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Evaluation of Tensile Strength of Dissimilar Metals SS 316-pure Zn Joining by Friction Welding Method

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Welding of dissimilar metals has always been a challenge in industrial applications. In this study, the joining of SS 316 and 99.9% pure zinc by continuous drive friction welding has been carried out. The welding process is carried out with parameters such as rotation speed, friction pressure, forging pressure, and burn length being kept constant for all weld joint samples. This friction time is selected through the process parameter approach carried out on aluminium alloy material. The experimental results were analysed by tensile test and microstructure using a scanning electron microscope (SEM) to characterise the microstructure. Tensile test results from friction welding with variations in friction time from 30 to 80 seconds obtained a higher tensile strength of the joint in the 30 to 50 seconds friction time range. In this experiment, the maximum joint tensile strength is obtained at 53.93 MPa, and the maximum modulus elasticity of 128.60 GPa at 35 seconds of friction. Solid-state welding makes it possible to join SS 316 and pure zinc, which is difficult to join in conventional fusion welding methods.

Keywords: friction welding; welding parameters; tensile strength; stainless steel; pure zinc; semi-biodegradable

I. INTRODUCTION

Diverse industries, including piping, electronics, chemical engineering (PratyushaRamana & Prasanthi, 2021), and healthcare (Nasution *et al.*, 2022) have expanded their use of varied metal joints. The substantial variations in the physical, mechanical, and metallurgical properties of the two base metals contribute to the difficulty of connecting dissimilar metals using friction welding (Nasution *et al.*, 2019). Moreover, issues include the joining of two metals with a substantial variation in melting temperature (Nasution *et al.*, 2019), porosity, and the development of brittle intermetallic compounds at the weld interface (Chaudhari, 2014). Considering the foregoing challenges, friction welding is a good process contender. The friction welding process is classified as a solid-state welding process by the American Welding Society (AWS) (Elmer & Kautz, 1993). According to Ananda Rao and Ramanaiah, friction welding is a procedure that has minimal impact on the heat-affected zone since the heat generated by friction is below the melting temperature of the base metals (Ananda Rao & Ramanaiah, 2019). Other benefits of friction welding include minimal heat input, a small heat-affected zone (HAZ), and low residual stresses and distortions (Rafi *et al.*, 2010; Nasution *et al.*, 2015).

In this process, the weld is created by friction between two solid materials, which generates heat. The heat input during friction welding is determined by the welding conditions and material qualities (Dey *et al.*, 2009; Winiczenko & Kaczorowski, 2013). In direct drive friction welding, the primary parameters are friction pressure, forging pressure, friction time, forging time, and spindle rotational speed (Dey

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et al., 2009; ÖzdemirSarsılmaz & Hasçalık, 2007; Özdemir, 2005). Most investigations on friction welding have focused on microstructure characterisation, microhardness fluctuation, production of interfacial phases, and evaluation of mechanical properties in relation to optimal welding parameters (SatyanarayanaMadhusudhan Reddy & Mohandas, 2005; SathiyaAravindan & Noorul Haq, 2005; Sahin, 2007; Ananthapadmanaban *et al.*, 2009).

Various forms of friction welding have been developed, including continuous or direct drive friction welding (Nasution *et al.*, 2022; Li *et al.*, 2016), inertia-friction welding (Tiley *et al.*, 2016; Guo *et al.*, 2017), linear friction welding (Mogami *et al.*, 2018; Matsuda *et al.*, 2019), and orbital friction welding (Raab *et al.*, 2015). In the test of current research, distinct benefits and drawbacks of these methods were identified and analysed. Among these, rotary friction welding (RFW) and linear friction welding (LFW), often referred to as continuous or direct drive friction welding, stand out as two prominent friction welding processes.

This technique has been successfully applied to various similar and dissimilar material combinations. These combinations include aluminium and magnesium alloy (Guo *et al.*, 2017), pure aluminium and copper (PratyushaRamana & Prasanthi, 2021), various dissimilar steel alloys, superalloy-steel composites, steel-aluminum composites (BasmaciFiliz & Şahin, 2020), tungsten-mild steel pairings (Skowrońska *et al.*, 2022), as well as tungsten and aluminium alloy composites (Winiczenko *et al.*, 2017), and even more complex combinations, such as aluminium-titanium (Anant Sagar *et al.*, 2022), and magnesium alloy and stainless steel (Nasution *et al.*, 2019). Employing friction welding for joining these materials has led to varying degrees of success and advantages.

Furthermore, zinc is a relatively reactive metal with stable compounds. Its discovery came considerably later compared to other less reactive metals like gold, copper, iron, silver, and lead. Interestingly, zinc does not occur naturally. While it is generally considered a relatively soft metal, through alloying with stronger materials and specific treatments, its impact strength can be enhanced. Zinc alloys have found utility in diverse applications. The suitability of zinc also determines its viability for automotive, medical, and construction applications. The establishment of production processes for zinc-based materials, including joining methods, remains a significant consideration in developing products and components. Not many researchers have conducted studies on the characteristics of SS316 and pure Zinc joints, including those carried out by the authors (Dahlan *et al.*, 2023).

Therefore, this study aims to fabricate SS 316 friction-welded joints with pure zinc and then evaluate their tensile strength. The SS 316 is A popular grade of stainless steel is stainless steel 316 is generally composed of 16 to 18% chromium, 10 to 14% nickel, 2 to 3% molybdenum, and a small percentage of carbon, and pure zinc is about 99.9% of zinc. A friction welding machine with a continuous drive is applied in the experiment.

II. EXPERIMENTAL PROCEDURE

In this investigation, a friction welding machine with a continuous drive a rotating speed of 1450 rpm, and a hydraulic pressure of 25 MPa was utilised (Figure 1). With a length of 60 mm and a diameter of 10 mm, respectively, SS 316 stainless steel and 99.9% pure zinc were employed as the basic materials. Samples were polished with #1000-grit abrasive paper and cleaned with ethanol for a smoother surface finish. Several parameters in friction welding are friction time, friction pressure, forging time, forging pressure, burn-off, and rotational speed (Dey *et al.*, 2009; ÖzdemirSarsılmaz & Hasçalık, 2007; Özdemir, 2005). While friction time is examined in this work, rotation speeds, friction pressure, and forging pressure are fixed parameters. The tensile strength of the samples was determined by a test conducted in accordance with ASTM E8 (ASTME8, 2016) using a universal testing machine (WDW-100E, China) with a 1.5 kN/min loading rate. SEM analysis of tensile test fractures (SEM, Hitachi S-3400N, Japan).

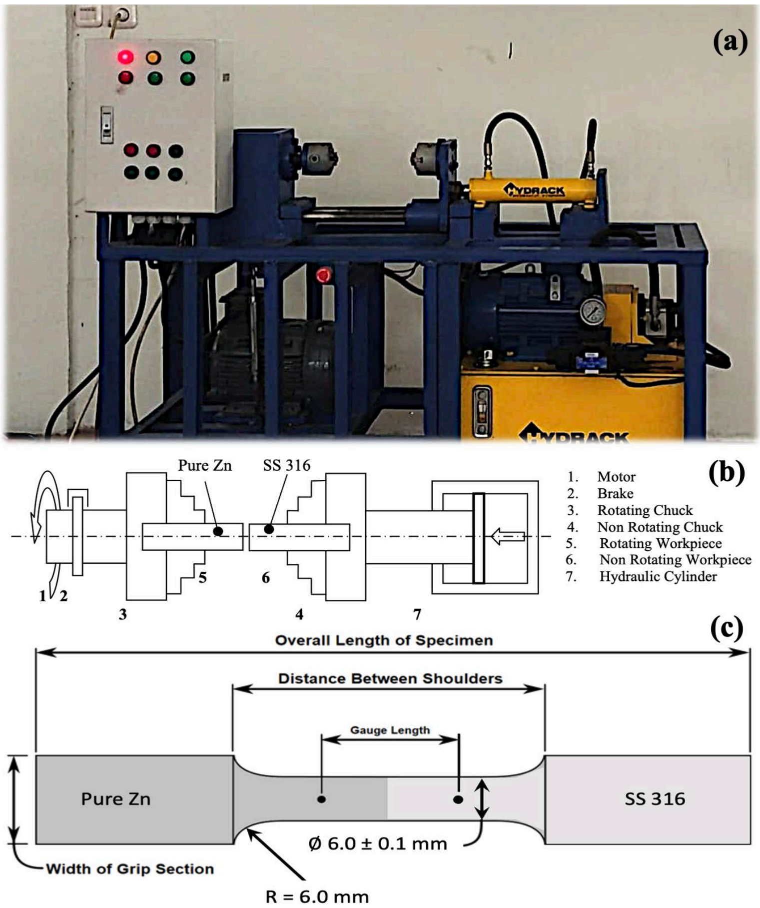

Figure 1. (a) Continuous drive friction welding machine, (b) schematic diagram for friction welding (c) the geometric of the tensile test specimen

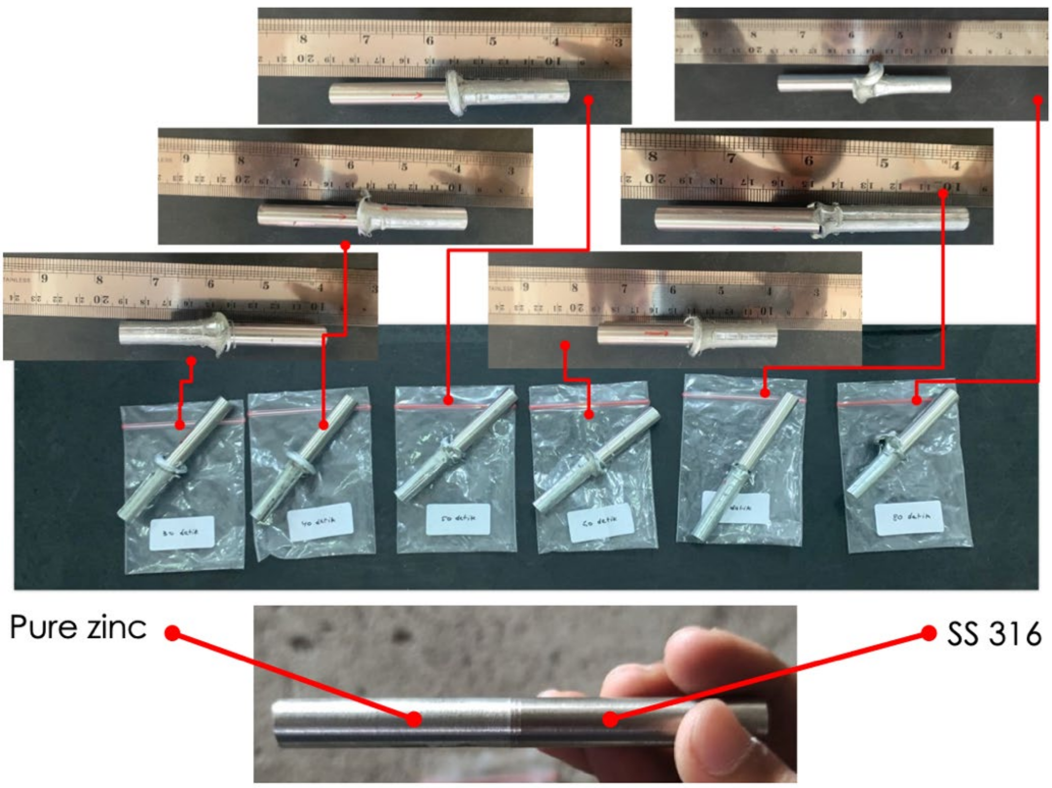

Figure 2. Dissimilar metal welded joints with friction time of 30 to 80 seconds

III. RESULT AND DISCUSSION

Table 1 includes the welding parameters for experiments one through six, including friction time, friction pressure, forging pressure, and rotating speed, for SS 316 stainless steel and pure zinc. Figure 2 depicts the outcomes of friction welding joints with friction periods of 30, 40, 50, 60, 70, and 80 seconds.

Longer friction times lead to deteriorating joints. Considering the findings of the friction welding connection between SS 316 and pure zinc, a second experiment was conducted by reducing the friction time to between 35 and 45 seconds. By decreasing the friction period during friction welding, the tensile strength of the joint will increase from 44.59 MPa to 53.93 MPa. With a friction duration of 35 seconds and a tensile strength of 53.93 MPa, the material is advantageous (Figure 3a). In addition to the parent material, welding was performed on pure Zn - pure Zn and SS 316 - SS 316 materials as a comparison. Figure 3b depicts the results of each material's tensile strength. Figure 3b demonstrates that the friction welding settings for one material cannot be applied to other materials. In comparison to the tensile strength of the basic metals, the tensile strength of pure Zn vs. pure Zn and SS 316 versus SS 316 has decreased significantly.

Figure 4 shows the microstructure analysed at 100X magnification using an electron microscope. In the friction welding joint, a perfect bond between the base metal between SS 316 and pure zinc is formed with good strength for welding parameters with friction times of 35, 40 and 45 seconds. Observations were made on the tensile test results showed that there was a bond between the two parent materials using the welding parameters specified above. The same thing also happened to the results of the friction welded joint between AZ31-SS316L in previous research, where in that research there was no diffusion between the base metals (Nasution *et al.*, 2019). Acceleration of diffusion, according to Çelikyürek *et al.* (2011), depends on the increase in temperature, friction time, and pressure (ÇelikyürekTorun & Baksan, 2011). Optimal welding parameters, according to Meshram *et al.* (2007) and Fukumoto *et al.* (2009) provides adequate heating and forging pressure and can prevent the formation of oxides at the weld interface. For further experimental steps so that oxidation does not occur, it can be done through the preheating process and post-weld heat treatment (PWHT) so that the diffusion process occurs.

Table 1. The friction welding parameters

First try

Specimens	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**	**Trial 6**
Friction Time	30 Sec.	40 Sec.	50 Sec.	60 Sec.	70 Sec.	80 Sec.
Friction Pressure	3.9 MPa	3.9 MPa	3.9 MPa	3.9 MPa	3.9 MPa	3.9 MPa
Forging Pressure	6.9 MPa	6.9 MPa	6.9 MPa	6.9 MPa	6.9 MPa	6.9 MPa
Rotation Speed	1450 RPM	1450 RPM	1450 RPM	1450 RPM	1450 RPM	1450 RPM
Tensile Strength	not joined	47.22 MPa	not joined	not joined	not joined	not joined

Second try

Specimens	**Trial 1**	**Trial 2**	**Trial 3**	**Zn-Zn**	**SS 316-SS 316**
Friction Time	35 Sec.	40 Sec.	45 Sec.	35 Sec.	35 Sec.
Friction Pressure	3.9 MPa	3.9 MPa	3.9 MPa	3.9 MPa	3.9 MPa
Forging Pressure	6.9 MPa	6.9 MPa	6.9 MPa	6.9 MPa	6.9 MPa
Rotation Speed	1450 RPM	1450 RPM	1450 RPM	1450 RPM	1450 RPM
Tensile Strength	53.93 MPa	47.22 MPa	44.59 MPa	19.62 MPa	545.90 MPa

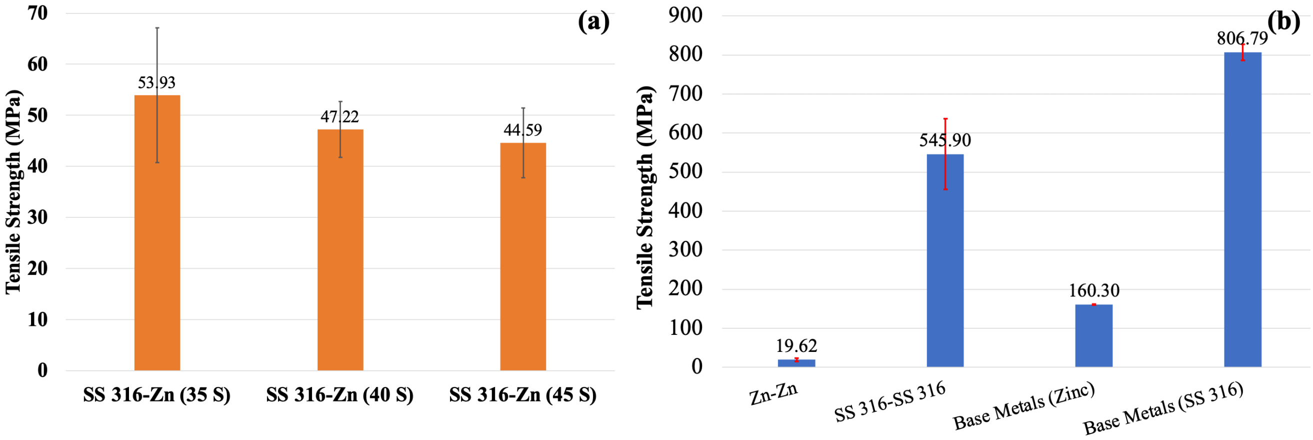

Figure 3. The results of the tensile strength of the material (a) the tensile strength of the joint for friction time of 35, 40, and 45 seconds (b) the tensile strength of the weld joint and the base metals

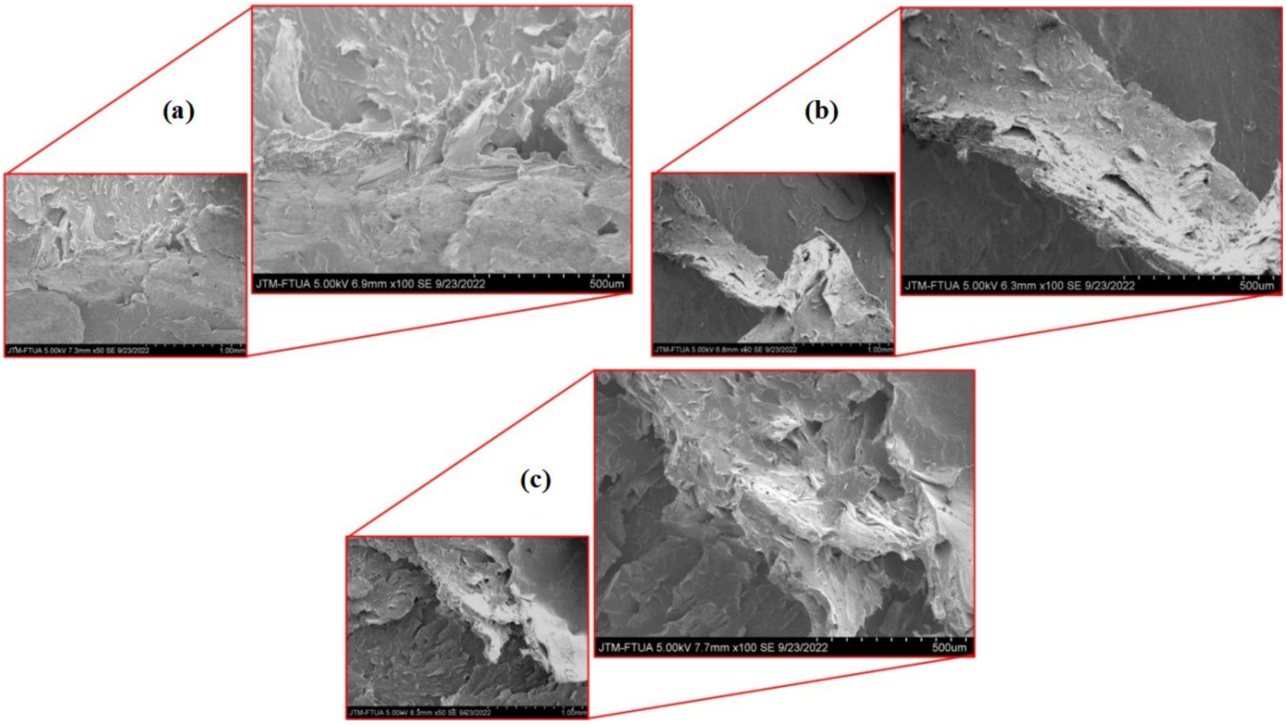

Figure 4. The fracture surface of the tensile test results (a) a friction time of 35 seconds (b) a friction time of 40 seconds and (c) a friction time of 45 seconds

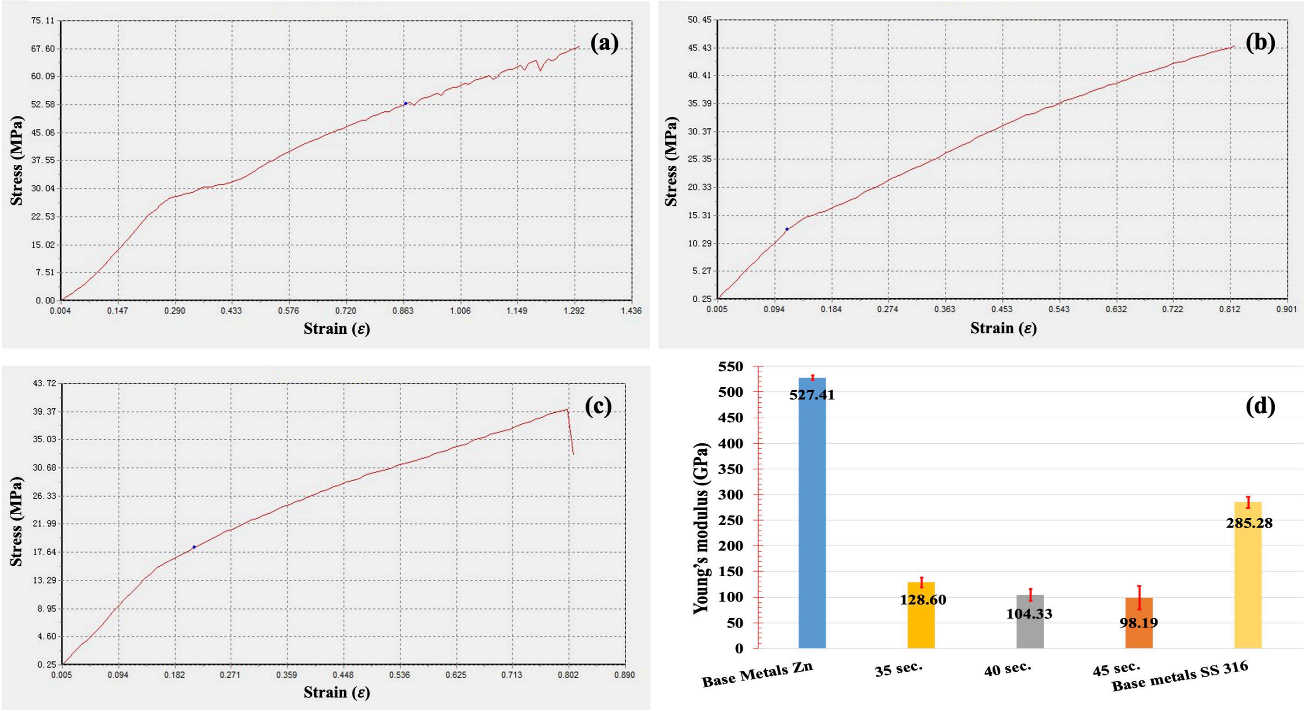

Figure 5. (a-c) Tensile test graphs for friction times of 35, 40, and 45 seconds. (d) Modulus of elasticity of all friction welds and base metals

The graph in Figure 5(a-c) depicts the tensile test (stress-strain) for welding parameters with friction periods of 35, 40, and 45 seconds. Figure 5(d) compares Young's modulus or modulus of Elasticity (E) of all friction welds to that of the base metal (SS 316 and pure zinc). The data from the graph of the tensile test indicate that the modulus of elasticity of all materials is extremely high for the base metal, namely 527.41±5.09 GPa and 285.28±11.11 GPa. The modulus of elasticity of welding with friction times of 35, 40, and 45 seconds is 128.60±9.41 GPa, 104.33±11.41 GPa, and 98.19±22.80 GPa, respectively.

The modulus of elasticity of the friction welding results for different materials between SS 316 and pure zinc is still quite high if the material is to be used as an implant in the healthcare industry. Comparatively, the modulus of elasticity for cancellous and cortical bone ranges between 10 and 20 GPa (RhoAshman & Turner, 1993). If the difference between the metallic prosthesis and bone is large enough, it will result in the stress-shielding effect (Brizuela *et al.*, 2019). In other words, when a load is applied, the metallic prosthesis (with the highest modulus of elasticity) will absorb the load, inhibiting bone regeneration and increasing bone resorption (Sumner *et al.*, 1998; Geetha *et al.*, 2009).

IV. CONCLUSION

Successful friction welding between SS 316 and pure zinc was achieved. In this work, the highest tensile strength is achieved by shortening the friction time of the welding parameters. This paper also shows the high Modulus of Elasticity (E) of friction welding SS 316 with pure zinc joints. The higher the elastic modulus value of the material, the smaller the elastic strain that occurs or the stiffer the material. Using heat treatment processes such as preheating or post-weld heat treatment (PWHT) and vacuum processes, additional research can be conducted on welding SS 316 and pure zinc.

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