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ARTICLE

The Influence of Friction Time on the Joint Interface and Mechanical Properties in Dissimilar Friction Welds

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ABSTRACT

The welding of dissimilar materials is one of the challenging issues in the fabrication industry to obtain required quality welds using fusion welding methods. However, some processes recently improved interface bonding with low joint strength. Unfortunately, the major intermetallic compounds could not alleviate from the joint interface. Alternatively, solid-state welding methods revealed fewer intermetallics at the joint interface for dissimilar material welds. Among them, friction welding was chosen to join incompatible materials with the necessary properties successfully. Friction time is a critical parameter for obtaining strong welds through friction welding, apart from friction pressure, forging pressure, forging time, and rotational speed. Variability of friction time can change the strength of friction by changing mechanical properties such as tensile strength. This change of tensile strength is typically influenced by the intermixing region, dependent on friction time. In this experiment, carbon steel and stainless steel have been friction welded to test the impact of friction time on the joint interface where the substrate's faying surface meets. This interface consists of the intermixing region of the two materials on which the friction welding is performed. The results showed an interesting variation in tensile strength, with varying friction time. The width of the intermixing zone increased gradually with friction time until and decreased with the further increasing. The strength of the welds obtained was the highest of 730 MPa at a friction time of 4 s and fell as friction time's increased value after 4 s.

1. Introduction

Though heat generated during the relative movement of two parts is considered undesirable because of the wear it could cause, it is sometimes used for other applications such as friction welding. Friction welding is a popular welding method for dissimilar metals because of several advantages the welding method offers. Friction welding

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is one of the solid-state welding processes like diffusion bonding, friction stir welding, etc. Solid-state welding processes are quite different from the fusion welding methods to produce the joints with quality. The quality of the joints is likely to depend on the heat input or the temperature of the welds. The joint temperature of the friction welding method is much lower than the other welding processes [1-4]. Therefore, the quality of the welds is uttermost for any kind of materials to be joined. The joining of a similar combination of materials revealed successful metallurgical bonding without defects. Similarly, dissimilar combinations materials were obtained with excellent joint properties [5-8]. Due to the increase in demand for joining dissimilar material combinations in applications such as cryogenic fluids, power generation industries, and reactor cooling systems, solid-state welding is most suitable in the current scenario [9-14]. Friction welding happens due to the heat produced by friction during the movement of two parts. Friction welding (FW) is a class of solid-state welding process that generates heat through mechanical friction between a moving workpiece and a stationary component, with the addition of a lateral force called upset to plastically displace and fuse the materials [15-18]. Because of the nature of the process of welding, the strength of friction welding could vary on different factors. Some of the factors that need to be optimized for efficient frictional welding are friction pressure, friction time, rotational speed, forging pressure, forging time, and burn-off length [19-22].

In addition, some of the studies were identified the relation between metallurgical properties and the mechanical properties of the similar and dissimilar combination of friction welds [23]. It is important to note that the interface of the two joining materials, which is referred to as the intermixing region has an impact on the mechanical properties of the weld. The bonding line and intermixing zones play an important role in the mechanical properties of the joints [24]. Moreover, the welding parameters influence the formation of the weld interface with the necessary strength to attain excellent mechanical properties [25]. Some of the studies reported that the axial shortening of the materials at the interface is affected by the welding conditions [26]. Based on the axial shortening, the joint interface is varied with the presence of intermixing zone. In this experiment, we aim to find how the intermixing region is affected by the various factors involved in friction welding, and specifically, we consider the effect of friction time and how the tensile strength of this weld joint is affected by changing the friction time. It was also reported by some studies on the impact of friction time on the properties of friction welded YSZ-alumina composite and 6061 aluminum alloy, they found that the experimental results showed that the friction time has a significant effect on the joint structure and mechanical properties [27]. In particular, the effect of burn-off length reported being changed the intermixing zone along with axial shortening. A large number of axial shortening joints were revealed with the hardened intermixing zone over the less axial shortening joints [28]. There are some incompatible dissimilar combinations that are unable to join them using fusion welding methods. Unfortunately, the same combination of materials was also not successful to obtain strong joint strength using friction welding [29]. However, the incompatible materials were joined using interlayer techniques inserting them in between the two substrates. For example, the joining of titanium to stainless steel was resulted in brittle joint failure due to the formation of brittle intermetallic layers. Therefore, Ni, V, Ta, Al, and Cu interlayers were used to avoid direct contact between the two materials [30]. Whatever, the joint method either with interlayers or without interlayers, the effect of friction time remains valid to obtain the excellent joint interface to control the joint strength.

Similarly, the studies on the friction welding of AISI 304 and the effect of friction time on microstructure, microhardness, and tension-compression properties were found that with increasing friction time, a hard zone was found at the interface of the welded joint because of extended high plastic deformation zone [31]. Also, in an experiment conducted by Hakan Ates and Nihat Kaya on the effect of friction time on microstructure and mechanical properties of friction welded AISI 304 stainless steel to AISI 1060 steel, the experiment revealed that the tensile strength of friction-welded joints was not affected by friction time. The tensile strength of obtained weld joints can exceed AISI 304SS strength by 30% [32]. Moreover, in an experiment conducted by Ozdemir et al., on the effect of rotational speed on the interface properties of friction-welded AISI 304L to 4340 steel, it was found that the thickness of full plastic deformed zone (FPDZ) formed at the interface was reduced as a result of more mas discarded from the welding interface with the increase of rotational speed [33].

The aim of this study is to investigate the influence of friction time on the dissimilar materials of stainless steel to carbon steel friction weld's tensile strength. The correlation between metallurgical and mechanical properties was also determined and analyzed with the friction time to obtain the required joint strength.

2. Experimental Procedure

In this study, austenitic stainless steel and carbon steel materials with the dimensions of 14 mm in diameter and 120 mm in length rods were used. The faying surfaces of the substrates were machined and cleaned before performing the welds. The weld surfaces were polished to get the required surface roughness, which has a more significant effect on the enhancement of joint strength. A continuous drive friction welding machine with a capacity of 200 kN of ETA make was used to make the friction welds. The process parameters have a more significant effect in the friction welding process to obtain the sound welds between dissimilar materials. The process parameters such as friction time, friction pressure, upset force, upset time, and rotational speed have a direct relation to the formation of joint and on its strength. To achieve the higher tensile strength of the welds, a new set of welding parameters were intended after the several experimental trails of the welds with varying the friction time from 1 s to 6 s, and other parameters were kept as constant with a friction pressure of 110 MPa, upset pressure of 240 MPa, upset time of 5 s and the rotational speed of 1500 rpm. Friction welded joints were cut into cross sections for metallographic sample preparations. To evaluate the mechanical properties of the joints, tensile and fatigue test samples were prepared as per the ASTM E8 standard. The tensile tests were performed on the universal testing machine of the TFUC-400 model. The joint interface microstructural observations were characterized by an optical microscope, scanning electron microscope (SEM). To reveal the microstructural features of the welds, polished surfaces were etched with 2% nital solution on the carbon steel side and an aqua-regia solution on the stainless steel side was used.

3. Results and Discussion

Dissimilar materials of austenitic stainless steel to carbon steel have joined using friction welding by varying friction time. Friction time is a significant parameter for generating the required heat to weld the materials. The selected materials in this study are almost hard and need to produce sufficient heat at the interface to obtain the necessary joint properties. It has been identified from the experimental results that friction time is a dominant parameter compared to others for this combination of materials. The impact of friction time on the weld interface and weld flash are also determined. Figure 1 illustrates the macrostructure of the friction welded joint with an interface and weld flash. The weld flash on the carbon steel side is higher than the stainless steel. It is due to that the yield strength of the carbon steel is much lower than the stainless steel that too at high temperature, it is much lower than the room temperature. Therefore, the deformed weld flash on carbon steel is more extensive than stainless steel. In addition, the weld interface is slightly irregular on the carbon steel side with deformed notches. The detailed observations of the weld interface have been examined in microstructures. Figure 2 indicated the formation of intermixing zone in with the carbon steel bands at different friction times. The dark-colored islands in the stainless steel matrix belong to the carbon steel, which is mixed during welding. The width of the intermixing zone was occupied with the more prominent bands of carbon steel. It is owing to the interchanging of softened metal at the interface during friction time with the rubbing action of faying surfaces. Figure 2b confirms that the weld interface is strongly bonded metallurgically without defects. It is worth mentioning the effect of friction time on the weld interface. In Figure 2, it is clearly indicated that the increase of intermixing zone as increasing friction time. In general, the weld interface examines to conform to the interface bonding and other defects caused by insufficient heat and pressure. The quantitative analysis of the intermixing zone between carbon steel and stainless steel has been determined according to the friction time depicted in Figure 3. It revealed that the remarkable trend between friction time and intermixing zone with the polynomial fitted curve R^2 is 0.99. The width of the intermixed zone increases with the increasing friction time. The effect of friction time until 4 s is not dominant to produce a broad intermixing region.

In contrast, the intermixing zone increased drastically with increasing friction time by more than 4 s. In addition, the weld interface becomes asymmetrical if the friction time raises further to 7 s. Therefore, the maximum friction time of 6 s was used for the selected dissimilar combination of materials. Intermixing zone consisting of hard and soft layers which belong to stainless steel and carbon steel, respectively. During friction welding, due to the action of angular velocity, the softened material from the carbon steel tries to go away from the center to the periphery of the joint. At this instance, some of the material remains in the central region and is mixed with the opposite matrix. Therefore, the intermixing region is directly related to the friction time up to some level and it also depends on the certain combination of materials.

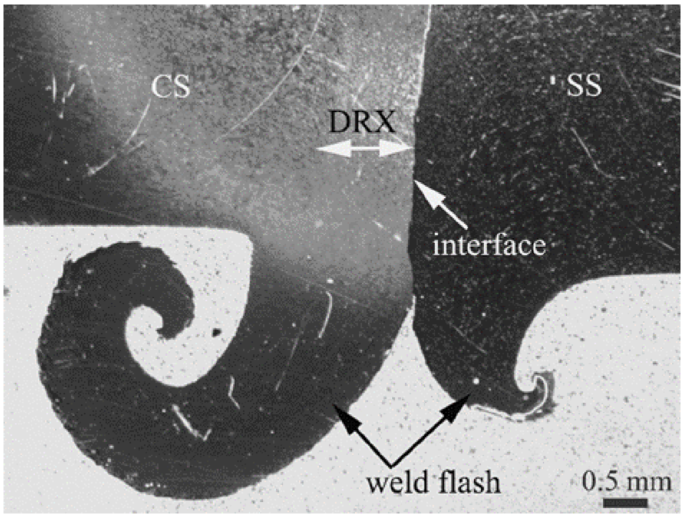

Figure 1. Macrostructure of the dissimilar friction welds with different amounts of weld flash.

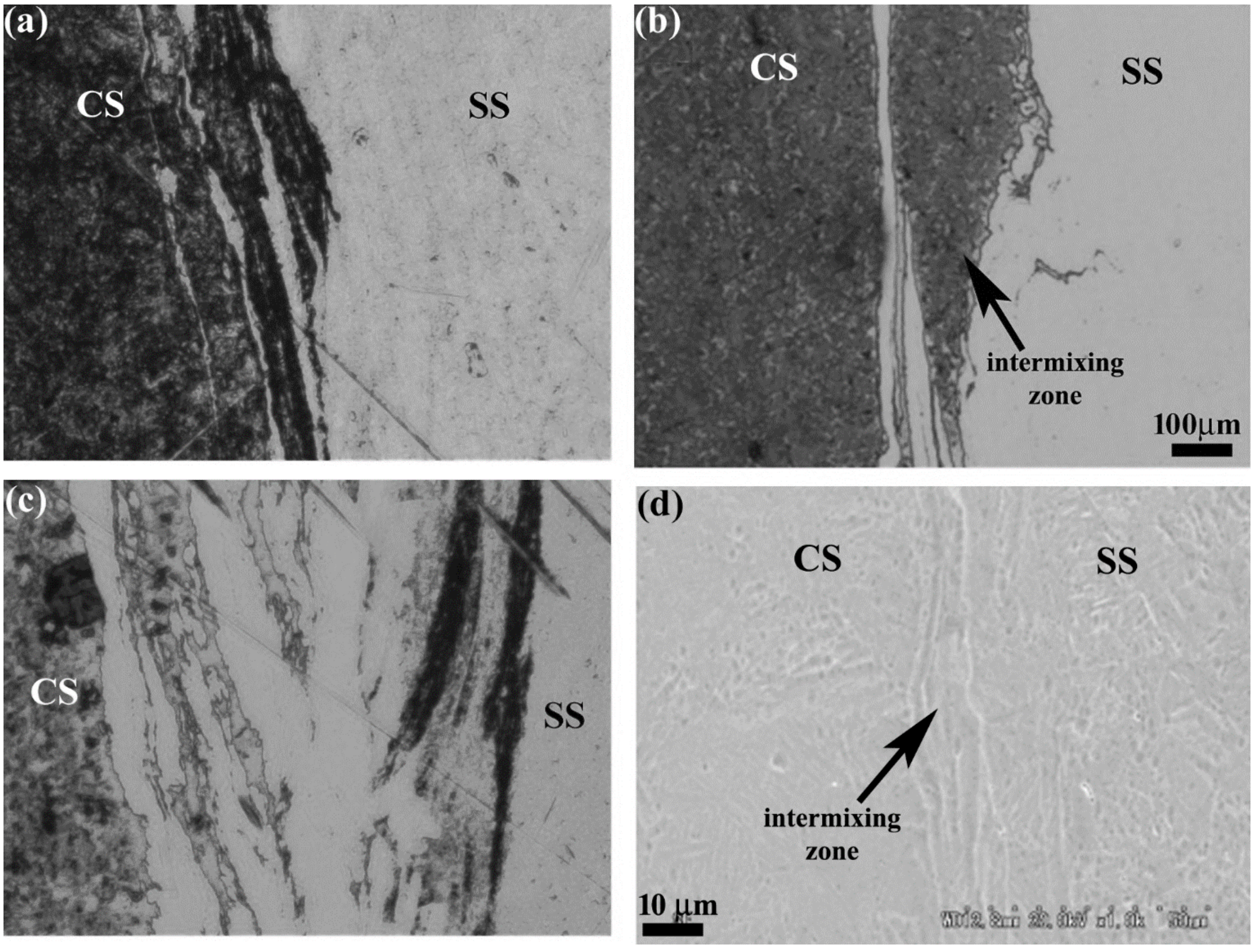

Figure 2. Microstructures show the weld interface with intermixing zone at friction time of (a) 1 s, (b) 3 s (c) 6 s, and (d) enlarged view of (b).

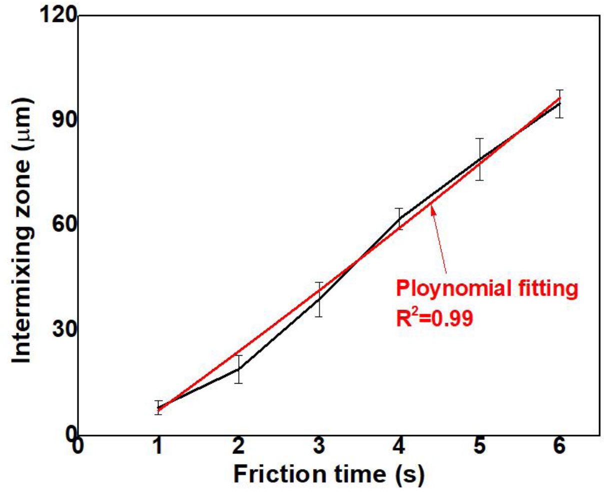

Figure 3. The relation between friction time and intermixing zone with the polynomial fitting curve.

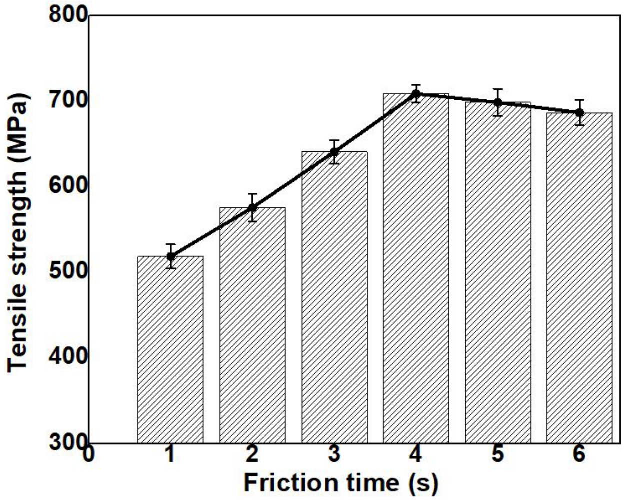

Figure 4. The effect of friction time on the tensile strength of the dissimilar friction welds

It is essential to analyze the intermixing zone and its characteristics with the mechanical properties of the welds. As mentioned earlier, the microhardness tests confirmed that the hard and soft later in the intermixing regions. But the mechanical properties dramatically depend on the width of intermixing zone. Figure 4 represents the joint tensile strength according to the friction time. The strength of the welds increases gradually with the increase of friction time until 4 s, while the strength of the welds decreases with the further increase of friction time. In the correlation study between the intermixing zone and the tensile strength concerning friction time, the maximum tensile strength was obtained at a width of the intermixing zone is about 65 μm. Figure 5 illustrates the fracture morphology of the tensile fractured surfaces with the ductile mode of fracture. The fracture surfaces confirmed that the welds were free from the cracks.

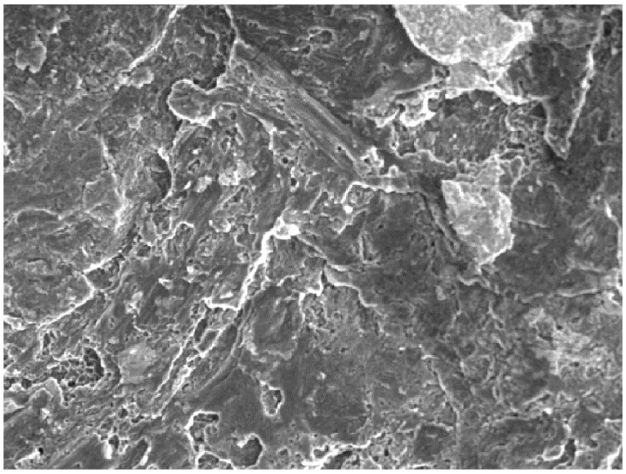

Figure 5. SEM analysis of the tensile fracture surface with ductile mode of failure.

4. Conclusions

The dissimilar materials of stainless steel to carbon steel have been friction welded to study the effect of friction time on the tensile strength of the welds. Based on the presented results, the following conclusions are drawn:

- The range of friction time from 1 s to 6 s was determined as suitable for the friction welding of carbon steel to stainless steel welds.
- The width of the intermixing zone increased gradually with friction time along with the axial shortening.
- The strength of the welds obtained was the highest of 730 MPa at a friction time of 4 s. The further increase of friction time after 4 s resulted in decreasing in joint strength.
- As a result of friction time the maximum tensile strength was obtained at a width of the intermixing zone is about 65 μm.
- The softened carbon steel materials diffused toward the stainless steel within the intermixed zone during the friction stage.

References

[1] Shanjeevi, C., Arputhabalan, J.J., Dutta, R., 2017. Investigation on the Effect of Friction Welding Parameters on Impact Strength in Dissimilar Joints. IOP Conference Series: Materials Science and Engineering. 197(1), 012069.

[2] Cheepu, M., Susila, P., 2020. Interface microstructure characteristics of friction-welded joint of titanium to stainless steel with interlayer. Transactions of the Indian Institute of Metals. 73(6), 1497-1501.

[3] Cheepu, M., Che, W.S., 2020. Influence of friction pressure on microstructure and joining phenomena of dissimilar joints. Transactions of the Indian Institute of Metals. 73(6), 1455-1460.

[4] Cheepu, M., Che, W.S., 2019. Friction welding of titanium to stainless steel using Al interlayer. Transactions of the Indian Institute of Metals. 72(6), 1563-1568.

[5] Kong, Y.S., Cheepu, M., Park, Y.W., 2020. Effect of heating time on thermomechanical behavior of friction-welded A105 bar to A312 pipe joints. Transactions of the Indian Institute of Metals. 73(6), 1433-1438.

[6] Muralimohan, C.H., Muthupandi, V., Sivaprasad, K., 2014. Properties of friction welding titanium-stainless steel joints with a nickel interlayer. Procedia Materials Science. 5, 1120-1129.

[7] Yoon, J.Y., Cheon, J., Kim, C., 2019. Characteristic Evaluation of Coaxial High-Frequency Induction Heating Hybrid Friction Stir Welding Process on High Strength Carbon Steel Sheets. Journal of Welding and Joining. 37(6), 585-590.

[8] Cheepu, M., Venkateswarlu, D., Rao, P.N., Muthupandi, V., Sivaprasad, K., Che, W.S., 2019. Microstructure characterization of superalloy 718 during dissimilar rotary friction welding. Materials Science Forum. 969, 211-217.

[9] Cheepu, M., Che, W.S., 2019. Effect of burn-off length on the properties of friction welded dissimilar steel bars. Journal of Welding and Joining. 37(1), 40-45.

[10] Cheepu, M., Muthupandi, V., Che, W.S., 2018. Improving mechanical properties of dissimilar material friction welds. Applied Mechanics and Materials. 877, 157-162.

[11] Muralimohan, C.H., Muthupandi, V., Sivaprasad, K., 2014. The influence of aluminium intermediate layer in dissimilar friction welds. International Journal of Materials Research. 105(4), 350-357.

[12] Cheepu, M., Muthupandi, V., Loganathan, S., 2012. Friction welding of titanium to 304 stainless steel with electroplated nickel interlayer. Materials Science Forum. 710, 620-625.

[13] Chandra, G.R., Venukumar, S., Cheepu, M., 2020, December. Influence of rotational speed on the dissimilar friction welding of heat-treated aluminum alloys. IOP Conference Series: Materials Science and Engineering. 998(1), 012070.

[14] Cheepu, M., Ashfaq, M., Muthupandi, V., 2017. A new approach for using interlayer and analysis of the friction welding of titanium to stainless steel. Transactions of the Indian Institute of Metals. 70(10), 2591-2600.

[15] Muralimohan, C.H., Ashfaq, M., Ashiri, R., Muthupandi, V., Sivaprasad, K., 2016. Analysis and characterization of the role of Ni interlayer in the friction welding of titanium and 304 austenitic stainless steel. Metallurgical and Materials Transactions A. 47(1), 347-359.

[16] Cheepu, M., Muthupandi, V., 2013. Friction welding of type 304 stainless steel to CP titanium using nickel interlayer. Advanced Materials Research. 794, 351-357.

[17] James, J.A., Sudhish, R., 2016. Study on effect of interlayer in friction welding for dissimilar steels: SS 304 and AISI 1040. Procedia Technology. 25, 1191-1198.

[18] Muralimohan, C.H., Haribabu, S., Reddy, Y.H., Muthupandi, V., Sivaprasad, K., 2014. Evaluation of microstructures and mechanical properties of dissimilar materials by friction welding. Procedia Materials Science. 5, 1107-1113.

[19] Cheepu, M., Che, W.S., 2019. Characterization of microstructure and interface reactions in friction welded bimetallic joints of titanium to 304 stainless steel using nickel interlayer. Transactions of the Indian Institute of Metals. 72(6), 1597-1601.

[20] Cheepu, M., Che, W.S., 2020. Characterization of interfacial microstructure in friction welds between Inconel 718 and SM45C steel. Transactions of the Indian Institute of Metals. 73(6), 1597-1571.

[21] Kong, Y.S., Park, Y.W., 2019. Optimization of PWHT on Dissimilar Friction Welding for Piping Material of A105 to A312. Journal of Welding and Joining. 37(2), 60-65.

[22] Aali, M., 2020. Investigation of Spindle Rotation Rate Effects on the Mechanical Behavior of Friction Stir Welded Ti 4Al 2V Alloy. Journal of Welding and Joining. 38(1), 81-91.

[23] Muhammad, W., Husain, W., Tauqir, A., Wadood, A., 2020. Optimization of Friction Stir Welding Parameters of AA2014-T6 Alloy using Taguchi Statistical Approach. Journal of Welding and Joining. 38(5), 494.

[24] Kim, J.H., Kim, N.Y., Kong, Y.S., Park, N.K., 2019. Microstructure and Mechanical Properties of Friction-Welded Alloy 718 and SNCRW Stainless Steel after Post-Weld Heat-Treatment. Journal of Welding and Joining. 37(4), 313-317.

[25] Kong, Y.S., Cheepu, M., Lee, J.K., 2021. Evaluation of the mechanical properties of Inconel 718 to SCM 440 dissimilar friction welding through real-time

monitoring of the acoustic emission system. Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications. pp.1464420721993838.

[26] Cheepu, M., Kumar Reddy, Y.A., Indumathi, S., Venkateswarlu, D., 2021. Laser welding of dissimilar alloys between high tensile steel and Inconel alloy for high temperature applications. Advances in Materials and Processing Technologies. pp. 1-12.

[27] Nadikudi, B.K.B., 2019. Behaviour of friction stir dissimilar welded blanks and the role of different tool pin profiles. Journal of Metallic Material Research. 2(2), 15-19.

[28] Cheepu, M., Venkateswarlu, D., Rao, P.N., Kumaran, S.S., Srinivasan, N., 2019. Effect of process parameters and heat input on weld bead geometry of laser welded titanium Ti-6Al-4V alloy. Materials Science Forum. 969, 613-618.

[29] Kong, Y.S., Cheepu, M., Kim, D.G., 2020. Microstructure and Mechanical Properties of Friction-Welded and Post-Heat-Treated Inconel 718. Transactions of the Indian Institute of Metals. 73(6), 1449-1453.

[30] Cheepu, M., Susila, P., 2020. Growth rate of intermetallics in aluminum to copper dissimilar welding. Transactions of the Indian Institute of Metals. 73(6), 1509-1514.

[31] Cheepu, M., Muthupandi, V., Che, W.S., 2019. Interface microstructural characterization of titanium to stainless steel dissimilar friction welds. In TMS 2019 148th Annual Meeting & Exhibition Supplemental Proceedings. Springer, Cham., pp. 259-268.

[32] Muralimohan, C.H., Haribabu, S., Reddy, Y.H., Muthupandi, V., Sivaprasad, K., 2015. Joining of AISI 1040 steel to 6082-T6 aluminium alloy by friction welding. Journal of Advances in Mechanical Engineering and Science. 1(1), 57-64.

[33] Jabbar Hassan, A., Boukharouba, T., Miroud, D., 2020. Friction welding of AISI 304: effect of friction time on micro-structure, micro-hardness and tension-compression properties. Acta Metallurgica Slovaca. 26(3), 78-83.