Influence of rotational speed on the dissimilar friction welding of heat-treated aluminum alloys

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Abstract. Union of dissimilar alloys by means of welding processes is often challenging than union of like material or alloys. The trivial distinction in mechanical, metallurgical and formation of alloys lead in major changes in the welded joints. Friction welding can be implemented effectively to unite a much wide variety of dissimilar materials. It efficiently resolves so many complex issues in front of contemporary manufacturing, like recuperating quality, dipping costs and safeguarding the environs. It produces the high strength joints compared to fusion welding process. The properties of the welded joints contingent on the right assortment of the welding parameters. In this investigation, the effect of rotational speed on mechanical properties was assessed by tensile, microhardness tests and weld flash appearance of friction welded joint of aluminium alloy 6063-O and aluminium alloy 6063-T6.

1. Introduction

The joining of dissimilar alloys demanding for the usage of various materials in the manufacturing industries. The recent technologies always intending to ease the components by combining various parts made by different materials. In order to obtain the multiplex components it is needed to join the parts effectively using suitable joining methods [1-2]. The joining of same materials leads in successful joint interface with solid weld integrity. Whereas, the union of dissimilar materials lacks in formation of strong weld interface and joining strength [3-5]. However, it is depending the type of dissimilar couples and their elemental composition. The elemental composition has much influence on the development of resulting phases that can deteriorate mechanical properties of welded joints [6-9]. The formation of the brittle phases and their position in the weld region is depending the type of welding processes applied for the joining. The severity of the brittle phases along with their size and amount varies greatly with the conventional welding methods compared to solid state welding methods [10-13]. The amount heat input into the weld is one of the important criterion to deal with the dissimilar welds. It is a known fact that the arc welding methods have high heat input and much heat energy stored in the welds during welding. The large amount of heat for a long duration in the welds until it cools down from the molten phases, welds were experienced to a large amount of thermal stresses and microstructural changes [14-18].

The dissimilar combinations of welded joints produced under arc welding processes experienced for the development of various phases in the fusion region. The dissimilar combinations of stainless
steel to aluminum using arc joining leads in the formation of Fe-Al-Zn secondary phases alongside the interface. The addition of Zn based filler might have beneficial for achieving strong welds, whereas the Zn also involved to make the intermetallic compound [19]. The same combination of materials were joined by solid state welding methods resulted in the formation of very few intermetallics with excellent mechanical properties [20-22]. There are many other dissimilar combinations were successfully joined using solid state welding methods with the excellent mechanical strength and strong metallurgical properties [23-30]. In particular, some of the alloys consisting of various types of heat treated alloys within the same materials with variation in their physical properties. the joining of these materials have different strategy that the degradation of the mechanical strength after welding due to reheating the alloys due to heat produced by welding processes [31-33]. The effect of welding processes also has similar effect on these alloys for the degradation of mechanical strength of the joints. The solid state welding methods were resulted in the producing of efficient welds over the arc welding methods to remain its original properties after welding [34-36].

Some of the arc welding methods were recently developed to produce dissimilar welds using cold metal transfer method. However, this process is limited to the thickness of metal and some of the geometries [37-39]. To weld these heat treated alloys friction stir and friction based welding methods were most suitable and easy to produce the strong welds [40-47]. In the present investigation, aluminum alloys with two different heat treated conditions such as AA6063-O and AA6063-T6 welded using friction welding. The welds were formed by friction welding under effect of rotational speed in order to keep the properties of the alloys constant with strong weld strength. The metallurgical and mechanical properties of the joints were studied using tensile and microhardness tests. The strength of welds were identified according to the rotational speed and structural changes of weld flash have been studied.

2. Experimental procedure

The materials put to use for present experiment were rods of 12 mm diameter AA6063-O and AA6063-T6. The sample for uniting has been procured and made to 70 mm span with uniform profile. Precedent to friction welding, the abutment faces of the original materials were make ready using #400 and #800 grit emery sheets. The specimens were cleaned with running water followed by distilled water. After they were wiped by means of acetone to take away the organic adulterant. Among the friction welding parameters, rotational speed was varied; this parameter was delineate to have noteworthy outcome on the joint properties and pursuance. The former variables those were remained without change were upset pressure, upset time, friction pressure and burn off length. For the period of friction welding, AA6063-T6 rod was kept fastened, and AA6063-O was used as the rotating specimen which was inserted in the spindle. A downward force is applied to maintain the contact. Individual part is placed in a motionless fix. The next piece is placed within the revolving spindle, which be after that reduced to a speed of prescribed revolving pace. When the desired pace is achieved already defined axial force will be applied by moving the spindle downwards. Such settings were vindicated for a persistent period. In the next step of load is imposed till the needed temperatures and material state remain. In the course of this juncture these materials are plasticized (develop into workable).

The amount of “burn off length” activates the end point when the element gets to intended desired span. Revolving speed is halted. After that axial force is functional to generate “forge pressure” to finishing the weld. This supply molecular bonding and grain refinement in the course of t weld region. The welds were cut for microstructural analysis and for the evaluation of mechanical properties. The welds were performed under microhardness measurements to analyse the strength variations in the various zones. The joint properties were evaluated by using tensile tests and the fracture surfaces characterised using scanning electron microscope. The axial reduction as a weld blaze was bulged around weld boundary and it was measured for analysis using diameter and thickness for the different welding conditions. The tensile sample was set according to ASTM
benchmark to test the joints strength. The failure joints were cut at the neck of the tensile tested specimens and carefully stored and used scanning electron microscope to observe fracture phenomenon and characteristics.

3. Results and discussion

The friction welds joined between heat treated dissimilar aluminum alloys, which have differences in their physical and metallurgical properties. In friction welding, due to the absence of melting the base materials no evidence of severe intermetallic phases. However, joint quality and the process parameters and welding method optimization are major concern in order to obtain the reliable welds. The selection of process parameters are depending the type of dissimilar combination of materials and their mechanical properties. The development of weld twinkle near boundary from both substrates is symmetry for the similar materials. Whereas it is varying with the dissimilar materials in their size and diameter due to their hard and soft nature of the properties. Joining of similar materials but with different heat treatment conditions is quite difficult to find the welding conditions due to the difference in their properties. In order to weld the ductile materials the selection of rotational speed is one of the solutions to obtain the strong welds. The rotational velocity and the force on the substrates have influence to deform the faying surface with extruded weld flash. The amount of weld flash is one of the significance to estimate the quality of the welds. The amount of weld zone is steadily augmented by the mounting of rotational speed from the 710 rpm to 1120 rpm. The amount of weld flash is quite higher for the aluminum alloys compared to other alloys due to their soft nature of the property at high temperature. Figure 1 shows the axial reduction of the welds at diverse rotational speed. Maximum axial shortening of 16 mm was occurred for the welds produced under the rotational speed of 1210 rpm. The axial shortening increased from 8.5 mm to 16 mm as the increasing of rotational speed. The axial shortening is almost doubled with the rotational speed from 710 rpm to 1120 rpm. Even though small amount of increment in the rotational speed there is a large amount of axial shortening in the welds. Therefore, the interval of increasing the rotational speed was decided smaller and observed the continuous change in the axial shortening. Based on the weld flash formation and axial shortening, it is easy to estimate the optimal welding conditions. It is observed that the axial shortening of 12 mm reasonable amount for the aluminum alloys and expected that condition is optimal and the further trails were not performed. The weld flash at the 1120 rpm tends to produce the cracks and changes the circular shape to irregular shape. It is not a common phenomenon in the formation of weld flash within the optimal range. The large amount of decrease in axial shortening is not beneficial and economical to the production, due the loss of material and accuracy of the components. Therefore, the small amount of axial shortening is recommended to avoid the material loss and improve the joint quality.
Figure 1. Axial shortening in the welds according to the rotational speed.

Figure 2. Optical microstructures of the welds showing the weld interface at different rotational speed (a) 710 rpm (b) 900 rpm and (c) 1120 rpm.

Figure 3. Microhardness of the welds at three different rotational speed.
Figure 2 elaborates the optical microstructures of the friction welds produced under different rotational speeds. The weld interface of the 710 rpm welds exhibited the nonlinear shape with the weaker bonding. The interface line is not formed strongly to obtain the required metallurgical bond between the two alloys. The metallurgical reactions and the bonding lines are subject to the correct selection of the welding situation. Based on the weld interface and its linear shape it is analysed that the rotational speed is not enough to make the strong bonding line between the alloys. The microstructure of the alloys adjacent to the interface is not changed greatly with the grain size or deformed regions. Figure 2b exhibit the microstructure of the welds at 900 rpm rotational speed with the clear interface between two substrates. The interface is linear and formed strongly with the metallurgical bonding without any defects along the weld interface. The required amount of heat and pressured is sufficiently obtained by the rotational speed of 900 rpm. The microstructure at the interface of the substrates shows clearly the formation of fine equi-axed grains. The presence of equi-axed grains region is narrow and the coarser grains region is slightly wider, which is away from the interface. The weld interface at the 1120 rpm rotational speed showed that the incomplete formation of the weld interface with a weaker metallurgical bonding (see Fig. 2c). The excess amount of heat and pressure due to high rotational speed has caused for the diminishing of metallurgical bonding at weld interface. Moreover, the interface microstructure also not formed clearly with the equi-axed grains and heat affected zone. The microstructural analysis confirmed the low or higher level of rotational speed causes the weaker metallurgical bonding.

Figure 3 elucidates microhardness of respective welds at three unlike rotational speed. The highest hardness was obtained for the welds of 700 rpm rotational speed compared to other welds. The hardness at the weld interface and adjacent regions have highest hardness. Even though the microstructures of the welds did not exhibit the clear view of the weld interface, the hardness results confirmed that the region along the interface and the dynamic recrystallization zone. The microstructures of the aluminum alloys neither are nor clear after experiencing the severe plastic deformation. The microhardness of the welds of non-identical zones of heat affected zone and the weld zone were presented in figure 4. The hardness of welds decreased gradually from the 700 rpm to 1120 rpm of rotational speed. Figure 5 shows the tensile strength of the welds at different rotational speed. The highest strength achieved at the rotational speed of 710 rpm contrast to the supplementary welding conditions. The strength of the welds progressively changed with rotational speed as like the microhardness. The lower rotational speeds have better results to achieve the friction welds between aluminum alloys.

![Figure 4. Microhardness of the welds at different zones.](image-url)
Figure 5. Tensile strength of the welds according to the rotational speed.

4. Conclusions

Friction welding of dissimilar aluminum alloys at heat treatment conditions of 6063-O and 6063-T6 were joined successfully using different rotational speed. The following observations were concluded based on the experimental results.

- The process parameter of rotational speed range was identified to weld the aluminum 6063 alloy.
- The axial shortening of the friction welds increased with the incremental of rotational speed along with the weld flash diameter.
- Microhardness of the welds at lower rotational speed achieved higher than the maximum rotational speed. The hardness at the dynamic recrystallization zone is superior to the weld interface.
- The highest tensile strength achieved for the welds at the rotational speed of 710 rpm with the base metal failure.
- The linear weld interface and the fine equi-axed region was obtained in the welds along with the curved shape of the interface at the periphery regions.

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