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Analysis of Wear Behaviourof the Friction Stir Welded Jointswith Varying Track Diametersfor Non-Welded and Welded Samples

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Abstract

Objectives: To analyze the wear behaviour of friction stir welding on similarAA6061-AA6061, AA6082-6082 and dissimilar Alloys AA6061-6082 with T6 condition and varying track diameters. **Methods/Statistical Analysis:** Ultrasonic test and penetratetest are some of the Non Destructive Test methods are used to check the weld defects. Pin on disc method is used to study the wear behavior. Metallurgical microscope is used for Micro structure analysis. Analysis of sliding distance Vs. weight loss was performed for samples of welded and non welded zones of similar Alloys AA6061-AA6061, AA6082-6082 and dissimilar Alloys AA6061-6082. **Findings:** NDT tests have shown no deflects inwelded zone,less amount of weight loss and similar material AA6061-6061 welded joints, has better outcome in welded zone. **Applications:** Further corrosion test and XRD analysis can be performed as Aluminum alloys has application in marine and modern transportation.

Keywords: Friction Stir Welding, Metallurgical Microscopes, Pin-on-disc, Sliding Distance vs.Weight Loss, Wear Behavior, XDR Analysis,

1. Introduction

Friction Stir Welding (FSW) is aprocess in which Alloys are joined in a solid state. This process was invented by the Welding Institute (U.K)[1]. Alloys which are of high strength and usually difficult to join with legacy techniques can be welded by FSW. A specially designed non consumable tool which has a shoulder and a pin is plunged on the abutting edges of the plate and moves along the edges to be joined. The tool while rotating creates frictional heat on the abutting surfaces. The non-consumable tool used in FSW makes joints with good mechanical properties without conventional defects. The design of the tool used in FSW influences the joint properties and determines the micro structure. The quality of the welding is largely dependent on the welding specifications like tool pin profile, axial force, tool rotational rate and traverse speed[2,3] etc.

The samples fabricated are subjected to Non-Destructive Testing to check the quality and reliability of the components, Wear Frictional behavior by pin on disc (pod) testing machine method, Micro Structure by optical metallurgical microscope.

1.1 NDT

NDT means Non-Destructive Testing. It is a technology which has been used continually advancing and it is unavoidable, atintervals, to update the published data on the subject. It is a process of inspectionwhichenables the part of the whole quality assurance or qualitycontrol (QA/QC) system[4]. It is large group of analysis techniques applied to evaluate the properties of material and component or system without causing any bane. A few methods of NDT are relatively simpleto apply whereas other methods needconsiderable skill.It can be used prior the use of component or while they are in use for the sake of quality

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control and to know the services related conditions caused due to wear,corrosion,stress or other parameters which affect reliability.NDT techniques include visual and Optical testing, radiography, Ultrasoundtesting. Magnetic particle testing, penetrate testing.

1.2 Wear Testing Methods

A process in which materials are removedfrom solid surfaces which are in solid state contact is known as wear. Wear reduction technologies may be evolved by understanding the conduct of materials under different conditions. Sliding,abrasive,erosive,corrosive and fatigue wear are some of the wears[5].

Under certain arbitrary conditions several tests have been evolved for wear testing. Some of the geometrytests used can be noted as pin-on-disc geometry or pin-on-ring geometry which is made up of the subject material. Thismethod is mostly used for aluminium. Another method that can be used for aluminium wear test is Abrasive wear, which is of industrial importance, but the reason is the low hardness values of aluminium alloys make it unsuitable.

These tests are used for checking the parameters like thickness, adhesive strength,ductility,porosity and ductilityofthe material or component[6]. The other tests for coated and uncoated cutting tools[7]. The other features like frictional force, co-efficient of friction, rate of wear are performed with the help of Pin-on-disc wear testing.

1.3 Metallurgical Microscopes

A metallurgical microscope is used mainly to know the grain size and phase of the metal by the researchers. Frontal lighting is used to illuminate metals as they are opaque in nature. Theypermit the viewing of surface structure to identify metal fatigue[8]. The important parameters in specifying metallurgical microscopes include magnification and resolution.

2. Literature Review

According to Sannino and Rack (1995), the important tribological parameters that control the rate of wear are reinforcement type, shape, size, orientation andpercentage of reinforcement. The applied load, sliding velocity, sliding distance, environment and temperature as well as counterpart material and these are collectively called as mechanical and physical factors which also play an important role in controlling the tribologicalbehavior of aluminium composites.Wear test methods are grouped into six categories: i) Machinery Field Tests. ii) Model Tests. iii) Components Bench Tests iv)Systems Bench Tests v) Machinery Bench Tests vi) Laboratory Tests[9]. Horst Czichos(1992).Low stress abrasion studies (three body) generally employ the use of a Rubber Wheel Abrasion Test (RWAT) is generally applied for load stress abrasive studies of ASTM-G65[10]. Modi et al. (2001), Izciler and Muratoglu (2003), Prasad et al. (1992). High stress abrasion studies (two body) are defined by a specimen pin sliding under a normalload for a known abrasive medium by pin-on-disc apparatus[12]. Deuis et al. 1996). The various researchers conducted abrasive wear test on pin-on-disc type apparatus. (Das et al. (2007), Kok and Ozdin (2007), Muratoglu and Aksoy (2006), Rajesh Sharma et al. (2007), Yilmaz and Buytoz (2001)).Some of the research work done have used a reciprocating type abrasive wear tester (Mondal and Das (2006), Sawla and Das (2004), Singh et al. (2002)[13,16]. These tests have been conducted by varying the materials parameters and operational parameters have shown that the rate-controlling wear mechanisms may change abruptly at certain sliding velocities and contact loads, leads to abrupt increase in the rate of wear.

3. Materials and Experimental Method

3.1 Frictional Stir Welding

FSW is performed by taking three plates of AA6061 and 3 plates of AA6082 having dimension (200mmx100mm) with 5mm thickness was taken as shown in Figure 1(a).Table 1 shows properties of AA6082 and Table 2shows the properties of AA6061. The process includes Friction Stir Welding of dissimilar and similar alloys as one piece (AA6061-AA6082). The selected parameters were travel speed of 50mm/min; tilt angle of 1°; rotating speed of 1120 rpm. In the similar manner welding of similar alloys as second piece (AA6061-AA6061) the selected parameters are travel speed of 50mm/min:tilt angle of 1°; rotating speed of 900 rpm (see Figure 1(b)). Welding of similar alloy (AA6082-AA6082) is made with selected parameters were, travels at a speed of 50mm/min: tilt angle of 1°: rotating speed of 1400 rpm.

3.2 Non Destructive Testing

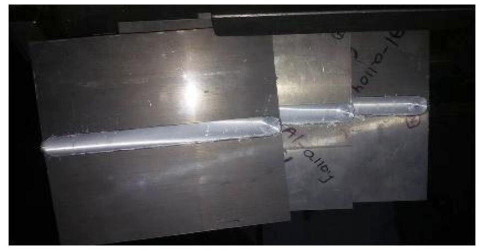
Here we had done penetrate testing (see Figure2(a))to find the defects at the outer surface and ultrasonic testing

Table 1. Properties of AA6082

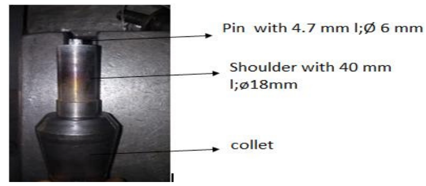
CHEMICAL PROPERTIES		PHYSICAL PROPERTIES	
Magnesium (Mg)	0.60 - 1.20	Density	2.70 g/cm³
Silicon (Si)	0.70 - 1.30		
Iron (Fe)	0.0 - 0.50	Melting Point	555 °C
Copper (Cu)	0.0 - 0.10		
Chromium (Cr)	0.0 - 0.25	Thermal Expansion	24 x10-6 /K
Zinc (Zn)	0.0 - 0.20		
Titanium (Ti)	0.0 - 0.10	Modulus of Elasticity	70 GPa
Manganese (Mn	0.40 - 1.00		
Others (Total)	0.0 - 0.05	Thermal Conductivity	180 W/m.K
Aluminium (Al)	Balance		
-	-	Electrical Resistivity	0.038 x10-6 O .m

Table 2. Properties of AA6061

CHEMICAL PROPERTIES		PHYSICAL PROPERTIES	
Magnesium (Mg)	0.60 - 1.20	s	2.70 g/cm³
Silicon (Si)	0.70 - 1.30		
Iron (Fe)	0.0 - 0.50	Melting Point	555 °C
Copper (Cu)	0.0 - 0.10		
Chromium (Cr)	0.0 - 0.25	Thermal Expansion	24 x10-6 /K
Zinc (Zn)	0.0 - 0.20		
Titanium (Ti)	0.0 - 0.10	Modulus of Elasticity	70 GPa
Manganese (Mn)	0.40 - 1.00		
Others (Total)	0.0 - 0.05	Thermal Conductivity	180 W/m.K
Aluminium (Al)	Balance		
-	-	Electrical Resistivity	0.038 x10-6 O .m



(a)



(b)

Figure 1. (a) FSW plates,(b) FSW tool.

(a)

(b)

Figure 2. (a) Penetrating test,(b) Ultrasonic test.

(see Figure2(b))is done to find the defects at inner surface of the welded zone. After the test there were no defects in the welded zone and at the joints then we proceed for the experiment work.

3.3 Wear Testing

3.3.1 Wear Testing Specimens

We had taken the welded plates after NDT and considered the samples for wear testing, from welded and non welded zones of dimensions [height=30mm, width=5mm, thickness=5mm] by using Wire EDM. Six(6) samples were taken from each [AA6061-AA6061], [AA6082-AA6082] and [AA6082-AA6061],two samples from welded zone and four samples from non welded zones as shown in Figures 3 and 4. The individual samples after Wire EDM are also shown in the Figure 5.

3.3.2 Experimental Procedure for Wear Test

Pin-on disk machine (Model TR 20, Ducom, India) is used to perform the dry sliding wear test as per ASTM G 99 standard[11]. The stationary pin is aluminums alloys of different samples taken from non-welded zones and welded zones, and hardened die steel with Rc65 hardness is the rotating disk of the machine. The dimensions of the disc and specimen are shown in Figure 6. Under dry sliding conditions, Wear tests were performed with normal weight. In order to monitor and record the wear, frictional force and coefficient of friction continuously WINDCOM 2013 software was used for each test.

We have conducted experiment using wear testing machine and the procedure for doing the wear test is explained here. Switch on the computer, control unit and Machine. Rotate the disks to some RPM and the set speed by adjusting the RPM nobe. Give support under the cantilever arm under unloading condition and arrest the arm without any movement. Based on the specimen dimension we can set the die and fix the work piece properly. i.e. (the specimen

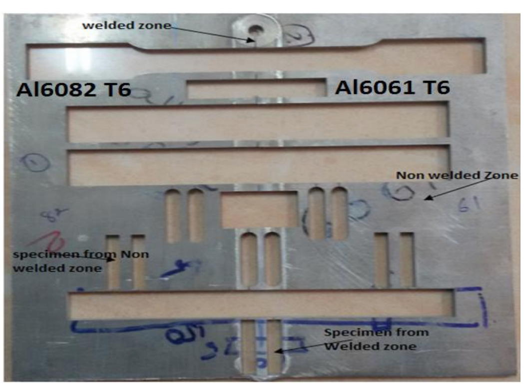
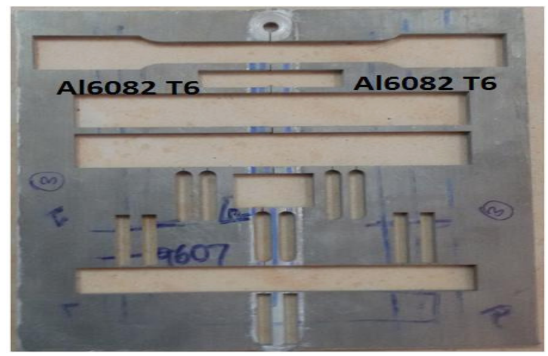


Figure 3. Friction Stir welded dissimilar joint (AA6061-AA6082) and indicating the specimens for wear test from welded and non-welded zones.

(a)



(b)

Figure 4. (a)Friction Stir welded similar joint(AA6082-AA6082),(b) Friction Stir welded similar s joint (AA6061-AA6061).

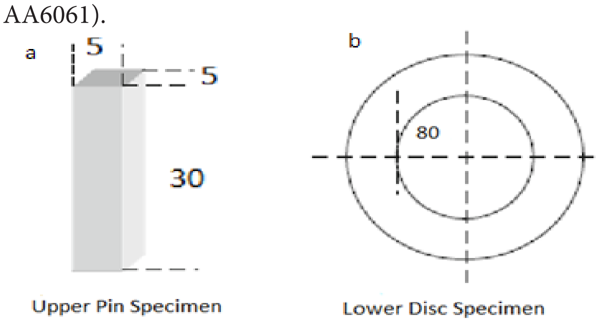


Figure 5. (a) Specimen dimension, (b) Track diameter.

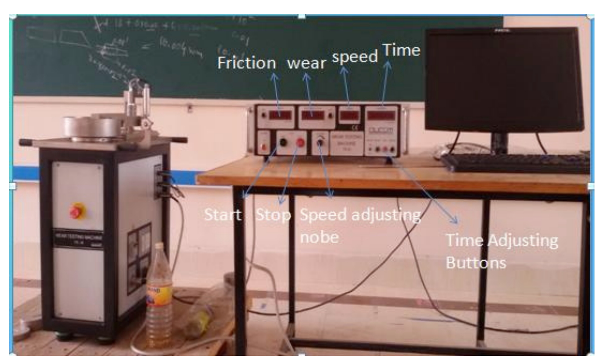


Figure 6. Model TR 20, Ducomwear testing machine.

should be in contact with the disc). Apply the load according to the requirement and remove the support under the arm. We had two nobes, adjusting nobe and thumb nobe, release the two nobes freely and check the values on the control unit. Now adjust the thumb nobe to get the value of wear and the frictional factor to zero on control unit and then fix the thumb nobe and set the required time by pressing the timing buttons. Open the Wind com icon from the desktop and give the input parameters (like file name, specimen dimensions, load, track diameter and time) on the Wind com software file. Now press the start button in the software as well as in the machine control unit simultaneously as shown in Figures 6 and 7. After the test is completed for the required time taken, the values and graphs of wear rate, friction factor are noted from the software and control unit simultaneously.

3.3.3 Experiment

In the second experiment with constant load 1Kg. The wear test for eight specimens (4 welded & 4 non welded specimens) was conducted under varying track diameter 65mm, 80mm and 100mm (Shown in Figure 8 and at aspeed of 640rpm for a time of 300 seconds.

The wear and frictional force were calculated from the wear test. The specimens after the wear testing are shown in Figures 9 and10. The values of the eight specimens are tabulated.

The microstructure shows grooves and fine scratches on the surfaces shown in Figure 12 (e). In the above Figure 11 (a), (b) and (h) shows sliding direction, cracks and wear debris on the surface of the specimens.

4. Results and Discussions

The results are shown from Tables 3 up to Table 8 and graphs are shown below in Figure11and Figure 12. The graphs of sliding distance Vs weight loss were plotted using the tabulated values for eight specimens (4 welded & 4 non welded specimens) are compared.

4.1 Summary of Experiment

As seen in the above Figure 13 during the wear test the weight loss is very less for II- Al6061W and very high for I-Al6061W at1 kg load compared to the other specimens taken from welded zone.

As seen in the above Figure 14 during the wear test the weight loss is very less for I- Al6082NW and very high for III-Al6082NW at I kg load compared to the other specimens taken from Non-welded zone.

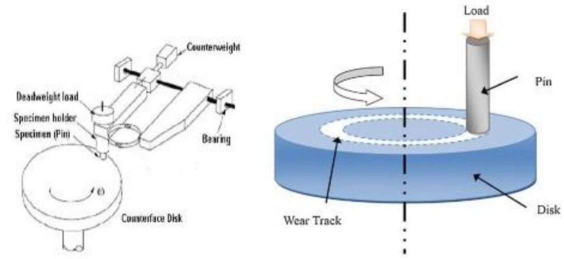
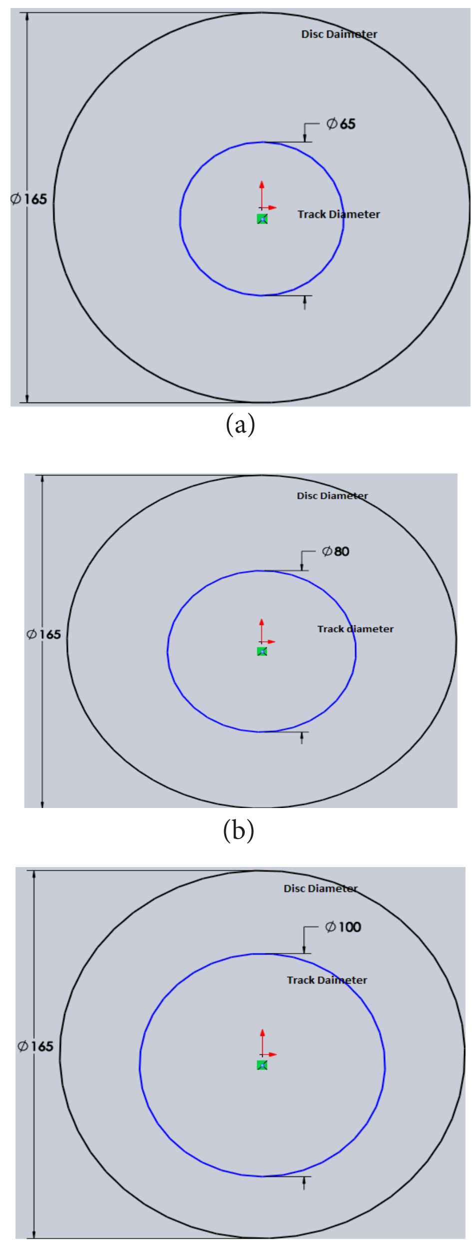


Figure 7. Schematic views of the pin-on-disk apparatus.



(a)

(b)

(c)

Figure 8. Track Diameter 65mm, 80mm and 100mm.

Figure 9. Front viewof specimens afterwear test.

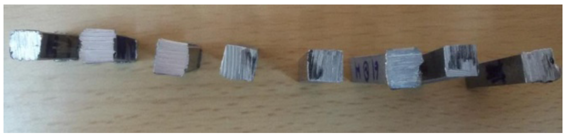
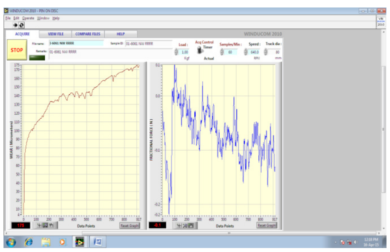
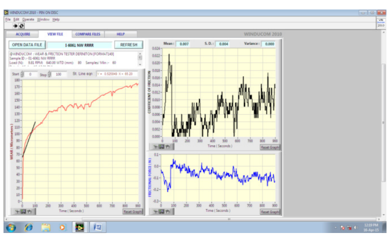


Figure 10. Top view of specimensafterwear test.



(a)



(b)

Figure 11. Values and graph of wear and frictional force using WINDUCOM Software.

Table 3. 1kg load at 65mm wear track diameter

sample	Applie d load (kg)	Time (min)	Speed (rpm)	Track dia-meter(mm)
i -6061/6082				
6061 W	1	5	640	65
6082 W	1	5	640	65
6061 NW	1	5	640	65
6082 NW	1	5	640	65
II- 6061/6061				
6061 NW	1	5	640	65
6061 W	1	5	640	65
III-6082/6082				
6082 NW	1	5	640	65
6082 W	1	5	640	65

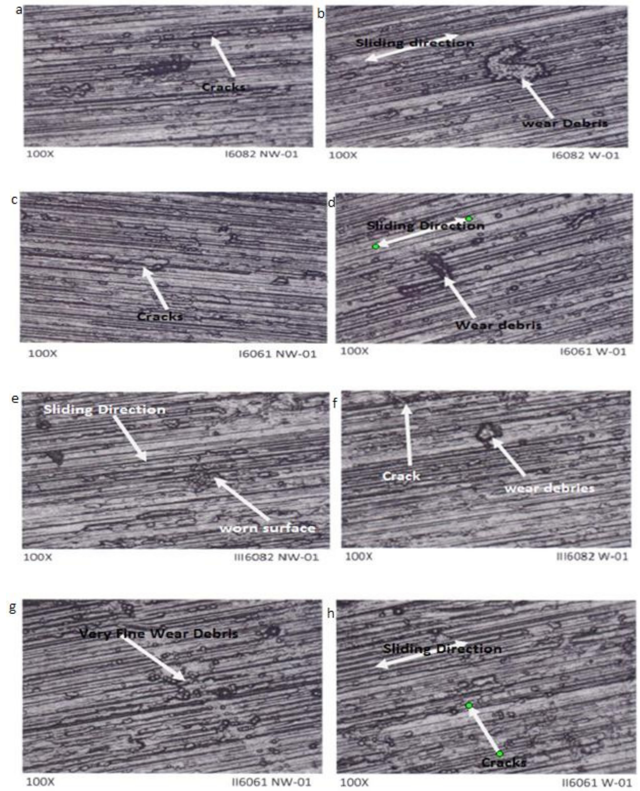


Figure 12. Microscopicobservationofweartestedspecimen of (a) I-AA6082NW (b) AA6082W (c) I-AA6061NW (d) I-AA6061W (e) III-AA6082NW (f) III-AA6082W (g) II-AA6061NW (h) II-AA6061W.

Table 4. 1kg load at 65mm wear track diameter

sample	Weightof sample before testing (mm)	Weigh of sample after testing(grams)	Weight loss (grams)	Wear (micro-meters)
6061 W	1.547	1.484	0.063	487
6082 W	1.601	1.584	0.017	168
6061 NW	2.118	2.111	0.001	35
6082 NW	2.023	2.022	0.001	40
II- 6061/6061				
6061 NW	2.123	2.1	0.023	191
6061 W	2.196	2.181	0.015	96
III-6082/6082				
6082 NW	2.046	1.972	0.074	1120
6082 W	1.978	1.97	0.008	102

Table 5.1kg load at 80 mm wear track **diameter**

sample	Applie d load (kg)	Time (min)	Speed (rpm)	Track diameter (mm)
i-6061/6082				
6061 W	1	5	640	80
6082 W	1	5	640	80
6061 NW	1	5	640	80
6082 NW	1	5	640	80
II- 6061/6061				
6061 NW	1	5	640	80
6061 W	1	5	640	80
III-6082/6082				
6082 NW	1	5	640	80
6082 W	1	5	640	80

Table 6.1kg load at 80mm wear track diameter

sample	Weightof sample before testing (mm)	Weigh of sample after testing(grams)	Weight loss (grams)	Wear (micro-meters)
6061 W	1.484	1.371	0.113	1208
6082 W	1.584	1.54	0.044	751
6061 NW	2.111	2.09	0.021	714
6082 NW	2.024	2.016	0.008	19
II- 6061/6061				
6061 NW	2.1	2.074	0.026	457
6061 W	2.181	2.173	0.008	107
III-6082/6082				
6082 NW	1.972	1.884	0.088	951
6082 W	1.97	1.897	0.073	1174

Table 7. 1kg load at 100mm wear track diameter

sample	Applie d load (kg)	Time (min)	Speed (rpm)	Track diameter (mm)
i -6061/6082				
6061 W	1	5	640	100
6082 W	1	5	640	100
6061 NW	1	5	640	100
6082 NW	1	5	640	100
II- 6061/6061				
6061 NW	1	5	640	100
6061 W	1	5	640	100
III-6082/6082				
6082 NW	1	5	640	100
6082 W	1	5	640	100

Table 8. 1kg load at 100mm wear track diameter

sample	Weightof sample before testing (mm)	Weigh of sample after testing(grams)	Weight loss (grams)	Wear (micro-meters)
6061 W	1.371	1.29	0.081	1215
6082 W	1.54	1.525	0.015	221
6061 NW	2.09	2.02	0.07	650
6082 NW	2.016	2.0148	0.0012	53
II- 6061/6061				
6061 NW	2.074	2.022	0.052	770
6061 W	2.173	2.16	0.013	81
III-6082/6082				
6082 NW	1.884	1.81	0.074	1250
6082 W	1.897	1.82	0.077	1310

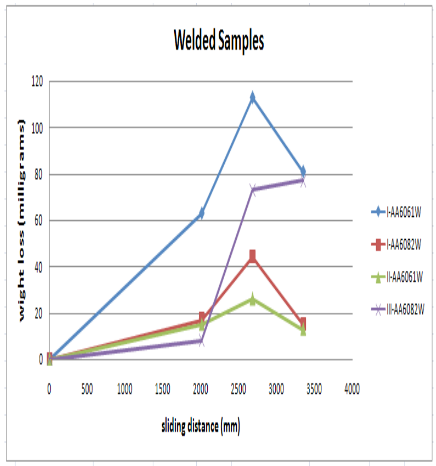


Figure 13. Sliding distance vs weight loss for welded samples.

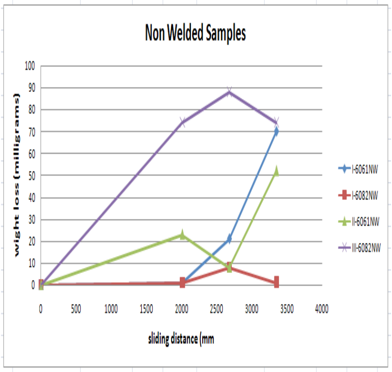


Figure 14. Sliding distance=$\frac{\pi dN}{60}$, sliding distance vs weight loss for non-welded samples.

5. Conclusion

Friction stir butt welds of dissimilar Alloys AA6082-T6 and AA6061-T6 were produced, as well as Friction Strill butt welds of similarAlloys. The specimens taken from welded and non welded zones are compared with each other by conducting the experiment and the results are concluded.

During wear test, the specimens taken from friction stir welded AA 6061-AA 6082 material has less amount of weight loss and lesser amount of wear compared to the other specimens and the secondary preference is given to the friction stir welded AA6061-AA6061 because it has-lesser amount of weight loss and wear at the welded zones.

During the wear test, the specimens taken from friction stir welded AA 6061-AA 6082 material has a better outcome in the non-welded zone compared to the other specimens.

During the wear test, the specimens taken from friction stir welded AA6061-AA6061 material has a better outcome in the welded zone compared to the other specimens.

The microstructures of pin specimen after wear test were examined by optical metallurgical microscope. The sliding direction, furrow, scratches, cracks, and wear debris are clearly visible in the microstructure.

6. Scope for Future Work

Further we can study about the Sliding distance vs. weight loss of the specimens taken from welded as well as non welded zone of similar and dissimilar FSW

Further we can study about the corrosion test and XRD analysis of the specimens taken from welded as well as non welded zone of similar and dissimilar FSW

Further we can study about the thermal conductivity of the specimens take from welded as well as non welded zone of similar and dissimilar FSW during wear test using thermo couple.

Further we can study about parametric optimization of wear test parameters

7. Acknowledgement

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