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THE EFFECT OF WELDING FRICTION PARAMETERS ON THE MECHANICAL PROPERTIES OF THE MAINTAINED ANODIC YOK IN THE ALUMINUM INDUSTRY

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ABSTRACT

In this paper, friction welding was applied in the aluminum industry at repairing operation. The process of repairing the anodic yoke, which was carried out by welding in the traditional way, was replaced by the method of rotary friction welding, as a friction welding machine was designed, manufactured and assembled, and the welding process was performed. The material selected for study and experimentation of RFW is low carbon steel S37 and rod dia. ϕ 130 mm. A setup of a rotary friction machine equipped with an electric motor of 75kW power was used. The rotary friction welding process was performed on the anodic yoke pins, that before being welded by fusion welding. The characteristics of microstructure and tensile strength in rotary friction welding of yoke pins were examined. The microstructure test showed friction welded pins had smaller grain size compared to those welded by fusion welding due to recrystallization and transformation of coarse ferrite phase into grain refined ferritic-pearlitic phase. The tensile strength of friction welded pins was higher than that of the fusion welded pins due to annealing effect.

KEYWORDS

Rotary friction welding, ferritic stainless steel, tensile strength, forging pressure, microstructures.

INTRODUCTION

The permanent aspirations of governments and international bodies towards a better environment and towards reducing environmentally harmful emissions from various industries have become a major concern of corporate management, especially those that export their products to foreign countries, as there are laws to track producing companies during the manufacture of these products and evaluate them for compliance with standards. International Environment to allow it to export its products to foreign countries. From this standpoint, The Egyptian Aluminum Company was keen to look towards modern methods in the various processes that take place during the extraction of aluminum, in order to achieve international

requirements in this regard, in order to be able to export its products to the markets of the outside world without any obstacles, in a way that preserves its reputation in international forums. Among the operations that are frequently carried out in the company are welding operations for the various parts needed by the work, including the process of welding low carbon steel anode yoke pins for the purpose of maintaining them after damage to them to replace them with new ones that conform to standard specifications. Fusion welding was the method used and this method has some drawbacks, so it was replaced by friction welding method. Rotary friction welding is a solid-state welding process that has acquired popularity in recent years due to its ability to join a variety of materials, including steel, without the drawbacks associated with fusion welding. Fusion welding processes, such as arc welding and gas welding, involve melting the base materials to complete the bond, which can lead to issues such as distortion, [1], porosity, and material degradation. This can lead to issues such as porosity, cracking, and distortion, which can decrease the strength of the weld and led to increase in the electric voltage drop of the welding area, [2].On the other hand, rotary friction welding relies on frictional forces to generate heat, lower than material melting, and create a metallurgical bond between two components, without melting the base materials, [3].

Literature review

In world of joining materials, welding considered as the most famous process. Rotary friction welding is the most common form of friction welding and has become an industry standard for several processes. It is a solid-state joining process, a commercial process which has developed early 1940's, that has gained significant interest in recent years due to its numerous advantages over traditional welding methods. The process involves the rotation of one component against another while applying axial pressure, resulting in heat generation due to friction. The heat generated causes the material to soften and become plastic, allowing the two components to be joined,

Fig. *1*. In the case of low carbon steel, rotary friction welding has the potential to produce high-quality joints with improved mechanical and electrical properties, such as higher strength and electric current resistivity, [4].

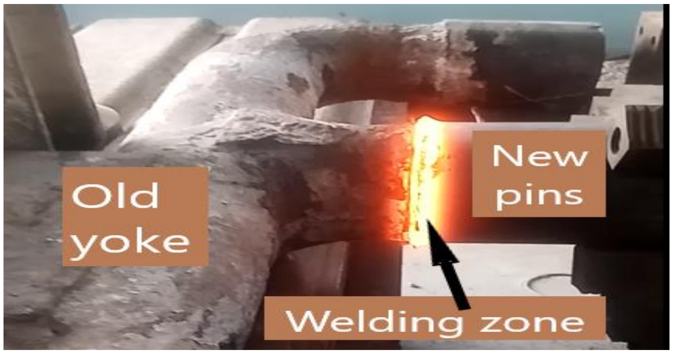

Fig. 1 Heat generated during friction.

Steels are commonly welded by a various welding processes, and joints with good mechanical properties have been produced with the more traditional arc welding processes, [5] as well as power beam process, such as laser, [6, 7] and electron beam welding [8]. However, when welding low carbon steels these fusion welding processes produce harmful hexavalent chromium fumes, [9], which means solid state welding processes, where fumes are not produced, may be beneficial in some situations.

During the rotary friction welding process, the most important parameter is the input heat of the welding process, [10 - 12]. The heat input depends on the coefficient of friction, rotation speed and axial pressure. Therefore, the change in these parameters affects the quality of the welded joint. Many researchers have investigated the effect of friction welding parameters on the welded joint quality of stainless steel, [10] aluminum and copper, [11, 12]. However, the rotating friction welding process is complex and nonlinear, and it is strongly affected by the mechanical and thermal properties of welding materials. The welding optimal technology parameters for one material may not be suitable for another material.

The electrical and mechanical properties of CDFW method applied to steel 37 commonly used for the production and maintenance of the anode yoke was investigated at laboratory scale. It revealed a significant improvement in the mechanical and electrical properties for the samples welded by friction compared to those welded by traditional methods, fusion. These electrical properties of the rotary friction welds were almost identical to the original alloy with small voltage drop compared to the fusion welds, and this of course has a major role in saving the cost and reducing the maintenance process, [13].

A comparison of the effects of friction processing parameters on the microstructure and mechanical properties of the joint were made, [14]. It was indicated that high frictional pressures would generate a too high temperature in the weld interface, which might lead to propagation of cracking. It was concluded that lower heating pressures decreases the material lost as flash during welding, [1]. A similar process optimization study, [15] showed that with decrease in friction time, the amount of axial shortening was reduced, which in turn reduced the quantity of metal lost as flash, this reduces costs significantly. It was concluded from his preliminary studies that, the forging pressure extensively affected the tensile properties of the rotary friction welds, [16]. He also suggested an optimum upset pressure range of 600 - 650 MPa for the welds. Other researchers elsewhere have reported, a reduction in the width of the HAZ [17]and an increase in the maximum strain rate, [18]with increase in upset pressure.

The main objective of this study is to investigate the improvement in the mechanical and electrical properties of low carbon steel friction welded joints. The specific objectives are to investigate the effect of welding parameters on the mechanical and electrical properties of low carbon steel friction welded joints, to analyze the

microstructure of the friction welded joints and its effect on the mechanical and electrical properties and to compare the mechanical and electrical properties of low carbon steel friction welded joints with those of other welding techniques.

EXPERIMENTAL

The material used in the rotary friction welding experiment of this study are cylindrical commercial low carbon steel rods with nominal diameter of 130 mm and the samples length varies from 50 to 229 mm depend on the deteriorated part to be maintained. The nominal composition of the material is shown in Table 1 . The welding surfaces of the steel rods are cleaned with acetone to eliminate any impurities and remove any oil, grease or dirt. The yoke with a deteriorated pin after cutting it fixed with a special hydraulic clamp while the new pin is attached to a rotated chuck aligned against the fixed yoke,

Fig. *1*.

Table 1 the chemical composition of low carbon steel yoke

element	C	Si	Mn	P	Cr	S	Ni	
value	0.2	0.4	0.9	0.05	0.13	0.05	0,09	

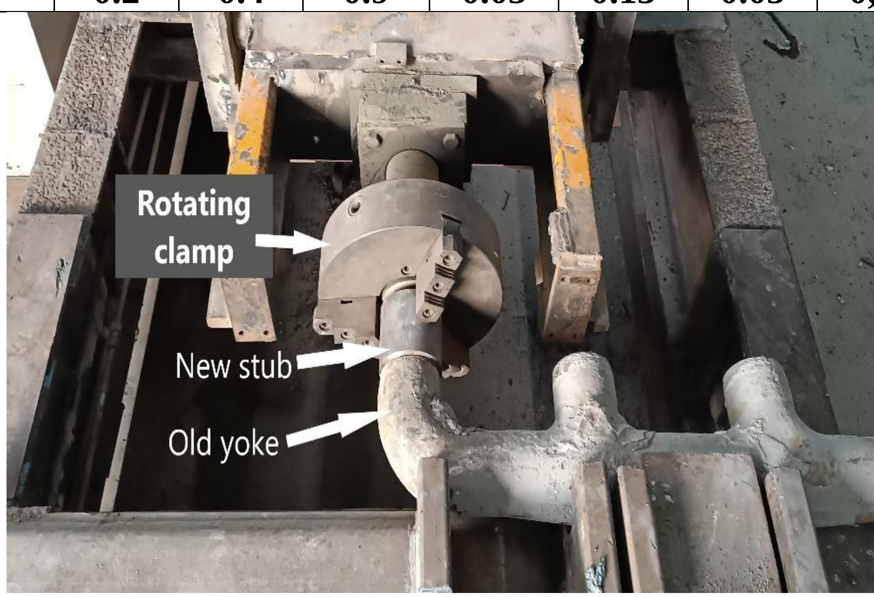

Fig. 2 The clamping during the friction process.

During the rotary friction welding process, One of the two pieces to be welded is rotated and pressed against the other so that total contact occurs on the interface surface, and the welding process takes place as follows: as presented in

Fig. *3*. During stage 1, one part is rotated against the other part, which is not moving

Fig. *3*, a. During stage 2, when the rotating part reaches a sufficient angular velocity, the fixed part is pressed and brought into contact with the rotated part by the axial

force, The friction of the two sides on the interface results in the generation of heat, as shown in

Fig. *3*, b. During stage 3, when the joint area is adequately plastic as a result of the generated temperature, the rotation is stopped, and the forging force is increased to the maximum value to upset and consolidate the joint, as shown in

Fig. *3*, c. At this point, expulsion of the plasticized material at the welding zone occurs, so a round collar shape at the periphery of the rod, flash, is formed where the material has squeezed out.

Fig. 3 Yoke welding process stages.

After completing the welding process, samples were taken to perform a tensile strength test to determine the mechanical properties. The anodic yokes were assembled with carbon blocks in the production line at Rodding Shop to form anodic conductors and transferred to the aluminum extraction Potlines for evaluation during the aluminum extraction process. To evaluate and compare the efficiency of both friction welding and fusion welding the anodes were equipped with tools and wires as electrodes to measure the voltage drop in the welding area,

Fig. *4*.

Comparison between fusion welding and friction welding

The anodic yoke caste from low carbon steel with a chemical composition presented in Table 1, which is a typical hypoeutectoid steel. The difference between the traditional fusion welding and rotary friction welding is shown in

Fig. 5 Chamfer of the traditional fusion welding. shows that in the traditional welding there is a chamfer need to be filled with electrode material while in the inertia welding,

Fig. *6*, with complete diffusion occurs between the welded parts no need to filling material.

There is another difference, which is that in the fusion welding the diffusion of the weld does not reach the inner diameter of the pin,

Fig. *5* ,and thus there is a micro space between the interface of the new pin and the old pin in the welding area, meaning that the electric current does not pass through this area, and thus reduces the area that the current passes through, thus increasing the voltage drop through this area, which does not happen in friction welding, where complete fusion takes place at the level of the diameter of the pin, and there is no void, as shown in

Fig. *6*.

Fig. 4 The complete anodic conductor.

Fig. 5 Chamfer of the traditional fusion welding.

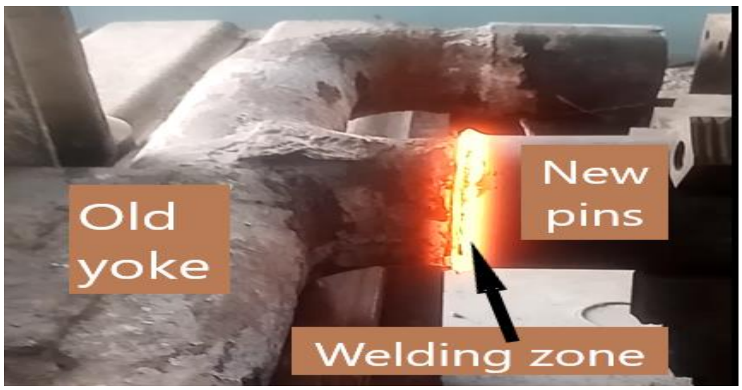

Fig. 6 Complete diffusion during fraction welding.

RESULTS AND DISCUSSION

The effect of the process parameters on the tensile strength of the welds

Friction welding is a solid-state joining process that utilizes heat generated by friction and pressure to join two materials. In low carbon steel, the mechanical properties of the joint are dependent on the weld microstructure which in turn influenced by several process parameters such as the rotation speed, forging pressure, and forging time. The tensile strength is one of the key properties of the joint that is affected by these parameters, and, in this application specifically, it is the most important mechanical property in this case because the welded yoke is supposed to lift a carbon block of 12000 N. Tensile Strength tests were performed using the Egyptian aluminum Company's Facility plant using an Instron 5569 tensile tester with 0.5 ipm rate of pull with 40 ton capacity. The type specimen for tensile strength have size according to ISO 82-1974 (E), DP8, lo = 80 mm, as shown in Fig. 7. The results of tests presented in table 2.

Table 2 Relation between tensile strength, forging pressure at different rotation speeds. Error! Reference source not found.

Fig. 7 tensile strength sample.

The choice of the welding parameters influences the microstructure. If the friction time is held long, a broad diffusion zone with intermetallic phases can be generated. The parameters such as short friction time, low friction pressure, and low upsetting pressure will result in a weakly bonded joint where voids are commonly found. To achieve higher strength, the friction time should be held as short as possible, while the friction and upsetting pressures should be as high as possible, [14].

The data of tensile test shows the relation between tensile strength, forging pressure at different rotation speeds is obtained and presented in

Fig. *8*.

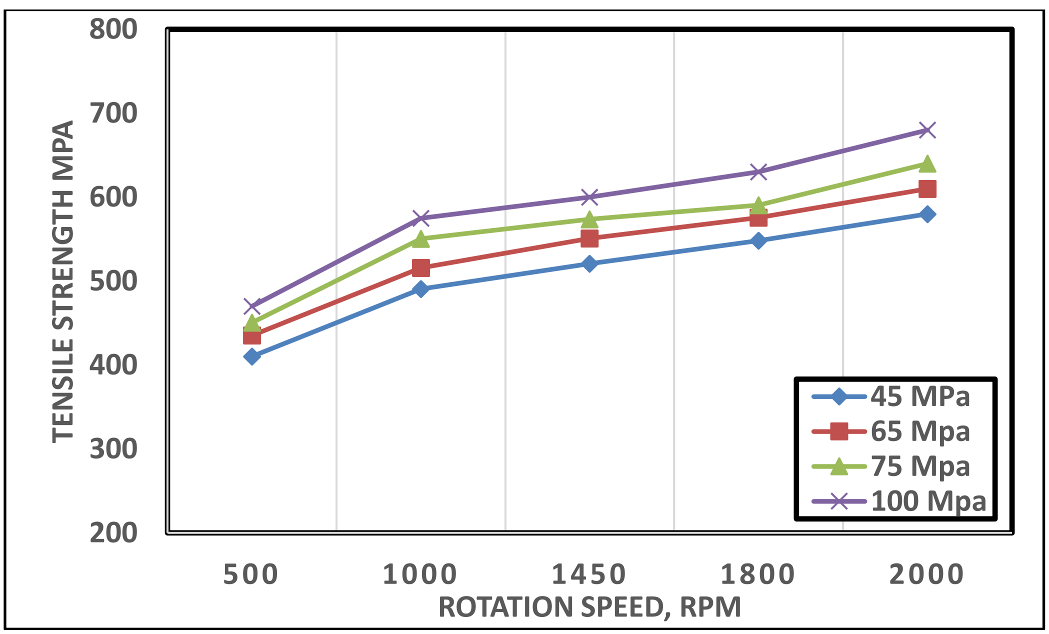

Fig. 8 Relation between tensile strength, forging pressure and rotation speed.

Based on the results obtained from data analysis, the tensile strength increases proportionally with increasing rotational speed and for increasing friction pressure. When the forging pressure is increased from 45 MPa to 100 MPa, the tensile strength of the material increases because the force exceeds the deformation limit of the plasticized material and the atoms of the material will be compressed and converged, and their density will increase. The denser the material, the higher its tensile strength as a result of the finer grains and formation of fine pearlite microstructure. Regarding the effect of speed on mechanical properties, we notice that in the range of speed from 500 to 1000rpm there is a significant increase in the value of tensile strength because the high rotation speed develops more quantity of generated heat that exceeds the heat of deformation limit of the plasticized material and the atoms of the material will be compressed and converged, and their density will increase. Beyond that in the range greater than 1000 rpm to 2000 rpm the value of the tensile strength increasing becomes lower as the value of the slope in the curve is less,

Fig. *8,* as a result of decreasing the compressibility of the material. The denser the material, the higher its tensile strength as a result of the finer grains and formation of fine ferritic-pearlite microstructure.

For example, an increase in rotation speed from 500 rpm to 1800 rpm also results in an increase in tensile strength. This is because a higher rotation speed leads to higher temperature, which in turns lead to a higher degree of deformation and strain in the material, which results in a refined microstructure as shown in

Figure 11. The refined microstructure consists of smaller grains, which enhances the strength of the material. It can be concluded that the strength of the welding results is greater than the strength of the raw material, thus all the welded specimens have a failure far from the welded joint area.

The microstructure phases of the welded joint

Although the interface temperature during RFW is not expected to exceed the melting temperature of the material being welded, the peak interface temperature is, nevertheless, very high, and could be close to the solidus temperature of the material being welded, [14]. In all reported cases, this high temperature, along with the applied pressure, causes significant microstructural variation close to the weld interface. Optical Microscope images of etched welding zone samples shows pearlite in dark,

and ferrite in white, [19]. As it is shown in the picture, the white part represents the ferrite, which is large percentage and small amounts of perlite, the dark part. At a low forging pressure of 45 MPa and a low rotation speed, the microstructure of the joint consists of a coarse ferrite phase,

Fig. 9 Microstructure of low forging and friction pressure with a coarse ferrite , which results in a relatively low tensile strength of 410.2 MPa.

Fig. 9 Microstructure of low forging and friction pressure with a coarse ferrite grain.

As shown here

Fig. ***10*** **the increase in the percentage of perlite, dark phase, and the reduction of the size of large grains of ferrite, the white phase. This is due to the increase of forging pressure and friction pressure, the microstructure becomes finer and more uniform, with a higher proportion of pearlite, resulting in a higher tensile strength** Error! Reference source not found. **At a higher forging pressure of 75 MPa and rotation speed of 1000 rpm, the microstructure of the joint consists of a fine-grained pearlite and ferrite phase, resulting in a higher tensile strength of 550.3 MPa.**

As the rotation speed, forging pressure and friction pressure increase, the microstructure becomes finer and more uniform, with a higher proportion of dark regions present pearlite, resulting in a higher tensile strength. For example, at a rotation speed of 1800 rpm and a forging pressure of 100 MPa, the microstructure consists of a fine-grained pearlite and ferrite phase, resulting in a high tensile strength of 630 MPa,

Figure 11.

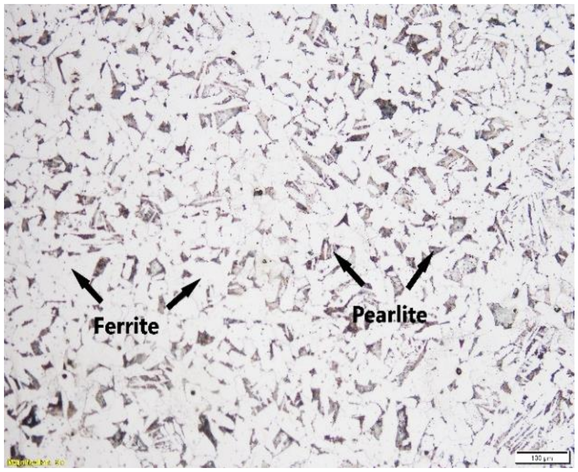

Fig. 10 Microstructure of welding area at 500 rpm and forging pressure 60 MPa.

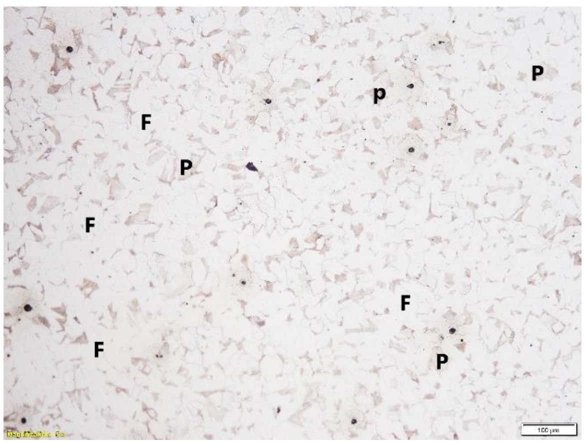

Figure 11 Microstructure of welding area at 1800 rpm and forging pressure 80 MPa.

In summary, the microstructural phases present in low carbon steel during friction welding play a critical role in determining the tensile strength of the joint. The processing parameters, including the rotation speed, forging pressure and time, and friction pressure, directly influence the microstructure of the joint. By optimizing the processing parameters, it is possible to achieve a strong and reliable joint. The understanding of the fundamental principles of friction welding and the relationship between these process parameters can be used to improve the design and optimization of friction welding processes, leading to better quality and more reliable products.

CONCLUSIONS

The RFW of low carbon steel, anodic yoke material, was investigated in this study. Corresponding to an evaluation of the microstructures and mechanical properties of the resulting junctures, the following conclusions were reached.

1. Rotary Friction welding can be used successfully to join low carbon steel, anodic yoke material (commercially S 37) in the aluminum industry.
2. The welds produced exhibited better mechanical and metallurgical characteristics than fusion welds. The welds did not experience major cracking problems. The welds were also liberated from undesirable elemental segregation.
3. The tensile strengths of the joints increased substantially with both rotational speed and forging pressure.
4. Joining low carbon steel alloys through fusion welding results in substantial problems including HAZ micro cracks, coarse grained phase formation, etc., apart from other fusion welding problems. Friction welding techniques offer improved welding properties, minimal fusion welding problems.
5. The choice of optimum process parameters is necessary for defect free joints. Studies have shown that inadequate speed or forging pressure might lead to lower mechanical properties due to incomplete bonding in the joints.
6. Improved mechanical properties increase the lifetime of the anodic yoke and reduce the repairing cost.

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