parameters
Series N° 1 Effect of friction time	S1	1	3	Rotational speed: N = 1000 rpm
	S2	2	3	Forging time: Tforg = 10 sec
	S3	3	3	Forging force: Fforg = 13 KN
	S4	4	3	
	S5	5	3	
Series N° 2 Effect of friction force	S6	3	1	
	S7	3	2	
	S8	3	3	
	S9	3	4	
	S10	3	5	

2.2 welding parameters

The welding experiments were performed using a vertical drilling machine modified to obtain a vertical rotary friction welding. Two series of welding experiments were selected to evaluate the effects of friction time and friction force on the strength of friction welds (table 2). Rotational speed (1000 rpm), forging force (13 kN) and forging time (10 seconds) were kept constant.

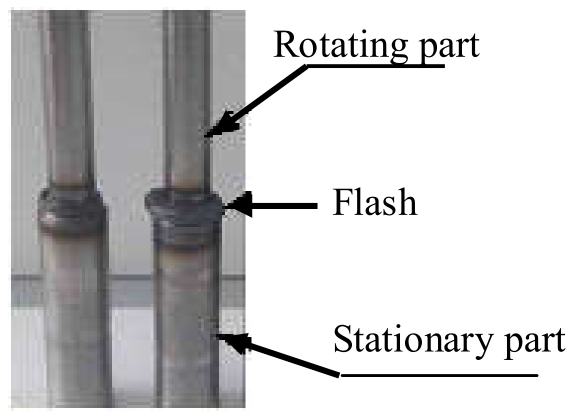

Fig. 2. Friction welded specimens

2.3 Characterization techniques

In order to examine the efficiency of the friction welds, a non-standard specimen (Fig.1a) was considered as a reference specimen for the tensile tests. The reference specimen and the welded specimens (Fig.2) were subjected to longitudinal tensile tests using a Zwick/Roell Z100 tensile testing machine, having a capacity of 100 kN. The original gauge length of all tensile test specimens was measured (L0 = 20 mm). The tensile properties were measured in terms of:

- Tensile force: maximum force which the test specimen withstands,
- Percentage of elongation: at maximum tensile force.

To investigate the microstructure changes in the welding zone, optical microscopy observations were carried out in different regions of the weld joint. Specimens were cut on the longitudinal direction of welded parts, prepared by

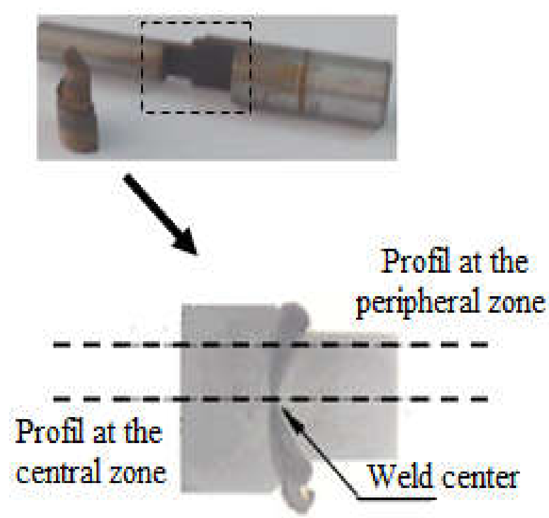

Fig. 3. Hardness test orientation

[DOI: 10.22068/ijmse.16.3.24]

Table 3. Tensile test results of friction welded specimens - as welded.

Samples N°		Tensile force (N)	Percent elongation (%)	Axial shortening (mm)
Reference specimen		36200	25	-
Series 1	S1	Weld failed	-	-
	S2	3420	3,5	2.06
	S3	17400	13,5	2.8
	S4	20900	16 ,5	7.42
	S5	20500	16,5	8
Series 2	S6	Weld failed	-	-
	S7	Weld failed	-	-
	S8	17400	13.5	2.8
	S9	20600	15.5	4
	S10	22100	18	6.3

mechanical polishing and etched using 3% Nital chemical solution. The hardness evaluation across the weld zone was conducted by Vickers hardness test under a load of 1N. The measurements were carried out at the periphery and weld center along a longitudinal section of the welded specimen. Two profiles were performed (Fig.3).

3. RESULTS AND DISCUSSION

3.1. Tensile test

Different specimens were tested for each series. The tensile test results are given in Table 3. From the experimental results, it was observed that all the as-welded tested specimens fractured in the weld region. The tensile values for all the friction welds were lower than those of the base material (reference specimen).

The effects of friction time and friction force on tensile properties are shown in Fig.4 and 5. The tensile force increases up to a maximum value of 20900 N with increasing friction time (Fig.4a). After that, a significant decrease in tensile force value was observed as friction time increases This shows that a longer friction time is not a recommended welding condition. From Fig.5a, it can be seen that the friction force has

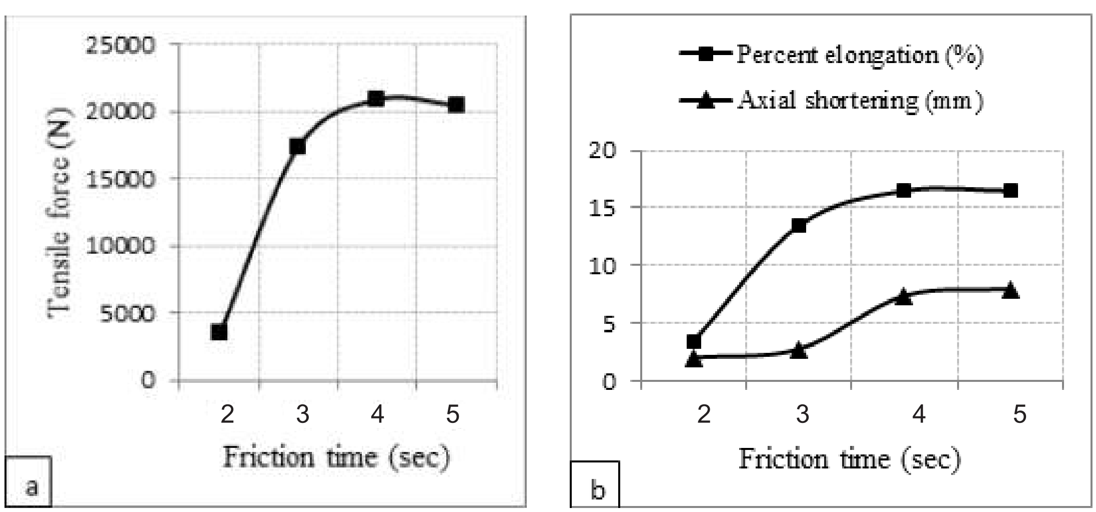

Fig. 4. Effect of friction time on tensile properties of friction welded specimens (series 1)

[DOI: 10.22068/ijmse.16.3.24]

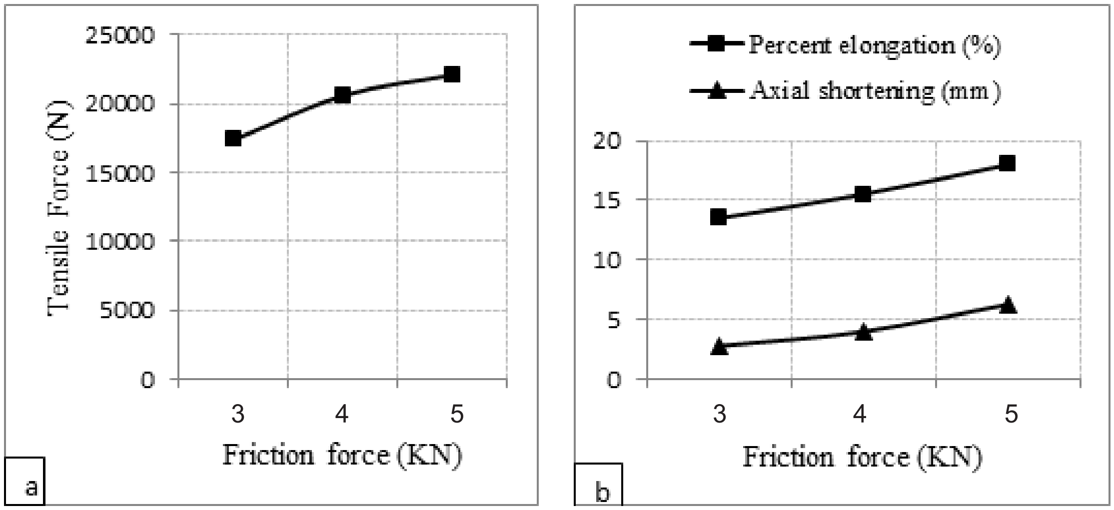

Fig. 5. Effect of friction force on tensile properties of friction welded specimens (series 2)

a significant effect on the tensile strength of the friction welds. As the friction force increases, the tensile force also increases. The highest tensile force reaches a maximum value of 22100 N for a friction time of 3 seconds and a friction force of 5 kN. This corresponds to 61 % of the base material tensile force. The effect of friction time and friction force on elongation and axial shortening for each friction welded specimen are plotted in Fig.4b and Fig.5b, respectively. It can be seen that the percent of elongation was lower for all welded specimens than that of the base material. However, the values increased with increase in friction time and friction force. The axial shortening is the difference between the axial length of the specimen before and after friction welding. It plays an important role in achieving good friction weld strength and it also influences the material consumption. It is governed by the process parameters and material properties of workpieces to be welded. It can be seen from Fig.4b and Fig.5b that the axial shortening increases as friction force and friction time increase. This is due to the increasing heat input and plastic deformation at the interface of the friction welded joints.

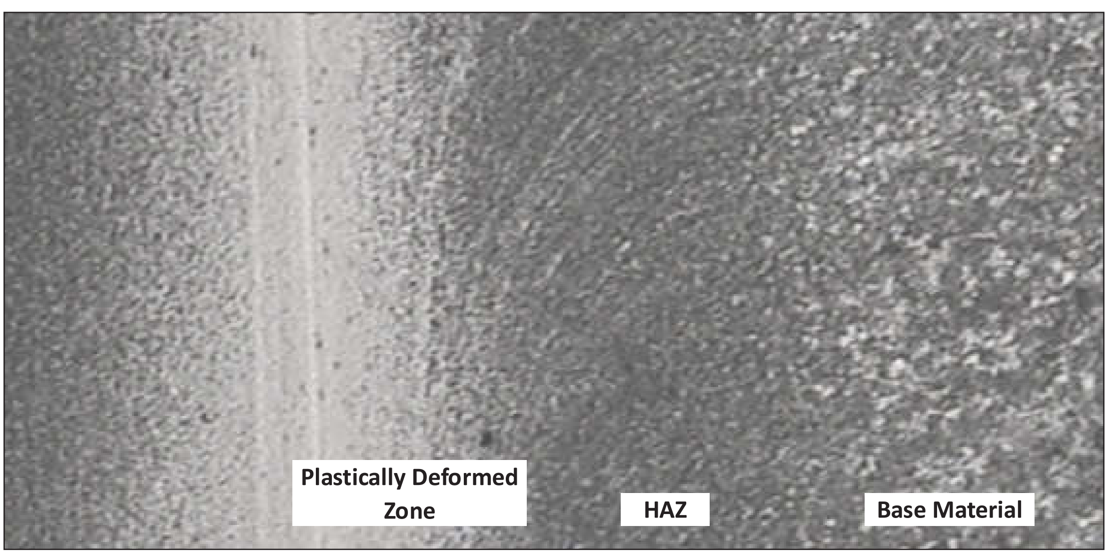

Fig. 6. Optical micrograph showing different regions of weld zone taken at the specimen S5 (as welded) - 100 x

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3.2 Microstructure

In the friction welding process, the material at the interface of workpieces is subjected to severe plastic deformation at high temperature. This thermomechanical treatment will influence the final microstructure and mechanical properties of the material. In the as-friction welded conditions, depending on the process parameters, the microstructure observations using optical microscopy along the longitudinal direction at the weld zone exhibited three distinct regions (Fig.6).

It consists of a plastically deformed zone (white zone), a heat affected zone (HAZ) and base material (BM). The morphology and microstructure of these zones are dependent on the material, faying surface geometries, and process parameters. Fig.7b shows the HAZ microstructure taken from sample S5, which exhibits a mixture of Ferrite and Pearlite. The change of microstructure can be attributed to the friction heat generated during friction welding.

As seen in Fig.7c and Fig.7d, the microstructure of the plastically deformed zone contains martensite (dark areas) and retained austenite (light areas). Martensite is a very hard and brittle nonequilibrium phase. It forms when steel is rapidly cooled from the austenitizing temperature to below martensite start (Ms) temperature and proceeds over a range of temperatures. Marten-

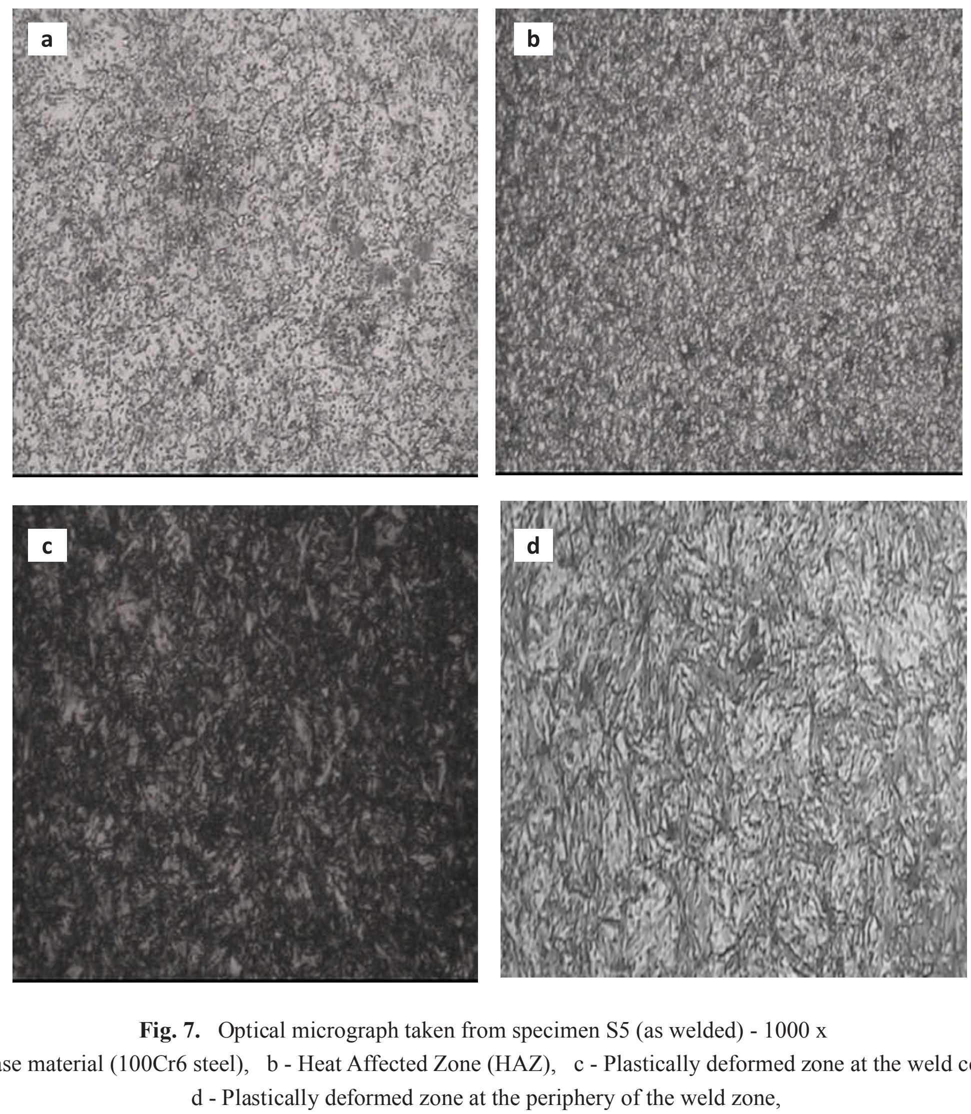

Fig. 7. Optical micrograph taken from specimen S5 (as welded) - 1000 x
a - base material (100Cr6 steel), b - Heat Affected Zone (HAZ), c - Plastically deformed zone at the weld centre, d - Plastically deformed zone at the periphery of the weld zone,

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site is characterized by its high hardness and lower ductility when compared to austenite. During transformation, there is a possibility that not all austenite transforms to martensite, some amount of austenite remains untransformed. This untransformed austenite is known as retained austenite. It is a relatively soft and ductile phase.

3.3 Hardness

The microhardness distribution on the weld joint taken from specimen S5 is shown in Fig.8. Friction welding increases the hardness in the weld joint. It changes longitudinally from the highest value of the plastically deformed zone, having an average value of about 950 HV, to the lowest values in the base material. This different hardness is due to the difference in microstructure in the weld joint. The high hardness in the plastically deformed region is related to the presence of martensite. Furthermore, the difference in microhardness between the center and the peripheral region can be attributed to the maximum heat input and the difference in the quantity of martensite between the center and the periphery of the weld joint.

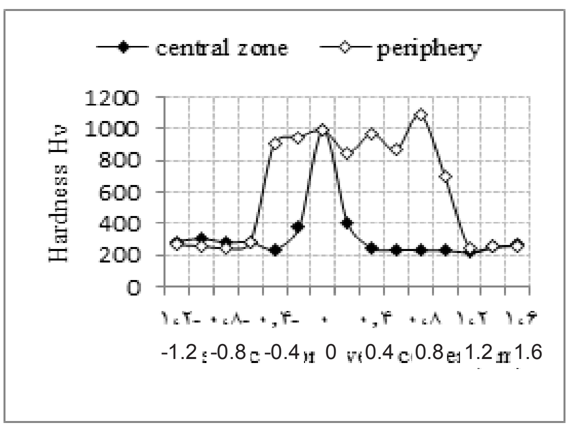

Fig. 8 Hardness profiles across the friction weld joint of specimen S5

4. CONCLUSION

In this work, the effect of friction time and friction force on the microstructure and mechanical properties of friction welding joints in high carbon 100Cr6 steel is investigated. The main results obtained are listed below:

- After friction welding where the base material is subjected to phase changes in the solid state, the affected zone near the joint is not homogenous but reveals several areas characterized by different morphologies as well as mechanical and microstructural properties.
- After welding, the microstructure of the center of the weld joint is mainly composed of martensite and retained austenite.
- Friction time and friction force parameters have a significant influence on the tensile strength of the weld joints. The tensile strength is found to increase as friction time increases; it reaches a maximum and then decreases again.
- The hardness measurements performed on the weld joint show a higher hardness at the plastically deformed zone when compared to the HAZ and base material hardness, causing a reduction in ductility of the material joint. This is due to the formation of martensite.

Acknowledgments

This research was supported by “physics and mechanics of metallic materials laboratory” at the “Institute of optics and precision mechanics” of Sétif university, Algeria.

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