MATHEMATICAL MODELLING OF ENGINEERING PROBLEMS

ISSN: 2369-0739 (Print), 2369-0747 (Online)
Vol. 4, No. 1, March 2017, pp. 43-47
DOI: 10.18280/mmep.040109

A publication of IIETA

IIETA International Information and Engineering Technology Association
Advancing the World of Information and Engineering
http://www.iieta.org/Journals/MMEP

Experimental characterization of the Heat Affected Zone (HAZ) properties of 100Cr6 steel joined by rotary friction welding method

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ABSTRACT

In machine parts producing, the welding methods and the weldability of materials has an important role in determining the limit of utilization of any material and its successful application in some important areas. 100Cr6 steel is a high carbon steel which has a poor weldability by conventional fusion welding processes. However, Friction welding method can be chosen for joining this metal. In rotary friction welding, the joint is carried out in the solid state where the heat is generated by friction at the interface of the pieces during rotation under axial pressure. In order to evaluate the ability to weld this metal by friction, the main aim of the present work was to produce similar metal joints of this steel by rotary friction welding method and investigate experimentally the weld joint properties. The joints are produced from 100Cr6 steel rods having different diameter and different interface geometries. A microstructural characterization was carried out of friction welded specimens by optical microscopy. The Vickers hardness distribution at the weld joint was examined. The welds exhibit high hardness in the central zone, which was characterized by a martensitic structure.

Keywords: Rotary Friction Welding, HAZ, 100Cr6 Steel, Microstructure, Hardness.

1. INTRODUCTION

Rotary friction welding is a solid-phase welding technique that has been used in the industry for a long time and has shown its ability to produce good quality of welds. This welding technique is currently the object of increasing interest in various industrial sectors (automobile, aeronautics, etc.) with the aim of assembling similar and dissimilar materials that are difficult or impossible to weld by conventional methods. In order to study the weldability of some materials that are difficult to weld by conventional processes, several works have been carried out to investigate the effect of the process parameters on the quality of the welds obtained.

MUMIN Sahin has experimentally characterized the mechanical and microstructural properties of friction welds of different steels such as high-speed steel and medium-carbon steel [2], stainless steel [3,5] under different process parameters. N. O¨zdemir and coauthors [7] have investigated the influence of rotational speed on the mechanical and structural properties of the plastically deformed zone at the interface of the weld during friction welding of two different steels (AISI 304L to AISI 4340 alloy steel). It was found that the tensile strength increases with increase of the rotational speed. S.T. Selvamani and coauthors [1] have focused on the analysis of the effect of process parameters on the hardness of friction welding joints of high carbon steel. U. Tomoyuki [4] investigated the feasibility of the friction welding of ODS and ferritic-martensitic steels. Parameter optimization and microstructure–mechanical property correlation of friction welding of austenitic–ferritic stainless steel combination were also studied by V.V. Satyanarayana [6]. Hakan Ates [8] investigated the Effect of friction pressure on the properties of friction welded hot rolled MA956 iron-based superalloy plate.

In this study, we will try to evaluate the weldability by rotary friction welding method of a commercial 100Cr6 steel. This steel which is a high carbon alloyed chromium steel, it has poor weldability by the fusion welding processes. We are mainly interested in studying the influence of the geometry of the section to be welded during friction welding on the hardness and the final metallurgical characteristics of the welds in order to better distinguish the evolution of the microstructure in the region of the weld joint.

2. PRINCIPLE

Rotary friction welding is a welding process used for the local assembly of two parts, at least one of which has an axis of revolution, using the heating generated by friction between the two parts. Its principle consists in putting one of the two parts in rotation by applying an axial pressure against each other. The heat generated by the friction at the interface brings the metal to a pasty state, which makes it possible, after solidification, achievement the welding.

Generally, a rotary friction welding cycle is realized in two phases: the heating phase (friction) and the welding phase. Figure 1. shows schematically the principle of rotary friction welding. The various process parameters are: the rotational speed of the rotating part, the friction time and the friction force for the heating phase and the forging time and forging force for the welding phase.

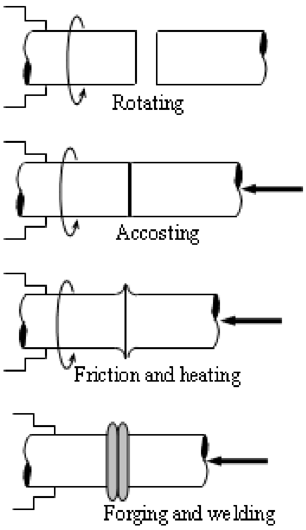

Figure 1. Steps of a rotary friction welding cycle

3. EXPERIMENTAL PROCEDURE

3.1 Base material

The material studied in this work is a high carbon steel 100Cr6. This steel is known for their poor weldability by fusion process. Figure 2. shows the initial microstructure of the used 100cr6 steel. It is consisting of a spheroidized structure. The chemical composition of the base metal is shown in table 1.

Table 1. Chemical composition of base metal (wt %)

C	Si	Mn	Cr	Mo	Ni
0.95	0.25	0.25	1.25	0.07	0.23
Cu	Fe	others			
0.19	96.86	< 0.0885			

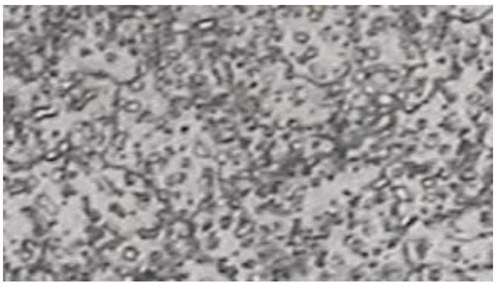

Figure 2. Optical Micrograph of base metal-X 1000

In order to evaluate the effect of the geometry of the welded section on the properties of the weld joint obtained, two samples with different sections were taken. One with a flat section and the other with a curved section of radius R = 5 mm. Each of these two pieces, which have a diameter of 9 mm, have been welded on a sample with a flat section of diameter of 14.5 mm (e.g., Fig. 3).

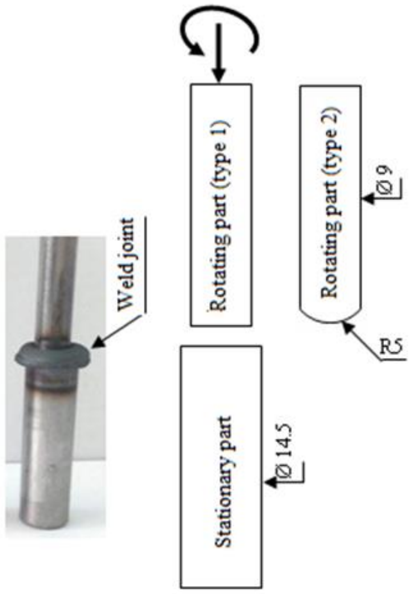

Figure 3. Friction welded specimen dimensions

The welding parameters chosen in this study are shown in the table 2.

Table 2. Process parameters used during friction welding

Heating phase	Forging phase
Rotational speed: N = 1000 rpm	Forging time: T_{fg} = 10 sec
Friction time: T_{fr} = 7 sec	
Friction Force: F_{fr} = 5 KN	Forging force: F_{fg} = 13 KN

The friction welding tests were carried out at the "Optics and Precision Mechanics Institute – setif of ALGERIA", on a conventional vertical drilling machine which was modified to an installation allowing to perform rotary friction welding operations. This installation is equipped with a force sensor to measure the axial force during welding.

To evaluate the quality of the welds produced, two characteristics were examined: measurement of the hardness and analysis of the microstructure of the weld obtained.

3.2 Visual examination

The fig 4. shows the macrograph of a longitudinal section of a friction welded workpiece. There are three zones metallurgically different.

-The plastically deformed zone in the center of the macrograph has a different contrast to the adjacent.

-The Heat Affected Zone (HAZ) which has a small width when compared with the central zone.

The unaffected zone of the base metal (BM).

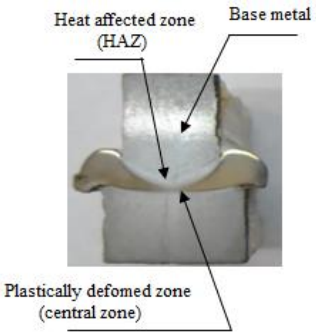

Figure 4. Cross sectional of the friction welded specimen

3.3 Hardness tests

The Hv hardness tests are carried out under a load of 1kg. The method adopted for the hardness tests consists of carrying out a series of hardness measurements along the weld (longitudinally) and a series of transverse measurements of the weld. Therefore, on each sample, two profiles were made in hardness (e.g., Fig 5):

- longitudinal profile,
- transverse profile from edge to edge of the weld joint.

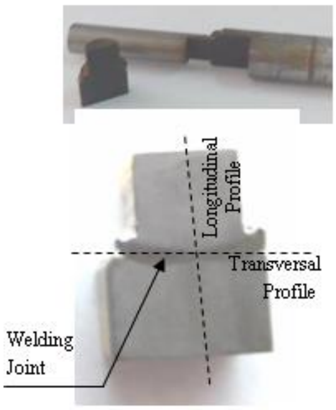

Figure 5. Hardness measurment orientation

The profiles obtained from hardness HV are shown in figures 6, 7, 8 and 9. The average hardness of the base material is 250 HV. For the two samples, a strong increase in the hardness (979HV) is observed at the center of the weld joint. This increase reveals the formation of a very hard structure: martensite. The remaining zones (HAZ on the rotating side and HAZ on the fixed side) are intermediate zones having hardness between those of the base metal and that of the hardening zone. All of these observed areas are found on each sample. Only their width varies (it is wider in the curved surface). It is also noted that the hardness remains constant transversely (between 800HV and 900HV on average) on the weld center.

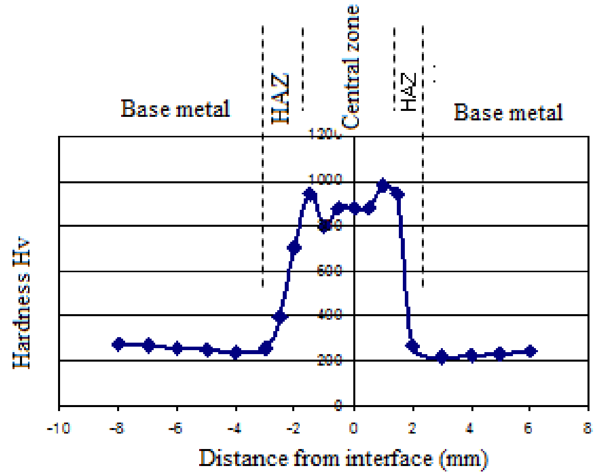

Figure 6. Hardness distribution-Longitudinal profile - Specimen type 2

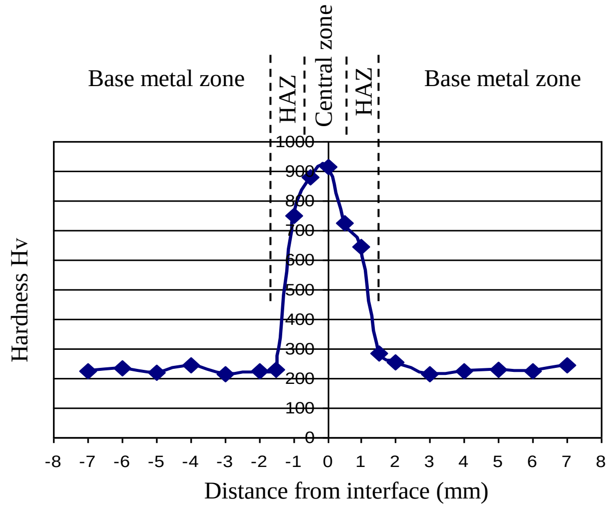

Figure 7. Hardness distribution
Longitudinal profile - Specimen type 1

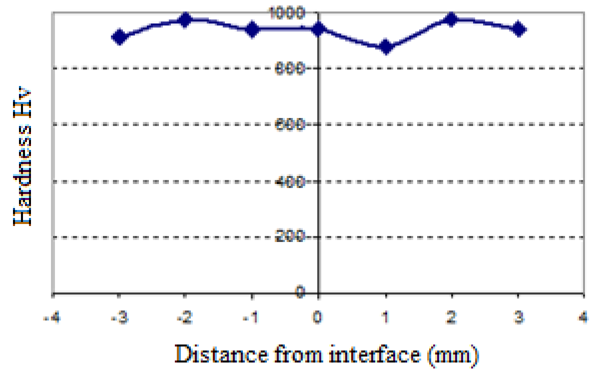

Figure 8. Hardness distribution –Transversal profile (Specimen type 2)

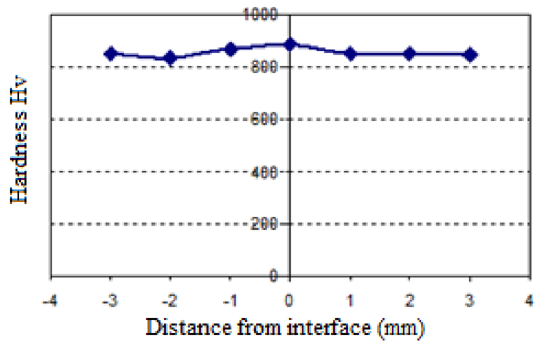

Figure 9. Hardness distribution –Transversal profile (Specimen type 1)

3.4 Microstructure

In order to examine the effect of the heat caused by the interfacial friction and the plastic deformation caused by the axial pressure on the microstructure, an optical microscopy observation of the metal structure at the weld joint was performed. Figures 10 and 11 show the micrographs taken at different zone of the weld joint.

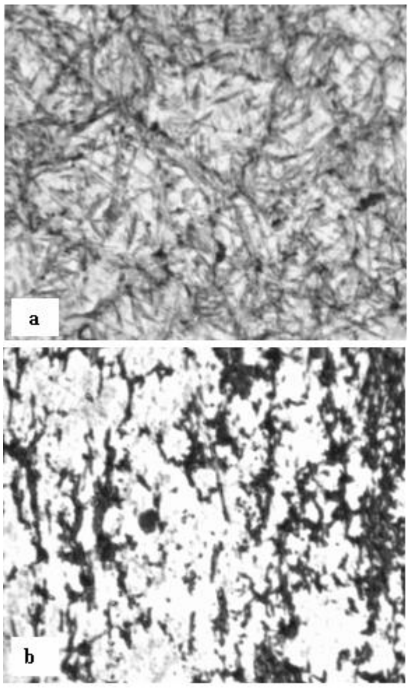

Figure 10. Optical micrographs at the center of the weld joint (Specimen type 1)-X 800
a-Deformed zone, *b*–HAZ

• *Plastically deformed zone:* The plastically deformed zone is carried below the melting point of the metal but always remains in the solid state at the time of welding. This critical zone, which determines the quality of the weld joint, has undergone severe deformations and temperature variations. The microstructural changes were made in the solid state.

The micrograph of this zone (e.g., Fig. 10a, 11a and 11b) shows that the grain distribution in size and geometry is complex. It is also noted that the grains have different morphologies between the center of the weld (Fig. 11a) and the periphery of the weld joint (e.g., Fig. 11b). These differences can be explained by the difference in cooling speed which is important at the periphery of the weld.

• *Heat affected Zone (HAZ):* The Heat Affected Zone (e.g., Fig. 10b and 11c), did not undergo mechanical deformations at the time of welding but undergoes large temperature variations. Therefore, microstructural changes are carried out in the solid state.

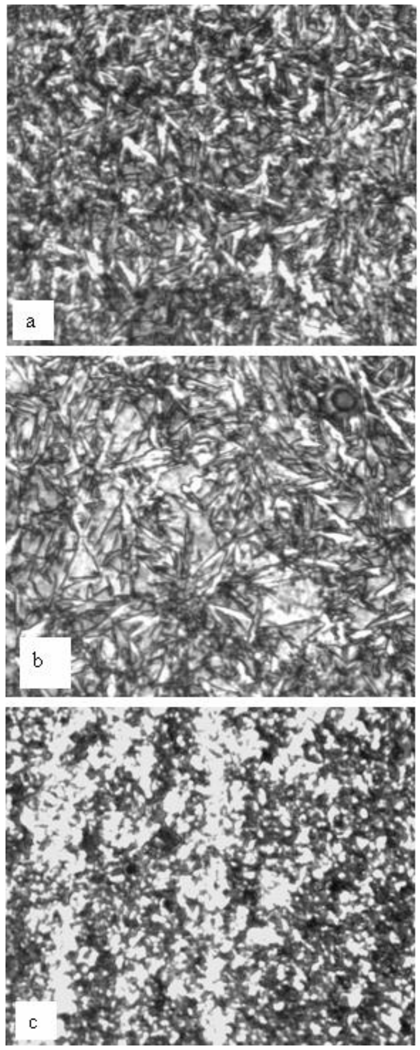

Figure 11. Optical micrographs of the weld joint (Specimen type 2) - X 800
a - Deformed zone at the center of weld,
b - Deformed zone at the periphery of weld,
c- HAZ at the center of weld

4. DISCUSSIONS

In friction welding, the weld has two zones in the joint with different microstructures. These two zones are located between the center of the weld and the base metal.

At the plastically deformed zone in which the plastic deformation occurred, the maximum temperature reached is very high. It is below the melting temperature. The deformed zone in both samples is typically characterized by a zone of martensite grains. However, at the deformed zone, there is a change in microstructure between the center and the edges of the weld joint. This difference may be due to the difference in the metallurgical transformation mechanisms during the heating phases and cooling. The presence of martensitic phases then explains the high hardness in this zone.

For the microstructure of the heat-affected zone (HAZ), In this zone where the modifications occur in the solid state without plastic deformation, there are always two phases present ferrite and pearlite with different rates and different grain orientation between the two samples (e.g., Fig. 10b and 11c).

In general, the most critical zone is the plastically deformed zone in which the hardness increases considerably, which causes a reduction in ductility. For this, heat treatments after welding are necessary to improve the characteristics and microstructures of the weld.

5. CONCLUSION

This work concerns the rotary friction welding of two parts with high carbon steel chromium alloyed (100Cr 6). Its main aim is to investigate the effect of the geometry of the section to be welded on the properties of the weld joint obtained in order to evaluate the weldability of this steel which has poor fusion weldability.

This study showed that this steel was successfully welded by friction. A change in microstructure between the center zone and the edge zone was observed. A difference in the extent of the weld joint, ie, when the interface is convex, the plastically deformed zone is wider, resulting in greater axial shortening. It can thus be concluded that the geometry of the welded surface has an effect on the resulting metallurgical characteristic of the weld. It is therefore important to evaluate this parameter carefully to ensure the desired penetration while maintaining good metallurgical characteristics.

In general, friction welding generates a very hard weld joint. The critical location corresponds to the peak of hardness at the deformed zone. This can result in fragile fracture.

ACKNOWLEDGMENT

This research was supported by the "Physics and mechanics of metallic materials laboratory "at the Institute of Optics and precision mechanics –Setif University - ALGERIA.

REFERENCES

[1] Selvamani1 S.T., Umanath K., Palanikumar K., Vigneswar K. (2014). The microhardness analysis of friction welded AISI 52100 grade carbon steel joints, *Advanced Materials Research*, Vol. 984-985, pp. 613-617. DOI: 10.4028/www.scientific.net/AMR.984-985.613

[2] Sahin M. (2005). Joining with friction welding of high-speed steel and medium-carbon steel, *Journal of Materials Processing Technology*, Vol. 168, pp. 202–210. DOI: 10.1016/j.jmatprotec.2004.11.015

[3] Sahin M. (2009). Characterization of properties in plastically deformed austenitic-stainless steels joined by friction Welding, *Materials and Design*, Vol 30, pp. 135–144. DOI: 10.1016/j.matdes.2008.04.033

[4] Tomoyuki U., Shigeharu U., Tatsuyoshi N., Masayuki Fujiwara. (2007). Properties of friction welds between 9Cr-ODS martensitic and ferritic–martensitic steels, *Journal of Nuclear Materials*, Vol. 367, pp. 1213– 1217. DOI: 10.1016/j.jnucmat.2007.03.221

[5] Sahin M. (2007). Evaluation of the joint-interface properties of austenitic-stainless steels (AISI 304) joined by friction welding, *Materials and Design*, Vol. 28, pp. 2244–2250. DOI: 10.1016/j.matdes.2006.05.031

[6] Satyanarayana V.V., Madhusudhan R.G., Mohandas T. (2005). Dissimilar metal friction welding of austenitic–ferritic stainless steels, *Journal of Materials Processing Technology*, Vol. 160, pp. 128–137. DOI: 10.1016/j.jmatprotec.2004.05.017

[7] Zdemira N.O., Sarsılmaz F., Hascalık A. (2007). Effect of rotational speed on the interface properties of friction- welded AISI 304L to 4340 steel, *Materials and Design*, Vol. 28, pp. 301–307. DOI: 10.1016/j.matdes.2005.06.011

[8] Hakan A., Mehmet T., Adem K. (2007). Effect of friction pressure on the properties of friction welded MA956 iron-based superalloy, *Materials and Design*, Vol. 28, pp. 948–953. DOI: 10.1016/j.matdes.2005.09.015