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EFFECT OF ADDITION OF PURE TITANIUM POWDER ON MECHANICAL PROPERTIES IN ROTARY FRICTION WELDING

Mehmet Erbil ÖZCAN[1]*

[1]*Fırat University, Faculty of Engineering, Department of Mechanical Engineering, 23200, Elazig, Türkiye*

Abstract: Rotary friction welding, which is a type of friction welding method, which is used as an alternative to traditional welding methods and has many advantages over traditional methods, has become a very popular method in the last twenty years. In this study, shafts with and without powder reinforcement were welded on a conventional lathe with rotary friction welding, tensile tests and temperature analyses were performed and the results were examined. Holes of variable diameters were drilled into the center of the shafts obtained from aluminum 6061 material and pure titanium powder was added, then pressed and sintered. The prepared shafts were welded with rotary friction welding method in appropriate combinations, and according to the results obtained, while the adhesion properties at constant speed were worse as the amount and volume of powder increased, the maximum temperature value obtained during welding increased as the volume of powder increased.

Keywords: Friction welding, Aluminum, Tensile test, Temperature analysis

***Corresponding author:** Fırat University, Faculty of Engineering, Department of Mechanical Engineering, 23200, Elazig, Türkiye
E mail: meozcan@firat.edu.tr (M. E. ÖZCAN)
Mehmet Erbil ÖZCAN https://orcid.org/0000-0003-1641-8279

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1. Introduction

In today's technology, the welding process of metallic materials is of greater importance. Considering that traditional joining methods are inadequate and have many negative aspects, it is seen that the tendency towards new solid state joining methods is increasing. One of these solid state joining methods, rotary friction welding (RFW), is a solid state joining process that can be used to join alloys that are not identical, unlike traditional welding methods. It is based on the principle that surfaces interact when one surface moves relative to another.

For friction welding, the rotational, or mechanical, motion of the method generates heat and causes the materials to be joined to soften and become viscous. In the softened state, the mechanical motion of the process mixes the materials to form a bond. When the rotational speed reaches a certain level, the opposing parts are brought into contact with each other. After this initial moment of contact, an axial pressure is applied so that the parts can reach the desired temperature and the welding process can begin. At this stage, the two materials pass from the heated area to a semi-molten state, allowing the materials to mix and adhere to each other. In order to obtain the desired temperature, the speed of the rotational motion given on one side or both sides is adjusted, and the desired welding process is performed by adjusting the pressure and other parameters.

Conventional welding methods are an important production technology in the aluminum alloy industry. In addition, critical problems may arise when focusing on heat treatable alloys such as 6061. For this reason, the choice of non-conventional welding methods in addition to conventional welding methods plays an important role in both having good weldability properties and having the desired internal structure of the material. For this reason, the coating method with rotary friction welding has become an important reason for preference in terms of overcoming the difficulties of welding with the conventional method and the difficulties of obtaining the desired properties after welding. Considering the wide application range of 6000 aluminum alloys, it is seen that there are still some points that need to be studied and clarified. In this context, the aim of this research was to investigate the behavior of the shaft made of aluminum 6061 series material in rotary friction welding and to investigate some of its mechanical properties (Meran et al., 2016).

The parameters affecting the welding quality in friction welding can be listed as the speed of the tool, the pressing force of the tool, the gap between the pipe and the tool, the pipe length (the amount of pipe end protrusion from the plate), the application time, the shoulder diameter and the temperature. Among these parameters, the two most effective parameters on weldability are the speed of the tool and the pressing force. Both of these variables directly affect the friction-based temperature during welding and cause the metallurgical properties of the weld zone to change

(Meran et al., 2016).
Hamade et al., (2019) conducted a feasibility and energy study showing the differences between the conventional Fusion Butt Welding (FBW) method and the Rotary Friction Welding (RFW) method for joining High-density polyethylene (HDPE) pipes and performed a cost analysis for both methods used in the study. In this cost analysis, it was shown that the energy consumption in RFW was one tenth of that of FBW.
Kasman et al. joined AA7075-T651 aluminum alloy sheets by friction stir welding method at two different rotation speeds using tools with 3 different pin geometries. Afterwards, they compared the mechanical properties and microstructures of the welded areas (Kasman et al., 2016).
Unlike traditional friction welding, it is possible to weld different materials in the friction welding method. Although much less than the problems encountered in traditional welding, some problems can occur in the joining processes performed with these methods. The problems related to friction welding of different metals are not only related to their individual properties such as hardness, melting point, etc., but also to the reactions that occur at the interface. These reactions can lead to the formation of brittle intermetallic phases or other undesirable components. The presence of intermetallic phases at the interface of Al/steel components adversely affects the bonding (Yılbas et al., 1995; Ochi et al., 1977; Hartwig and Kouptsidis, 1978; Achar et al., 1980). These intermetallic phases are FeAl, FeAl2, Fe2Al5 and FeAl3 and the intermetallic phases are stable up to high temperatures. These phases can be expected to occur at the component interface and thus affect the mechanical properties of the welded component (Fukumoto et al., 1998; Atabaki et al., 2014). The thickness of the intermetallic phase in friction welded components is an important parameter contributing to the mechanical properties and therefore should be controlled (Fukumoto et al., 1999).
When the studies in the literature are examined, although there are many studies based on the principle of melting and merging of the metal by reaching temperatures close to the recrystallization zone such as friction welding, friction stir welding, friction coating, very few studies on rotary friction welding have been found. Based on these studies, there is no study in the literature with titanium powder. In this study, after pressing pure titanium powder into the shaft to be subjected to rotary friction welding and then sintering, the welding process was performed and the obtained results were examined.

2. Materials and Methods

The properties of the spindle Al6061 and the additional powder material pure Titanium powder used in rotary friction welding are shown in Table 1 and Table 2. The experimental parameters are shown in Table 3. Pure titanium is an important material with a wide range of potential uses in many sectors. Thanks to its lightness, durability and various usage advantages, it provides advantages in many points, whether used alone or in combination.

Table 1. Chemistry composition of Al6061

Al6061	%
Si	0.40-0.8
Fe	0.7
Cu	0.15-0.40
Mn	0.15
Mg	0.8-1.2
Cr	0.04-0.35
Ni	-
Zn	0.25
Ti	0.15
Zr	-
A1	Remainder

Table 2. Mechanical properties of pure titanium

Pure Ti	%
Yield Strength	275 MPa
Tensile Strength	345 MPa
Elongation	20%
Hardness	35 Rockwell C
Density	4.5 g/cm^3

Table 3. Experimental setup

Exp. Nu.	Rotary Side	Fixed Side
1	8 mm hole, pure Ti added	Non-additive
2	8 mm hole, pure Ti added	8 mm hole, pure Ti added
3	12 mm hole, pure Ti added	12 mm hole, pure Ti added

Aluminum 6061 shafts were machined as shown in Figure 1 to prepare for the experiments.

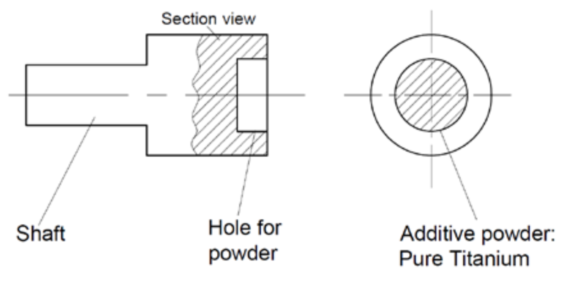

Figure 1. Preparing the samples for experiments.

As seen in Figure 1, 25 mm diameter shafts made of Aluminum 6061 material were connected to the lathe and 8 and 12 mm holes were drilled in their centers respectively and made suitable for powder pressing. A 12 mm diameter bearing area was made on the back of the shaft in accordance with the tensile tests, after the rotary friction welding process, to connect it to the tensile device. Pure Titanium powder was pressed into these shafts under a constant pressure of 50 Bar and made ready for the sintering process. The powder pressed shafts prepared in the press were taken to the sintering furnace from here and subjected to the sintering process at 400 °C (after reaching this temperature) for 90 minutes. After the sintering process, the shafts that were ready for the rotary friction welding process were subjected to experiments according to the experimental program in Figure 2 and the results of all these processes were ready to be examined.

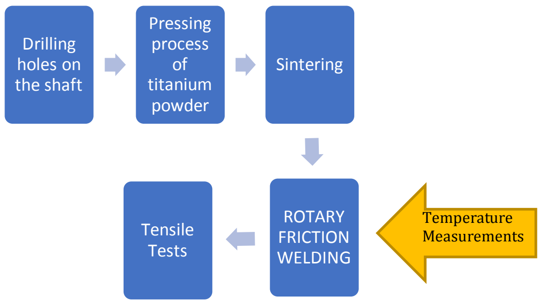

Figure 2. Overview of the experimentals.

2.1. Temperature Measurements

The rotary friction welding process was carried out at a rotation speed of 700 rpm with a powder-pressed shaft and a shaft without powder added in a hole opened with a diameter of 8 mm. In the welding process where the shaft on one side is rotary and the shaft on the other side is fixed, the shaft with powder added is connected to the lathe chuck and the shaft without powder added is connected to the moving tailstock of the machine.

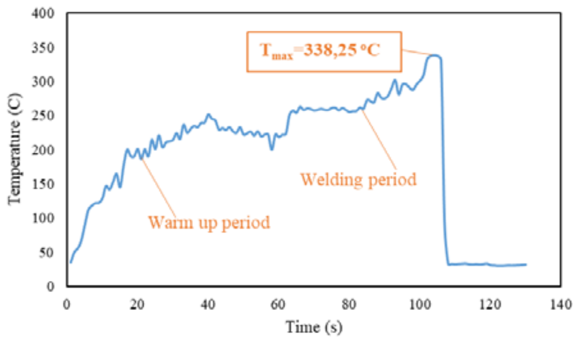

Figure 3. Temperature distribution in rotary friction welding process where the rotary shaft powder added (8 mm) and the fixed shaft without powder added.

The contact point temperature from the point of contact was measured with the help of an infrared thermometer. These obtained temperature values are shown in Figure 3. As can be seen from the graph, the temperature value starting from the moment of contact around room temperature first entered the heating period with the contact of the two shafts and then after the contact area reached the desired temperatures, the plasticized material entered the welding phase. After the flange formation and the interlocking phase of the weld, the machine was stopped and the process was completed. The maximum temperature reached during this time was 338.25 °C.

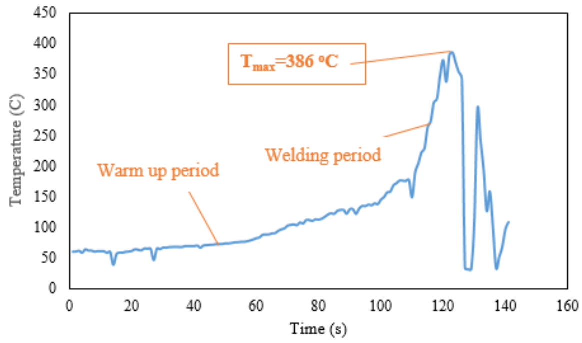

Figure 4. Temperature distribution in rotary friction welding process with rotary (8 mm) and fixed shaft (8mm) both have powder addition.

In Figure 4, the shaft with powder pressed into a hole opened with a diameter of 8 mm and the shaft with powder pressed into a shaft with a hole opened with an 8 mm hole are positioned opposite each other and the temperature values measured during the welding process are given. When these temperature values are examined, the heating period starting at around room temperature passed to the welding period with the material starting without plasticization after a period of 100 seconds and the welding process started. When compared to the welding process performed with titanium powder on one side and without powder on the other side (Figure 3), the materials plasticized later in the welding process with powder added on both shafts. The reason for this is that the melting temperature of the titanium material is 1660°C. When compared to the melting temperature of the aluminum, which is the shaft material (660 °C), the reinforcement material pure titanium, which is seen to be well above this temperature, extended this process shown as the 'warm up period' and caused the welding process to start later.

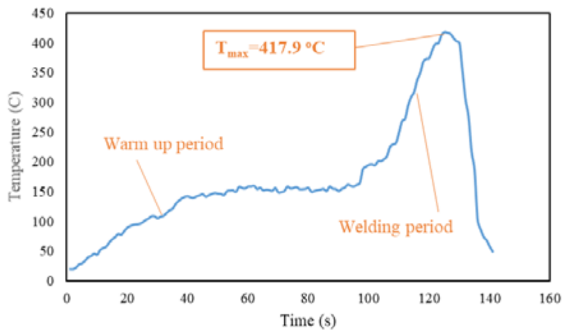

Figure 5. Temperature distribution in rotary friction welding process with rotary (12 mm) and fixed (12 mm) shaft both powder added (12 mm).

Figure 5 shows the temperature-time graphs of shafts with 12 mm diameter holes drilled into both shafts and pressed with pure titanium powder. Temperature is a function of both space and time (Ünal and Akkaş, 2022). For this reason, the temperature time graph was drawn in accordance with the obtained data. According to the graph, the process that started at room temperature entered the welding period after the first contact and heating period and the rotary friction welding process of the two shafts was completed by reaching a maximum temperature of T=417.9 ºC. Since both shafts contained pure titanium powder, the heating period was longer (around 100 s) than the shafts without powder. The shafts that were plasticized later completed their heating in 40% longer time and entered into the welding period. After the welding process, the shafts were allowed to cool down to room temperature and then placed to the tensile device for tensile tests.

2.2. Tensile Tests

After the rotary friction welding process, the samples were placed to the tensile device for tensile tests. Tensile tests were carried out on the UTEST brand test device at a speed of 1 mm/min. The basic mechanical properties of the materials were determined with the tensile tests. In the experiment number 1 (1st spindle 8 mm hole powder added and 2nd spindle without powder added), the rotary friction welding process followed a very good process in terms of heating and welding properties and as a result, a good welding area was obtained. As a result, the tensile test exceeded 7000 N and then started to creep and the areas holding on to the drawing bench started to give necks and the force started to decrease. After this stage, the experiment was terminated and the graph was obtained. In the experiment number 2 (both shaft have 8 mm hole and powder added), since the melting temperature of the additional titanium powder was very high compared to the aluminum material, the adhesion was relatively more porous compared to the welding in the first experiment and as a result, the tensile test reached around 1018 N and the rupture occurred. In experiment number 3 (both shafts have 12 mm holes and powder added), shafts with 50% more powder added were used compared to the shafts used in experiments number 2. Therefore, the higher amount of titanium powder caused the heating and adhesion properties between the two shafts to be more difficult and delayed, and a weld area with more gaps was formed after welding. As a result, the force in the tensile test increased to around 800 N and then rupture occurred. Factors such as porosity in the weld zone or inadequate bonding of titanium particles to aluminum are thought to potentially play a role in the decrease in tensile strength.

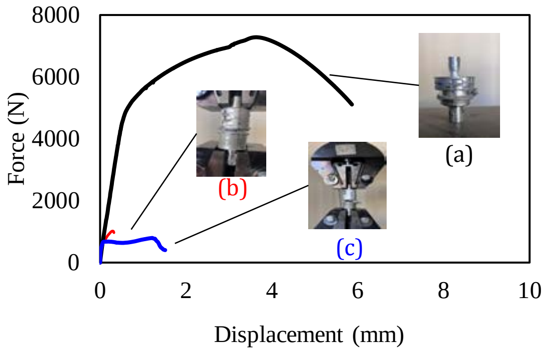

Figure 6. Tensile tests of rotary friction welded pairs. a) Non-additive b) 8 mm Ti added-8 mm Ti added pair c) 12 mm Ti added- 12 mm Ti added pair sample.

3. Results and Discussion

In this study, pure titanium powder was pressed into the shaft to be subjected to rotary friction welding and then sintered, followed by welding and the results obtained are as follows.

In the rotary friction welding process, the shafts come into contact with each other and reach temperatures close to the melting temperature, and then they are welded together with the principle of plasticization of the metal. In the study, since the pure titanium powder pressed into the shaft increases the average melting temperature, the welding process was the best in experiment number 1 (powder pressed into an 8 mm diameter hole in the moving shaft, fixed shaft without powder addition), while a relatively worse union was seen in experiment number 2 (pure titanium powder pressed into an 8 mm diameter hole in both shafts); and the least adhesion was seen in experiment number 3 (pure titanium powder added into a 12 mm diameter hole in both shafts). When the tensile test graphs are examined, in line with the results of these adhesions, the tensile force increased to 7000 N in experiment number 1, around 1000 N in experiment number 2, and in experiment number 3, separations occurred in the welding area around 800 N and the experiment was completed. It is estimated that better welded shafts can be obtained if the experiments are carried out by selecting a higher rotation speed on the bench and reaching higher melting temperatures in order to achieve better adhesion in the experiments where pure titanium powder is added. As a result of the experiments, in addition to obtaining the relevant data, the fact that the adhesion was not very good in some shaft pairs prevented further examination of the samples. For this reason, in future studies, experiments performed by changing the titanium ratio and hole diameter will yield more detailed results.

Author Contributions

The percentages of the author' contributions are presented below. The author reviewed and approved the final version of the manuscript.

	M.E.Ö.
C	100
D	100
S	100
DCP	100
DAI	100
L	100
W	100
CR	100
SR	100
PM	100
FA	100

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The author declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

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