FRICTION WELD OF AISI 304 STAINLESS STEEL AND PURE COPPER MATERIALS

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Abstract

In the present study the aim is to investigate the metallurgical and mechanical properties of friction welded stainless steel-copper joints. Austenitic stainless steel and copper parts were joined by friction welding. Tensile, fatigue, and notch-impact tests were applied to friction welded specimens, and the results were compared with those for the original materials. Microstructure, energy dispersive x-ray, and x-ray diffraction (XRD) analysis and hardness variations were conducted on the joints. Results showed that various intermetallic phases such as FeCu4 and Cu2NiZn occurred at the interface. It was found from the microstructure and XRD analysis that intermetallic phases formed in the interface which further caused a decrease in the strength of the joints.

Keywords: friction welding, mechanical characterization, metallography

INTRODUCTION

Welding technology is widely used in manufacturing. Development of new welding methods has gained importance along with developing technology [1-4]. Welding of different metals and their alloys is a common application in engineering solutions. Conventional welding methods are nearly impossible in such cases due to incompatible physical characteristics and chemical composition of different metals and alloys. As a result, friction welding has been developed [5-7]. In friction welding, heat is generated at the interface of the work pieces, since mechanical energy is dissipated as heat during rotation under pressure. Friction welding is classified as a solid state welding process where metallic bonding is produced at temperatures lower than the melting point of the base metals. Friction welding is generally used to join the parts which have axial symmetry and circular crosssection. But it can easily be used to join parts without circular sections with the aid of automation devices and computerized control facilities [8]. It is an energy saver since heat is not applied. Friction time and pressure, upset time and pressure, and the speed of rotation are the principal variables in the friction welding [9-13]. There are two types of friction welding techniques: continuous drive friction welding and inertia friction welding. In the continuous drive friction method, one of the components is held stationary while the other is rotated at a constant speed (s). The two components are brought together under axial pressure (Pf) for a certain period of time (tf). Then the clutch is separated from the drive, and the rotary component is brought to a stop while the axial pressure on the stationary part is increased to a higher upset pressure (Pu) for a predetermined period of time (tu).

Although stainless steel-copper joints by friction welding have been performed before, none of these studies involve detailed investigations on the metallurgical and mechanical properties of these joints. In the present study, tensile, fatigue, and notch-impact tests were performed on welded test parts and results obtained results were compared with those of the original materials. Microstructure, EDX and XRD analysis, and hardness variations were also carried out on the test parts.

EXPERIMENTS

In the experiments, AISI 304 austenitic stainless steel and copper were used. Austenitic stainless steels are very compatible with regard to forming capabilities, mechanical specifications and corrosion resistance. Austenitic stainless steels have perfect corrosion resistance and weldability. They are furnished with desired mechanical qualities at high temperatures, they are easily workable when ductile and they are not magnetic. On the other hand, copper is an excellent conductor of electricity and heat. It is strong, ductile and easily joined by soldering or brazing. It is hygienic, easy to alloy and resists corrosion. Composition of materials is given in Tables 1 and 2. Specimens were machined from the materials described above according to geometry given in Fig. 1. 2. Experimental set-up was designed and constructed to apply the continuous drive friction welding method. A 4 kW motor drive with a rotational speed of 1410 rpm was used. The motor drive was selected so as to supply the torque needed to supply the friction and upset pressures necessary for friction welding of steel bars 10 mm in diameter. Stages of the welding sequence were controlled using the solenoid valve driven by an external timer. Parts to be joined were left were left in acetone for 10 min before welding. Optimum parameters found in a previous different study [25] were used in the experiments (friction time = 8.5 s, friction pressure = 75 MPa, upset time = 20 s, and upset pressure = 160 MPa). Later, tensile, fatigue, and notch-impact tests were applied to the joined parts, and the microstructure analysis and hardness variations of the joints were examined. These tests and analysis are given below in detail.

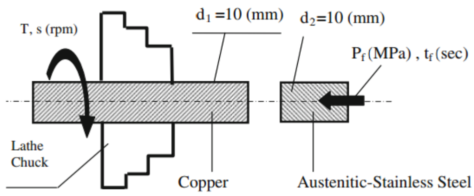

Fig. 1. *Parts used in the experiments*

Table 1 Chemical compositions of austenitic-stainless steel used in the experiment (Ref 24)

Material	% C	% P	% S	% Mn	% Si	% Cr	% Ni	Tensile strength, MPa
AISI 304 (X5CrNi1810)	<0.07	<0.045	<0.030	<2.0	<1.0	17-19	8.5-10.5	825

Table 2 Chemical compositions obtained using chemical analysis of copper used in the experiment

Copper	% Sn	% Pb	% Zn	% P	% Mn	% Fe	% Ni	% Si	% Mg	% Al	% Bi	% S	% Sb	% Cu	Tensile Strength, MPa
	0.00222	<0.00200	<0.00100	0.00137	<0.00050	0.0381	<0.00100	0.00745	0.00376	0.00500	<0.00050	0.00251	<0.00200	99.93	300

RESULTS

Tensile tests (ASTM E8M) were conducted using an Instron 8501 machine (Fig. 2). The specimen was clamped to the grips at both ends. The upper grip was fixed, but the vertical position could be adjusted to accommodate specimens of different sizes. The lower grip was driven by a hydraulic actuator. Vertical movement of the lower grip generated desired loading on the specimen.

Fig. 2. *Tensile Test Machine*

Effects of friction time and friction pressure on the strength of the parts joined were examined by the welding parts having the same diameter.

Results reported are the arithmetic mean for three specimens for a set of given friction welding conditions. In order to determine friction time and friction pressure, a twostep welding experiment was conducted in which upset time (20 s) and pressure (160 MPa) were maintained constant. In the first step, friction pressure (75 MPa) was kept constant while friction time was changed. In the second step, the friction time was held constant (8.5 s) while the friction pressure was changed.

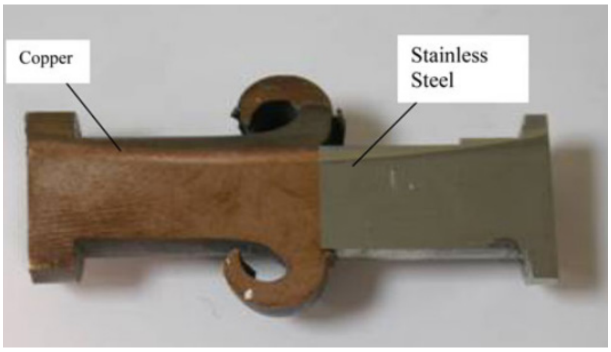

Fig. 3. *Welded parts*

Differences in thermal and physical properties of the materials generally result in asymmetric deformation in welding of dissimilar metals. Axial shortening on the copper side of joints is more than the axial shortening on the stainless steel side (Fig. 3). Since the melting temperature of copper is lower than the melting temperature of steel, welding flashes occur the copper side of the interface. However, while copper undergoes extensive melting due to high generated and concentrated frictional heat; stainless steel does not undergo extensive deformation.

CONCLUSION

The strengths of the welded zones were determined through tensile tests and the results were compared with the strength of he fully machined parts. Tensile strength of the joined parts was calculated by dividing the tensile force to an area of 10 mm in diameter. The variations of tensile strength in accordance with the change in friction time and friction pressure are shown in Fig. 4 and 5. Tensile strength of the joints increased with increase in friction time and pressure up to a certain critical value beyond which the parts were deformed (Fig. 4, 5). The highest strength obtained for the joints was equal to 75% of the strength of copper, which is known to have the lowest strength. Superiority of the welds made by dissimilar materials strongly depends on the temperature attained by each substrate during the welding processes. Differences in mechanical, thermophysical properties, and behavior of each substrate at the interface during welding influence the quality of the joint.

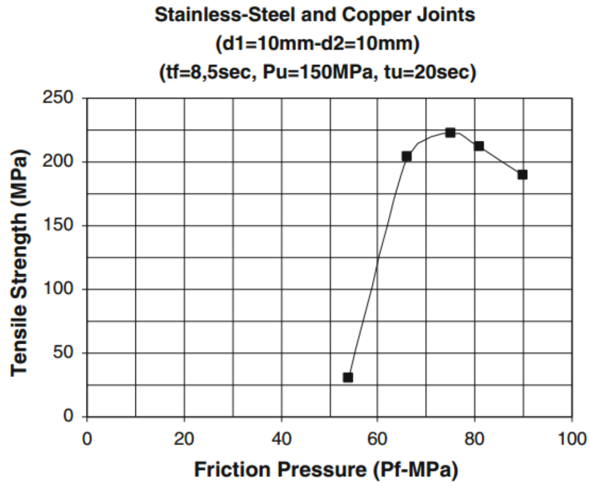

Fig. 4. *Welded parts*

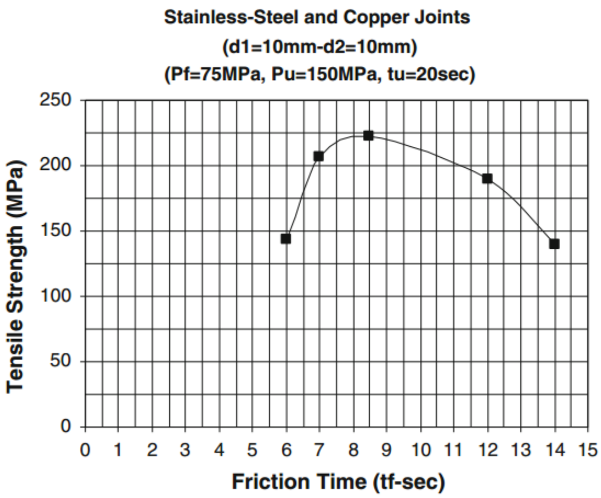

Fig. 5. *Welded parts*

Stainless steel is in the austenitic grain structure, which is the natural structure of this type of steel at room temperature. On the other hand, copper is formed of eutectic particles (dark points) indicating that it is a mixture of pure copper and cuprous oxide, dispersed into ground copper. HAZ was small, thus the effect of melting was minimal at the interface (Fig. 6). Copper has higher thermal conductivity than steel, thus the HAZ on the copper side was wider than that of the steel side. There was no change in the grain size of the steel side. Presence of small particles on the copper side revealed that there is hardening on the copper side. There are equiaxed grains and Cu2O particles on the copper side. The interface elements of both materials diffused along the interface and some intermetallic phases were formed at the interface.

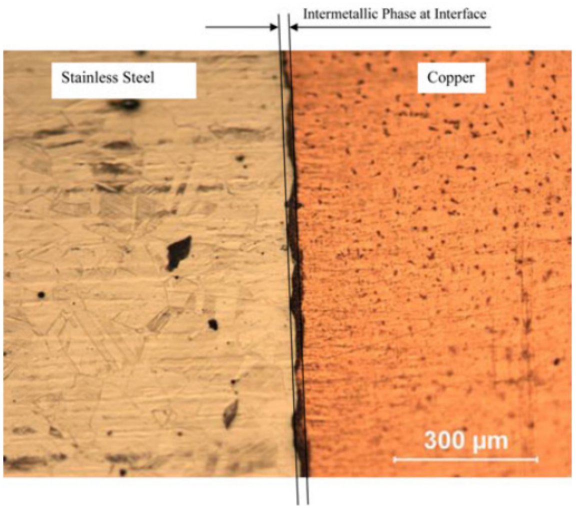

Fig. 6. *Welded parts*

In this study, steel and copper materials were friction joined successfully and tensile tests, fatigue tests and notch-impact tests were applied to the joined parts. Moreover, at the interface of these parts, microstructure, EDS analysis, and hardness variations were examined. As a result, the obtained results can be summarized as follows:

• Optimum friction time and pressure were found to be 8.5 s and 75 MPa, respectively. Tensile strength of the joints increased with the friction time and friction pressure up to a certain point. The optimum is dictated by a competition between inadequate heat dissipation that can stabilize the joints, and excessive formation of intermetallic phases that decrease strength of the joints.

• The fluctuating stresses of the stainless steels, which have high strength, are higher than the fluctuating stresses of the copper. In addition, the fluctuating stress of the stainless steel and copper joints is quite low due to intermetallic phases which occur at the interface.

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