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Morphology Study of The Corrosion Rate on Weld Joint of Double Side Friction Stir Welding Aluminum Alloy AA6061

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ABSTRACT

The purpose of this study is to experimentally analyze the main causes of failure of AA6061 DSFSW joints based on welding temperature, weld defects, microstructure, corrosion rate and morphology of the corroded surface. Temperature testing using thermocouple to analyze the temperature, welding joint defects using DSLR camera and radiography test, microstructure using optical microscope, corrosion rate using AUTOLAB PGSTAT and morphology of corroded surface using SEM. The temperature analysis results show that the advancing side has a higher temperature than the retreating side, due to friction between the tool and base metal accompanied by the opposite welding direction. Visual inspection shows that all specimens and welding positions produce flash that is quite rough on the top (1G) and bottom (4G) surfaces and radiographic test results show incomplete fusion in 4 specimens. Microstructure shows a change in shape and size resulting in recrystallization in the form of fine grains. The highest corrosion rate is found in specimen B 1G welding position of 0.63856mm/year and the lowest corrosion rate in specimen A of 0.058567mm/year. SEM test results show the type of corrosion that occurs in DSFSW welding joints is pitting corrosion.

Keywords: DSFSW, Morphology Corrosion Rate

ABSTRAK

Tujuan dari penelitian ini adalah untuk menganalisis penyebab utama kegagalan sambungan DSFSW AA6061 berdasarkan temperatur pengelasan, cacat las, struktur mikro, laju korosi, dan morfologi permukaan yang terkorosi. Pengujian temperatur menggunakan termokopel, cacat sambungan menggunakan kamera DSLR dan uji radiografi, struktur mikro menggunakan mikroskop optik, laju korosi menggunakan AUTOLAB PGSTAT dan morfologi permukaan yang terkorosi menggunakan SEM. Hasil analisis temperatur menunjukkan bahwa *advancing side* memiliki temperatur yang lebih tinggi dibandingkan dengan *retreating side*, karena pengaruh arah pengelasan yang berlawanan. Inspeksi visual menunjukkan bahwa semua spesimen menghasilkan *flash* yang cukup kasar, dan hasil uji radiografi menunjukkan adanya *Incomplete Fusion*. Struktur mikro menunjukkan adanya perubahan bentuk dan ukuran yang mengakibatkan terjadinya rekristalisasi butiran halus. Laju korosi tertinggi terdapat pada spesimen B posisi pengelasan 1G sebesar 0.63856mm/tahun dan laju korosi terendah pada spesimen A sebesar 0.058567mm/tahun. Hasil uji SEM menunjukkan jenis korosi yang terjadi pada sambungan las DSFSW adalah korosi sumuran.

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Kata Kunci: DSFSW, Morfologi Laju Korosi

1. Introduction

Defects are one of the failures in the fabrication process [1]. The defect trigger needs to be researched and investigated by analyzing the failure [2]. Failure analysis was critical in detecting the start of failure and its prevention [3]. Determining failure triggers can be done through laboratory observation, inspection, and also sample testing [4][2]. Appropriate analysis can reduce or prevent failures in the fabrication of a product or component [5]. The welding fabrication process cannot be separated from defects and failures, because of its usefulness in connected two specimens [6]. One type of the welding that is starting to become a research trend is Friction Stir Welding (FSW).

FSW, or friction stir welding, is a technique for joining specimens with various metal shapes [7]. FSW also has flaws, some of which being the welding process's lack of flexibility currently, FSW is only done on one side of the welded plate, therefore it cannot be applied to thick materials, and even if it can, the material must be flipped over [8]. Cox et al., (2014) successfully devised in his research, where the plate to be connected encounters friction from two chisels on opposing sides. DSFSW joints can have more strength than single-sided FSW joints because the stirring action is thoroughly blended [10].

The working principle of this welding utilizes the friction of the tool rotation with the workpiece which generates heat until the metal softens [11][12]. The corrosion rate is further affected by high heat created by friction and non-uniform cooling rates; this heat produces metallurgical transformations to across Heat Affected Zone (HAZ) and Weld Metal (WM) sectors [13][14], and can cause defects such as porosity, kissing bond, cracks, cavities (welding penetration), and flash and changes in microstructure [15]. The microstructure changes in welded joints can affect the resistance of welded joints to corrosion.

Corrosions cause damage to a material as a result of a chemical or electrochemical reaction between the material and its environment, usually the constituent metal alloy and its quality [16][17]. Corrosion can occur quickly if environmental control and prevention are not done properly [18]. Attempts are currently being made today to limit material damage produced by the manufacturing process, so that the corrosion rate is kept as low as feasible and does not surpass the metal's economic worth, or before the metal gets damaged [19]. This corrosion has a major impact on the performance of welded joints [20]. Siddesh Kumar et al., (2022) dan Balaji Naik et al., (2019) in their research stated the importance of welding parameters to obtain joints that have resistance to corrosion rates. The study of welding joint failures is important to obtain good quality joints that can function optimally. The purpose of this study is to identify the morphology of the corrosion rate of Double Side Friction Stir Welding joints on Aluminum Alloys 6061-T6.

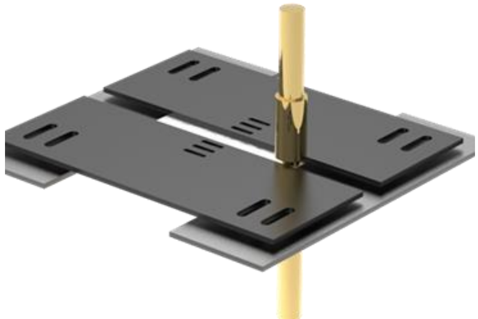


Figure 1. Illustration DSFSW process

2. Materials and Methods

2.1. Materials

The material used in this study is Aluminum Alloy 6061 series. The chemical composition of the specimen can be seen in Table 1.

Table 1. AA6061 Chemical Formulation

Composition	Al	Si	Cu	Fe	Mn	Mg	Ti	Zn	Other
%	95,8-98,6	0,4-0,8	0,15-0,4	0,7	0,15	0,8-1,2	0,15	0,25	0,05

Figure 2. depict the workpiece's dimensions and cutting the plate using a saw.

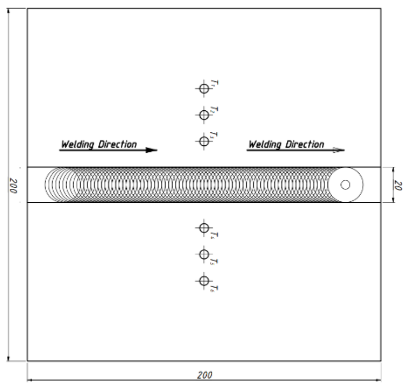


Figure 2. DSFSW Specimen Dimensions

2.2. Methodology of Research

2.2.1 Welding Temperature

The temperature during the welding process is measured using a thermocouple integrated with Arduino Mega to display the temperature in degrees Celsius against time and welding direction.

2.2.2 Visual Inspection

To maintain test data, drawing designs, visual presentations utilizing written words, or shooting pictures or films of the recorded surface conditions are used instead of tools.

2.2.3 Radiography Test

Non-destructive testing of joint defects using radiography tests based on ASTM-E1032 standard practice for radiographic examination of weldments using industrial A-ray film.

2.2.4 Microstructure

Microstructure testing is conducted to determine changes in grain shape, grain size, joint properties, and phase using an optical microscope. Observations were made on the weld metal part of the welding joint.

2.2.5 Corrosion Rate

This same rate of corrosion was tested and used the electrochemical method with three electrode cells and a Potentiostat integrated with NOVA Software based on ASTM G102 Establishing for Measurement of Corrosion Rates and Related Data from Electrochemical Measurements as shown in Figure 2.2. This corrosion test utilizes a chemical substance as just an alternate for seawater with a sanitary 3.5% NaCl as shown in Figure 3.

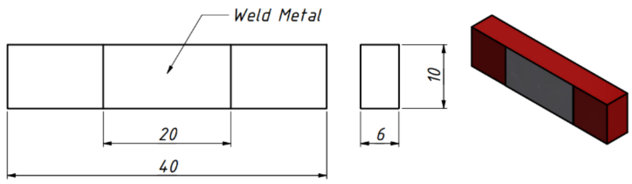


Figure 3. Dimensions of Corrosion Testing Specimens

An electrochemical technique is a way of measuring the corrosion rate by measuring the potential difference of the item in order to acquire the corrosion rate that happens; this approach measures the corrosion rate only when the rate is assessed over a lengthy period of time. The benefit of this approach is that we can quickly determine the corrosion rate when it is measured, therefore the measurement period is short. Testing the corrosion rate by electrochemical methods with polarization of the free corrosion potential can be calculated using a formula based on Faraday's Law as below.

$$\text{Corrosion Rate} = K\frac{i_{corr}}{\rho}EW$$

Where:

K = Constanta (0,129m/years or 0,00327mm/years)

i = Current Density (μA/cm^2)

EW = Equivalent Weight

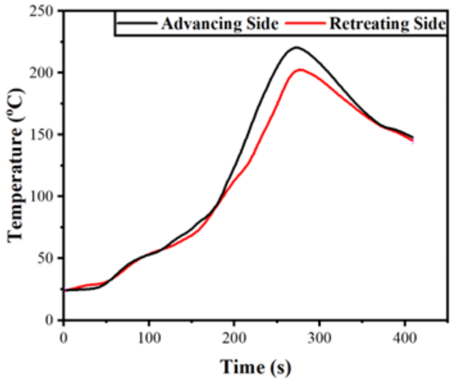
ρ = Corroded Metal Density (gram/cm^3)

2.2.6 Scanning Electron Microscopy (SEM)

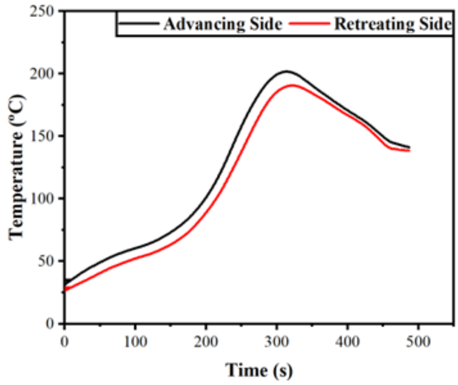
The surface of the corroded welding joint is tested by producing a specimen based on the size or capability of the SEM.

3. Result and Discussion

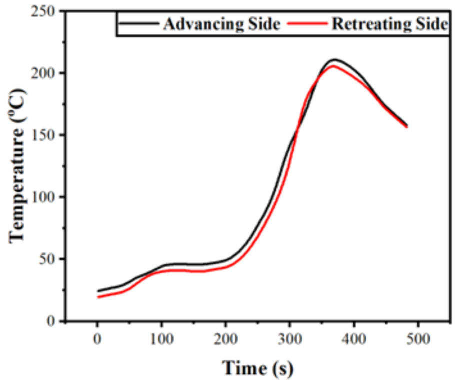
3.1. Welding Temperature



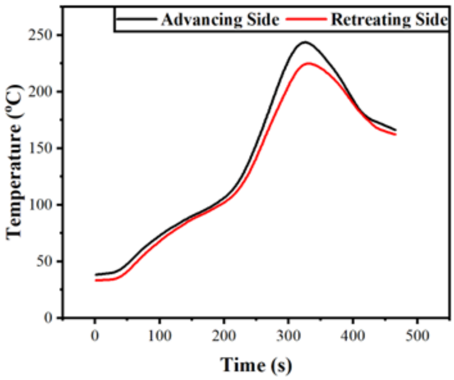
(a)



(b)



(c)



(d)

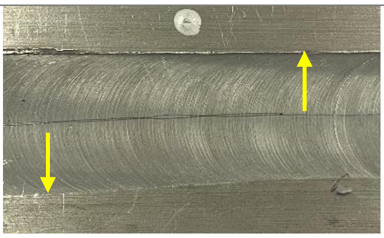
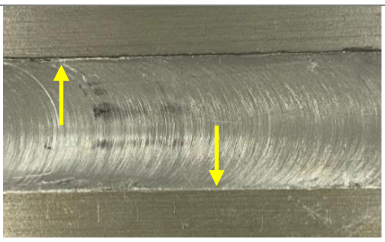
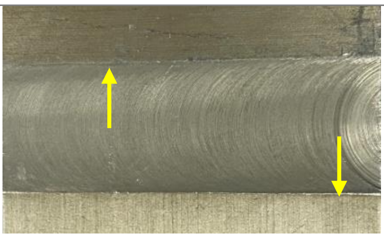
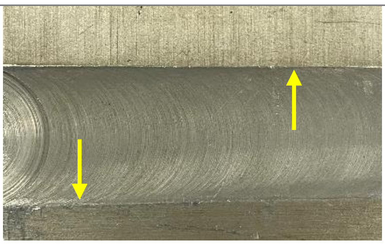
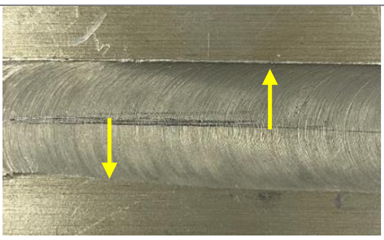
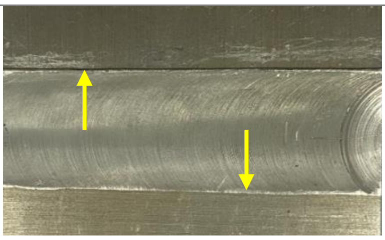
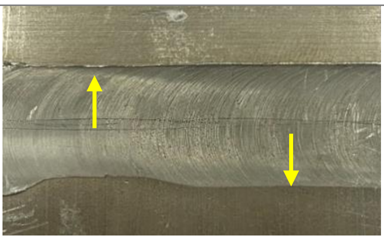
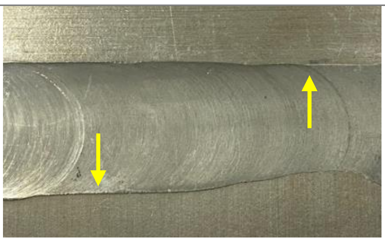
Figure 4. Temperature Distribution Graph **(a)** Specimen A, **(b)** Specimen B, **(c)** Specimen C, **(d)** Specimen D

The advancing side has a greater temperature than the receding side, as shown in Figure 4. This is due to the fact that the friction force between the tool and the base metal is complemented by the reverse of welding. The retreating side temperature is lower due to the direction of friction of the tool and base metal in the direction of welding [23][24]. The highest temperature occurs when the tool is in the center position of the workpiece and the temperature decreases with increasing welding time and distance, this is due to the cooling process of the material as a result of conduction to the backing plate and room temperature [25]. The heat generated during welding is a mix of thermal conduction and heat by material plasticity [26] [27].

3.2. Visual Inspection

Table 2. shows that all specimens and welding positions produce flash (yellow arrows) that is quite rough on the top (1G) and bottom (4G) surfaces. At higher rotational speeds and lower welding speeds, the material undergoes severe plastic deformation, leading to excessive flash formation. This is due to the excessive heat that softens the test material and due to the tool pressing on the soft material so that it is lifted above the surface into flash [20][33]. Therefore, an optimal combination of welding speed and tool rotation speed must be maintained to prevent flash formation.

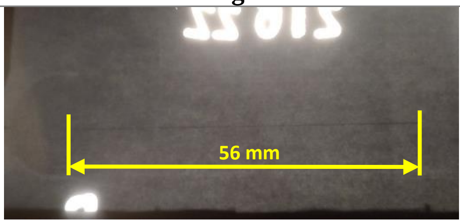
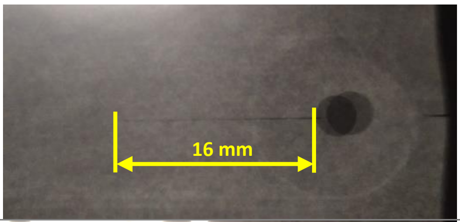
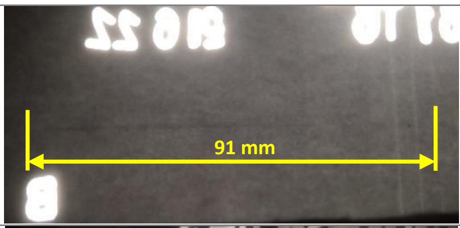
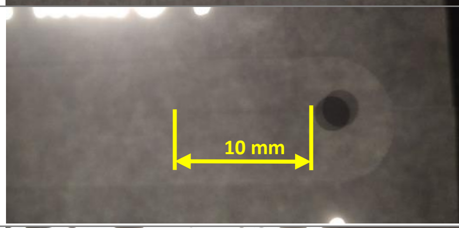
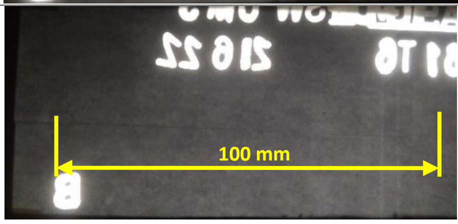
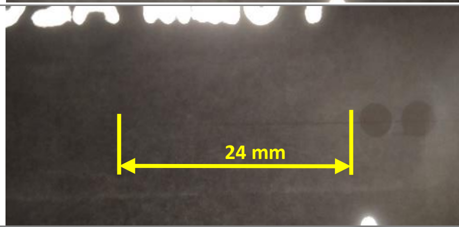
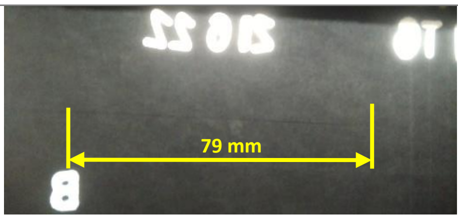
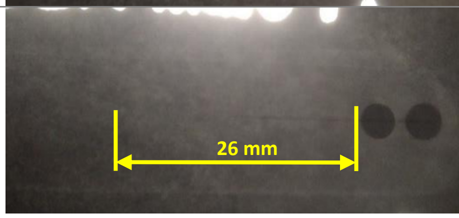
Table 2. Results of Visual Inspections

Specimen	**Flash Defects Welding Tool Position**	
	1G	**4G**
Specimen A		
Specimen B		
Specimen C		
Specimen D		

3.3. Radiography Testing

Based on radiographic testing shown in Table 3., all specimens show Incomplete fusion (IF) defects caused by low heat input at the beginning of each welding and a rapid cooling process resulting in insufficient plasticity of the material due to non-optimal welding speed and tool rotation speed [28]. To reduce defects in the connection, we must pay attention to dwell time, tool rotation speed, welding speed, tool geometry, and plate thickness [29].

Table 3. Results of DSFSW Radiography Testing

Specimen	Defective Section (Incomplete Fusion)	
	Starting Point	End Point
Specimen A		
Specimen B		
Specimen C		
Specimen D		

3.4. Microstructure

3.5. Corrosion Rate

3.6. SEM Testing

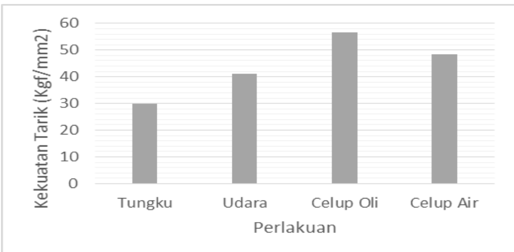
Berikut disajikan tabel hasil uji kekerasan pada baja karbon.

Table 1. Hasil uji kekerasan (Judul tabel menggunakan font Times New Roman ukuran 10, dan isi tabel menggunakan font Times New Roman ukuran 9, spasi 1).

No	Jenis Media Pendingin	Kecepatan Pendinginan (◦C/menit)	Kekerasan (Brinnel) (Kg/mm^2)
1	Tungku	5	124,4
2	Udara	50	143,1
3	Celup oli	100	182,96
4	Celup air	100	370,96

3.7. Kekuatan tarik baja karbon

Grafik yang disajikan hendaknya menggunakan format warna *grayscale/pattern.*



Gambar 2. Hasil pengujian kekuatan tarik baja karbon dengan berbagai macam perlakuan pendinginan (Sumber: Hasil olah data penulis).

Table 2. *Peptidyl* dan *peptidomimetic P_1-argininal* turunan **2a-t** hasil skema 1

	Kondisi	Rasio α:β	Hasil (%)
1.0 *equiv*	TfOH (0.04 equiv), toluene, −20 °C	1:1	72
3.0 *equiv*	TfOH (0.01 equiv), toluene, −20 °C	2:3	89
3.0 *equiv*	TMSOTf (0.01 equiv), Et_2O, −20 °C	7:3	88
3.0 *equiv*	TMSOTf (0.01 equiv), Et_2O, −30 °C	11:0	95

4. Conclusion

The purpose of this research is to identify the morphology of corrosion rate in AA6061 DSFSW joints which includes temperature, weld defects (visual inspection and radiography test), microstructure, corrosion rate and morphology of the corroded surface. The temperature analysis results show that the Advancing Side (AS) has a higher temperature than the Retreating Side (RS), due to friction between the tool and specimen accompanied by differences in welding direction. Visual inspection shows that all specimens and welding positions produce flash that is quite rough on the top (1G) and bottom (4G) surfaces and radiographic test results show the presence of Incomplete Fusion (IF) in 4 specimens. Microstructure shows a change in shape and size, leading in crystallization as finer particles. There is a difference in corrosion rate values after being investigated from NOVA Software and Faraday's Law. The result difference is impacted by high tool speed, which causes greater heat during in the weld metal and has an impact on SEM testing. The SEM test results show that the type of corrosion that occurs in DSFSW joints is pitting corrosion.

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