G-Tech : Jurnal Teknologi Terapan
Vol. 8, No. 1, Januari 2024, hlmn. 226-236
E-ISSN: 2623-064X | P-ISSN: 2580-8737

The Influence of Tool Rotational Speed on Mechanical Properties of Friction Stir Welded Dissimilar AA5083-H112/AA6061-T6 Joints

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Informasi Artikel

Riwayat Artikel

Diserahkan : 06-12-2023
Direvisi : 14-12-2023
Diterima : 19-12-2023

Kata Kunci:

Kekuatan; Logam Tak Sejenis; Pengelasan.

Keywords **:**

Strength, Dissimilar Metals, Friction Stir Welding.

ABSTRAK

Teknik pengelasan yang relatif baru dan inovatif yang dikenal sebagai *friction stir welding* (FSW) telah diaplikasikan di industri otomotif, kereta api, dan pesawat terbang pada sektor transportasi. Dengan pertimbangan teknik dan finansial, pengelasan logam yang berbeda sering dilakukan di industri tersebut. Selama proses FSW, tiga kecepatan putaran *tool* yang berbeda—910, 1500, dan 2280 rpm—digunakan, sedangkan kecepatan pengelasan dijaga konstan pada 30 mm/menit. Beberapa pengujian eksperimental, termasuk fraktografi, uji tarik, dan pengamatan struktur mikro, dilakukan setelah pengelasan. Hasil penelitian menunjukkan bahwa kekuatan maksimum (UTS) dan kekuatan luluh (YS) meningkat seiring dengan peningkatan kecepatan putaran *tool* dan UTS dan YS terbaik, sebesar 228 MPa dan 156 MPa diperoleh pada kecepatan 2280 rpm. Pengendapan presipitat AA6061-T6 di *stir zone* (SZ) dan peningkatan derajat pencampuran dikaitkan dengan peningkatan kekuatan las.

ABSTRACT

The relatively new and innovative welding technique known as friction stir welding (FSW) has found widespread application in the automotive, railway, and aircraft industries. Due to engineering and financial considerations, welding of dissimilar metals is frequently carried out in these industries. During the friction stir welding process, three tool rotational speeds—910, 1500, and 2280 rpm—were utilized, while the welding speed remained constant at 30 mm/min. Several experimental works, including fractography, tensile tests, and observations of the microstructure, were carried out following welding. Results showed that ultimate tensile strength (UTS) and yield strength (YS) expanded as the tool rotational speed was expanded and the best UTS and YS, typically 228 MPa and 156 MPa at the speed of 2280 rpm. The precipitation of AA6061-T6 in the stir zone (SZ) and the increased degree of mixing were linked to the improved weld strengths.

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INTRODUCTION

One of the non-ferrous metals that are lightweight and generally utilized is aluminum. There are aluminum and its alloys that can meet the need for a high strength-to-weight ratio and good resistance to corrosion (Wahid et al., 2020). However, aluminum alloys have various weldability and some of them, i.e., 2xxx and 7xxx series cannot be welded using conventional fusion welding processes due to solidification cracking. Friction Stir Welding (FSW), a type of solid-state welding, can solve this issue. Additionally, dissimilar metal welding can be accomplished with FSW. In ventures, welding of divergent metals is frequently led because of designing and financial contemplations.

The principal challenge in contact mix welding of disparate metals is the counteraction of arrangement of fragile intermetallic stages (Akin & Weldi, 2013). The fact that a small number of process parameters, like welding speed and tool rotational speed, can be controlled to improve weld properties gives FSW a distinct advantage over fusion welding processes (Cetkin et al., 2019; Devaiah et al., 2017; Venkat Ramana et al., 2021; Venkat Ramana & Sanke, 2019). Venkat Ramana & Sanke (2019) have concluded that tensile properties and hardness of dissimilar AA5082/AA6061 FSW joints were better compared to those of similar joints of AA6061 and the best quality of welded at welding speed which cause the proper mixing of material. In recent years, the applications of dissimilar metals between AA5xxx and AA6xxx especially for structures have considerably increased. It has been known that the weldability of the 5xxx series is better than that of the 6xxx series because the 6xxx series tends to suffer from hot cracks (Mandal, 2005). Heat treatable 6061 aluminum alloys and non-heat treatable 5083 aluminum alloys are important materials, especially for critical applications which require high strength and ductility and good toughness but unfortunately, joining of these dissimilar alloys sometimes finds difficulty by conventional welding processes. Therefore, in basic utilizations of aviation where special heat treatable alloys are used, FSW is the only choice suitable for such purpose (Devaiah et al., 2016).

Successful studies on dissimilar welding of AA6061 and AA7075 have been reported by Ravikumar et al. (2014) who showed that reducing heat input can increase the strength of the FSW welded joints, while the combination of low welding speed and high rotational speed can increase the degree of mixing. Selamat et al. (2016) suggested that different kinds of pins be used for the same welding parameters, like the speed of the welding, so that the strength of the welded joints can be compared. To improve the quality of welded joints, this study investigated the effect of tool rotational speed on the mechanical properties of dissimilar AA5083-H112/AA6061-T6 FSW joints. Subsequent to welding, a few exploratory works including microstructure perceptions, hardness estimations, elastic tests joined with fractography were led. The purpose of this study is to determine how the different mechanical properties of the AA5083-H112/AA6061-T6 FSW joints are affected by tool rotational speed.

RESEARCH METHOD

Materials

In this experiment, aluminum alloys AA5083-H112/AA6061-T6 were used. Their chemical compositions are shown in Table 1. The plates with aspects of 300 mm × 100 mm × 3 mm were welded along the plate length. The retreating and advancing sides were represented by the AA5083-112 and AA6061-T6 alloys, respectively.

Table 1. Chemical Composition of The Alloys (wt.%)

Material	Si	Fe	Cu	Mn	Mg	Zn	Cr	Ti	Al
AA 5083-H112	0.06	0.24	0.015	0.61	4.51	0.008	0.088	0.024	Bal.
AA 6061-T6	0..44	0.25	0.205	0.10	0.91	0.021	0.100	0.013	Bal.

Flowchart

This research was carried out through several stages as shown in Figure 1.

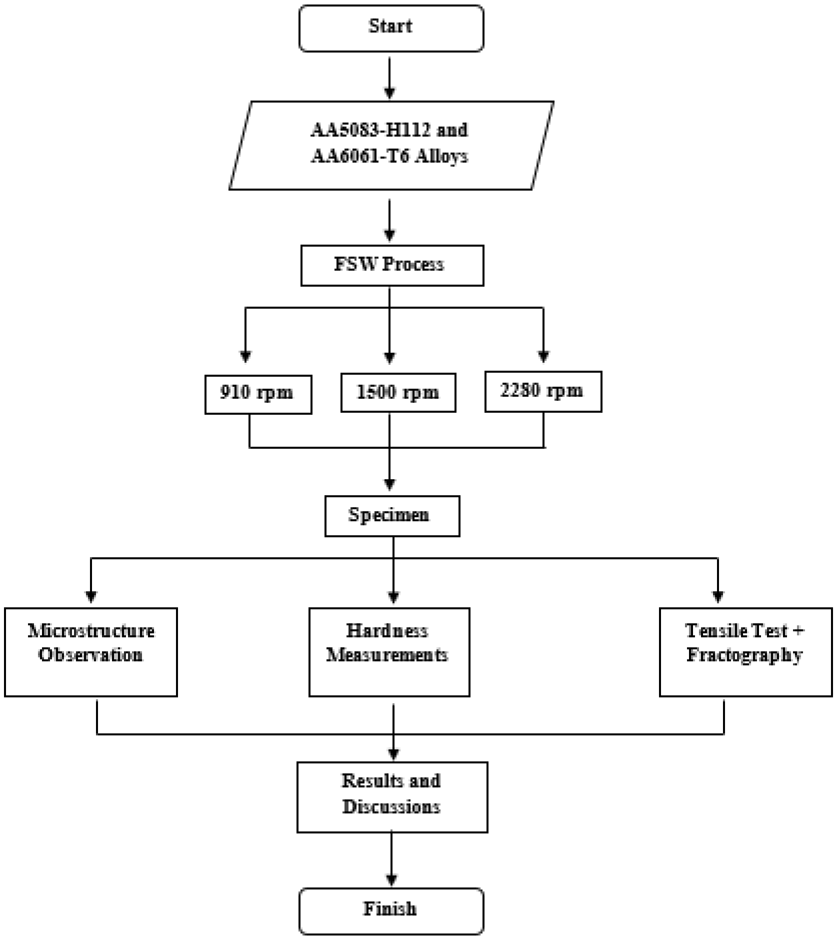

Figure 1. Research flowchart

Welding Process

The cylinder pin of the FSW tool used in this investigation was made of H13 steel, as shown in Figure 2. The tool had a shoulder diameter of 15 mm, a pin diameter of 5 mm, and a length of 2.8 mm.

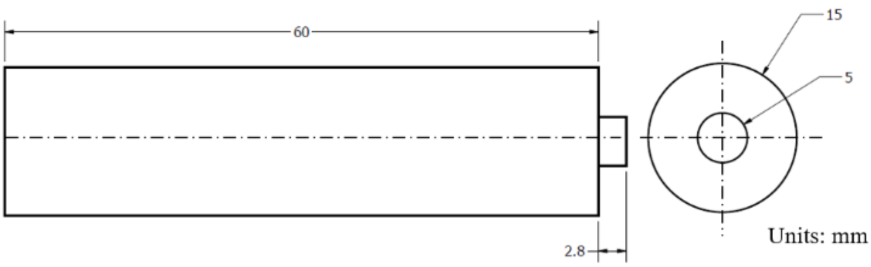

Figure 2. Tool dimension

An Achiera milling machine with tool rotational speeds of 910, 1500, and 2280 rpm was used for the FSW procedure. The welding speed was kept consistent at 30 mm/min and the point of tendency was 2°. Figure 3 depicts the schematic of the welding procedure.

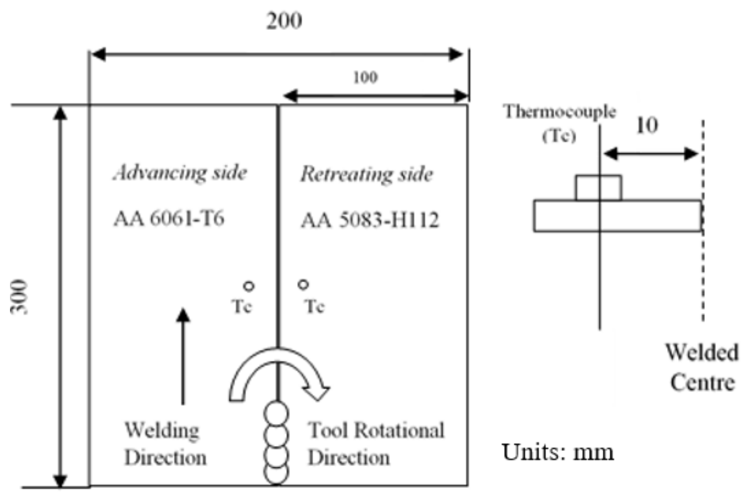

Figure 3. Schematic of welding process

Thermal cycle measurements were carried out by installing K-type thermocouples as illustrated in Figure 3. Thermocouples are installed on 2 sides of the top surface of the material with a distance of 10mm from the welding centre. Temperature measured is the surface temperature of the thermocouple holder. The results were displayed using the Signal Express 2010 software.

Mechanical Properties Testing

After welding, some experimental works including microstructure observations (1 sample for each variation), hardness measurements (1 sample for each variation), and tensile tests (3 samples for each variation) combined with fractography were conducted.

Microstructure Observation

Observation of the microstructure was conducted using an optical microscope with Olympus brand as shown in Figure 4. The sample preparation for metallography included cutting, mounting, grinding, polishing, and followed by etching. The etching used in this study. Keller's reagent solution made from a mixture of 25 ml HCl, 25 ml HNO_3, 2 ml HF, and 25 ml H_2O on the sample surface.


Figure 4. Optical microscope

Hardness Measurements

Hardness testing was carried out using the Vickers micro-hardness Buehler Micromet 2100 brand as shown in Figure 5 with the aim of knowing the distribution of the hardness values of across the welds. The hardness values (VHN) of the test specimens were calculated by the equation:

$$VHN = 1.8544\frac{F}{D^2} \tag{1}$$

Figure 5. Vickers micro-hardness

The preparation of the specimens for this testing was the same as that done for microstructure observations. The hardness measurements were performed using the load of 100 gram-force with the dwell time of 10 seconds. The location of the hardness test was determined at mid thickness of the plate as shown in Figure 6. The hardness data were taken along 40 mm with the distance between two points of measurement was 0.5 mm.

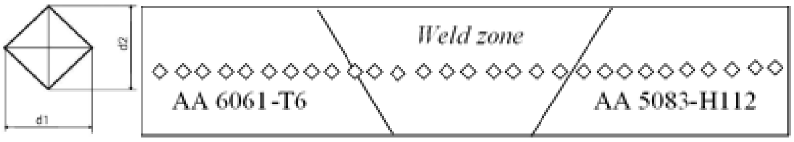

Figure 6. Hardness test scheme

Tensile Tests

The type and dimension of the specimens used in this test followed the ASTM E8 standard (ASTM E8, 2010), as shown in Figure 7.

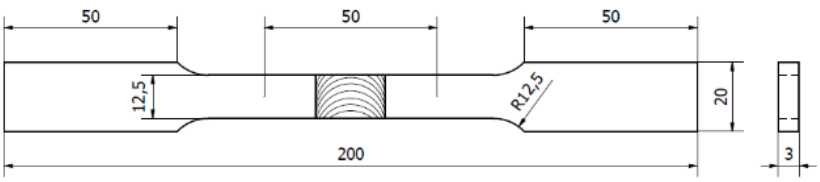

Figure 7. Tensile test specimen

Testing was carried out with a universal servo-hydraulic testing machine as shown in Figure 8. This testing was aimed to determine the ultimate strength, yield strength, strain and fractography of the tested FSW welded joints.

Figure 8. Universal servo-hydraulic testing machine

RESULTS AND DISCUSSION

Thermal Cycles

Thermal cycles were measured during welding process. These thermal cycles were used to determine the cooling rate and maximum temperature for each specimen under variations in tool rotational speed. Figure 5 and Figure 6 are a welding thermal cycles that show the maximum temperature differences that occur in each weld specimen.

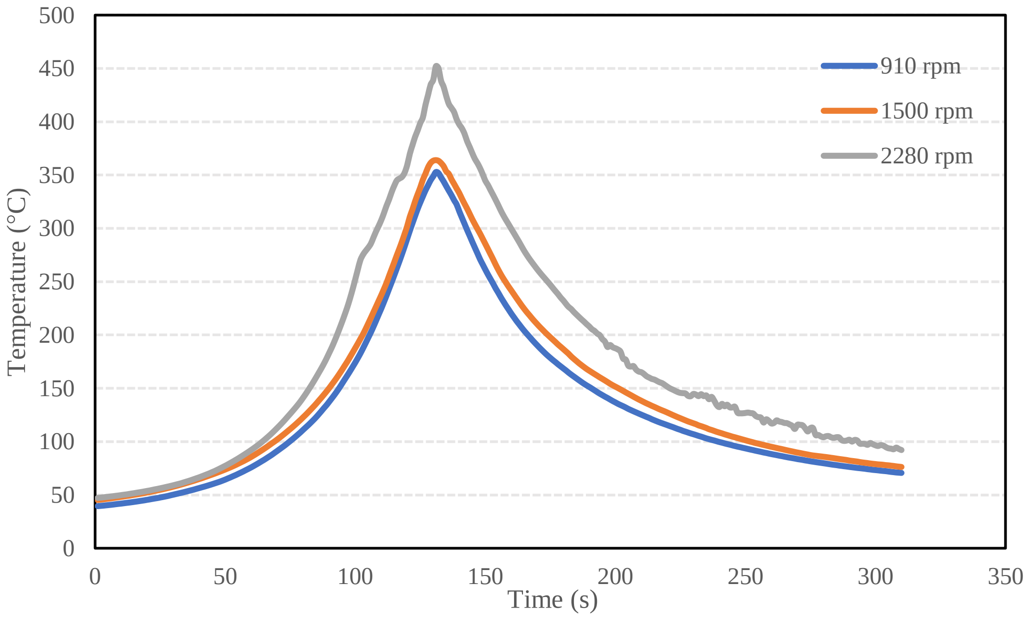

Figure 5. Thermal cycle curve (Advancing Side)

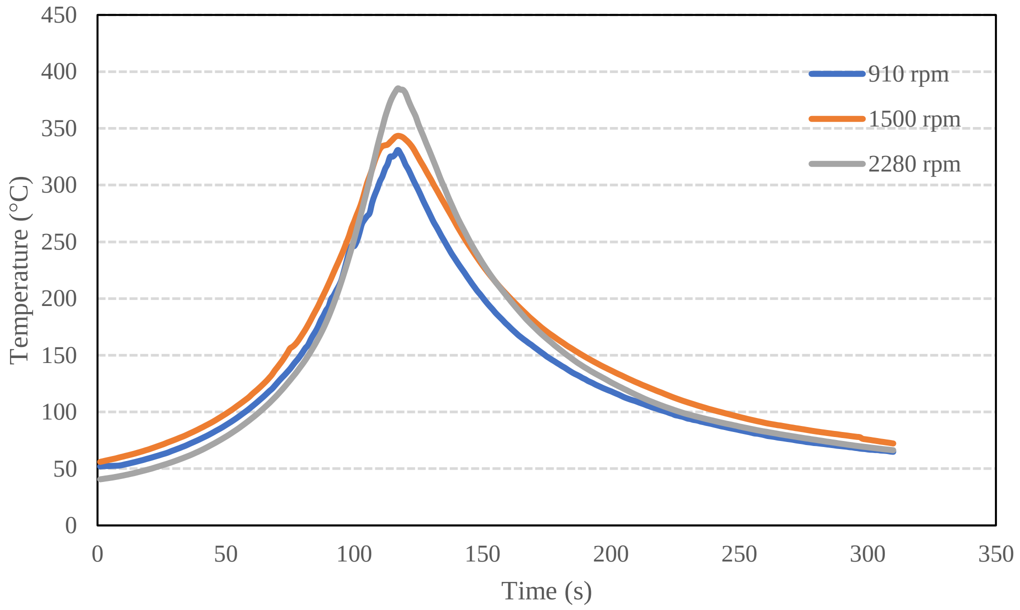

Figure 6. Thermal cycle curve (Retreating Side)

From Figure 5 and Figure 6, the maximum temperature for all weld joints under study is influenced by tool rotation speed. As the tool rotation speed increases, the maximum temperature produced is higher. This is because the heat that occurs during the welding process is proportional to the tool's rotational speed. The peak temperature of advancing side (AS) and retreating side (RS), typically 451℃ and 385℃ respectively were obtained at the speed of 2280 rpm. The higher temperature of AS compared to RS is caused by the fact that the tool rotation direction in AS is opposite to that of traveling speed. The present works has confirmed that the highest temperature in FSW process has a strong function of tool rotational speed (Mishra & Ma, 2005).

Microstructure

Figure 7 shows typical microstructures of the FSW dissimilar AA5083-H112/AA6061-T6 joints. The combined influence of friction heat and plastic strain in the region close to stir zone (SZ) results in a thermo-mechanically affected zone (TMAZ). This region consists of bent and highly elongated fine grains. Stirring by the tool at SZ causes high plastic deformation followed by rapid recrystallization at higher temperatures resulting in a fine grained structure with a polygonal morphology.

Another microstructural feature seen in Figure 7 is that the grains of TMAZ in AS are more severely bent than those observed in TMAZ in RS. In addition, increasing tool rotation causes coarsening of the grains in SZ owing to high friction heat which leads to grain growth during welding. TMAZ and HAZ areas on the RS with rotation variations, there is no clear boundary between TMAZ and HAZ. This is because the friction heat in RS is lower than in AS. Metal flow (mass flow) is not as good as in the AS.

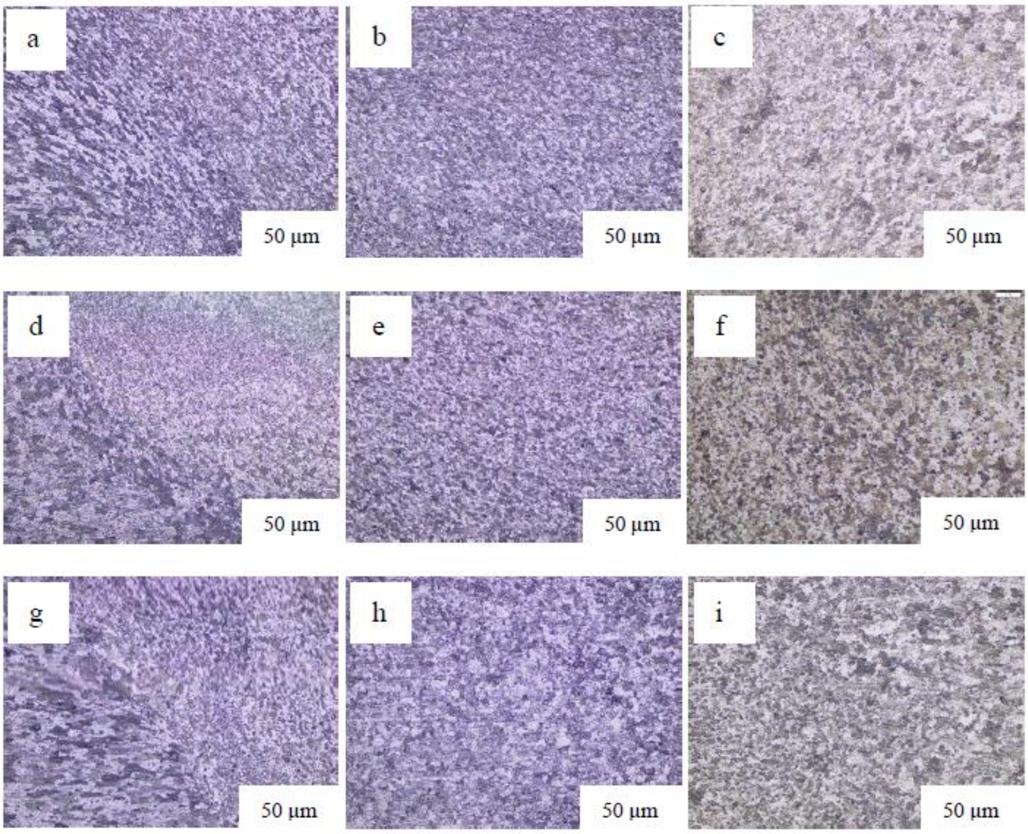

Figure 7. Microstructure (a) TMAZ/SZ AS 910 rpm, (b) SZ 910 rpm, (c) TMAZ/SZ RS 910 rpm, (d) TMAZ/SZ AS 1500 rpm, (e) SZ 1500 rpm, (f) TMAZ/SZ RS 1500 rpm, (g) TMAZ/SZ AS 2280 rpm, (h) SZ 2280 rpm, (i) TMAZ/SZ RS 2280 rpm

Microhardness

The microhardness profiles for all welded specimens are depicted in Figure 8. For each weld joint, the HAZ is far reaching from around 5.5 mm to around 15 mm from the weld community. The dispersion of hardness in the weld metal uncovers a "W" molded profile as shown by the presence of a little pinnacle of hardness at the focal point of the weld.

The hardness of the weld metal (SZ) can be increased by increasing the tool rotational speed, as depicted in Figure 7. Apparently the variety in the miniature hardness Vickers conveyance along the weld zone connects with changes in microstructures by apparatus rotational speed.

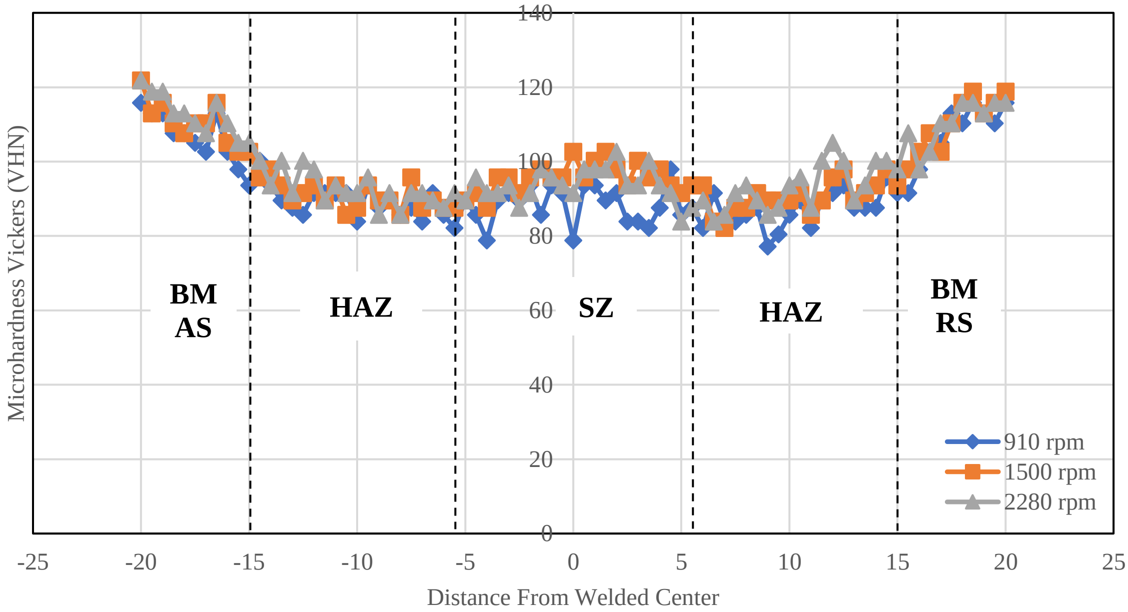

Figure 8. Micro-hardness Vickers

Tensile Strength

The impact of hardware pivot speed on rigidity, yield strength, and % of prolongation of divergent FSW AA5083-H112 and AA6061-T6 compound joints as displayed in Figure 9 and Figure 10. When the tool rotation speed was increased, the dissimilar FSW AA5083-H112/AA6061-T6 joint ultimate tensile strength (UTS) and yield strength (YS) increased. The best UTS and YS, typically 228 MPa and 156 MPa, were obtained at the speed of 2280 rpm. The results are in line with previous research results which state that the higher the tool rotation in the FSW process, the tensile strength will increase. The maximum tensile strength occurs at 1600 rpm, with a value of 151 MPa (Riswanda & N. Ilman, 2012).

The precipitation of AA6061-T6 in the stir zone (SZ) and the increased degree of mixing were linked to the improved weld strengths. Similar to the AA5083-H112 and AA6061-T6 base metals, the strains increased with tool rotational speed, but their values were lower.

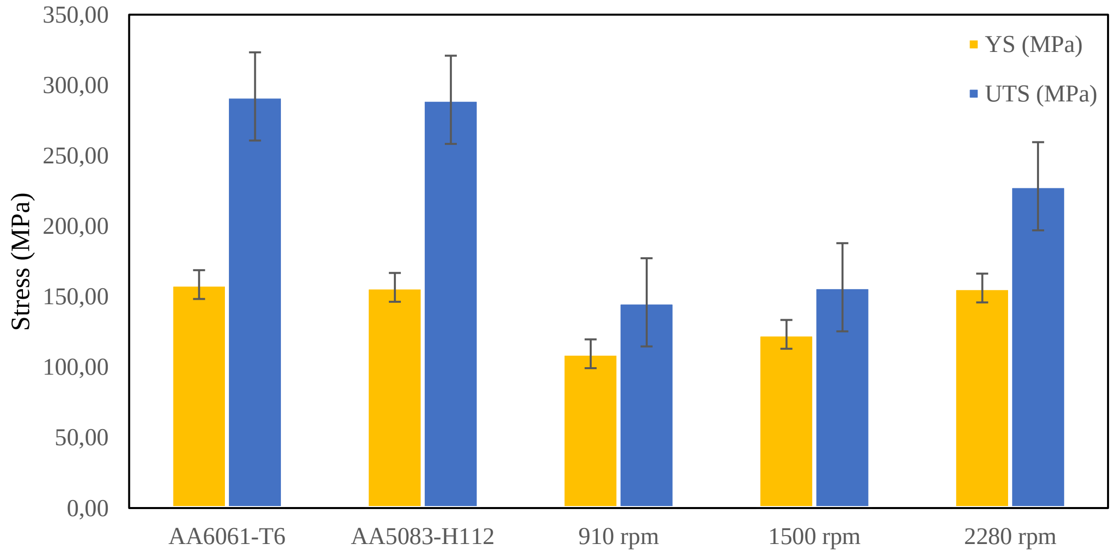

Figure 9. Tensile strength

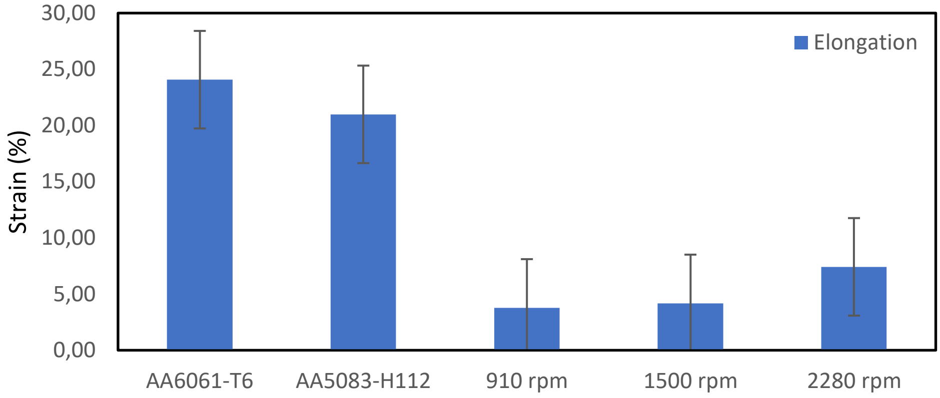

Figure 10. Elongation

Fractography

The break way of the welded example after the pliable test is displayed in Figure 11. The area of the break for the FSW joints at the apparatus turn speed of 910 and 1500 rpm happens nearby close to the propelling side of TMAZ. The area of the crack movements to SZ when the turn speed is expanded to 2280 rpm. These outcomes are as per the microhardness values in Figure 8 which shows a "W" molded profile. The hardness will be straightforwardly corresponding to the strength, the area of the break surface is anticipated to happen close to TMAZ which has generally low mechanical properties (Ilman et al., 2022).

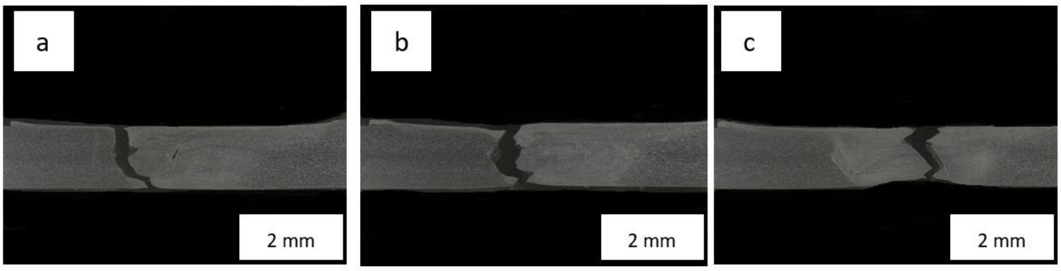

Figure 11. Fractography (a) 910 rpm, (b) 1500 rpm, (c) 2280 rpm

CONCLUSIONS

The tool rotation speed increased the mechanical properties of dissimilar AA5083-H112/AA6061-T6 welded joints. The best ultimate tensile strength and yield strength, normally 228 MPa and 156 MPa individually were acquired at the speed of 2280 rpm. The better weld qualities were related with the expanded level of blending in mix zone (SZ) and precipitation of AA6061-T6 in SZ.

ACKNOWLEDGMENTS

The authors would like to sincerely thank to Puslapdik-Kemendikbudristek and LPDP which has provided funding of research through BPI Scholarships, and the Department of Mechanical and Industrial Engineering UGM who have given the opportunity to do research.

REFERECES

Akin, E. T., & Weldi, H. E. (2013). Friction Stir Welding of Dissimilar Materials : An Overview. *International Journal of Mechanical and Mechatronics Engineering*, *7*(4), 6–11.

ASTM E8. (2010). ASTM E8/E8M standard test methods for tension testing of metallic materials 1. *Annual Book of ASTM Standards 4*, *C*, 1–27. https://doi.org/10.1520/E0008

Cetkin, E., Çelik, Y. H., & Temiz, S. (2019). Microstructure and mechanical properties of AA7075/AA5182 jointed by FSW. *Journal of Materials Processing Technology*, *268*(September 2018), 107–116. https://doi.org/10.1016/j.jmatprotec.2019.01.005

Devaiah, D., Kishore, Dr. K., & Laxminarayana, Dr. P. (2016). Effect of Material Location and Tool Rotational Speed on the Mechanical Properties of Dissimilar Friction Stir Welded Aluminum Alloys (5083-H321to 6061-T6). *Bonfring International Journal of Industrial Engineering and Management Science*, *6*(4), 186–190. https://doi.org/10.9756/bijiems.8311

Devaiah, D., Kishore, K., & Laxminarayana, P. (2017). Effect of Welding Speed on Mechanical Properties of Dissimilar Friction Stir Welded AA5083-H321 and AA6061-T6 Aluminum Alloys. *International Journal of Advanced Engineering Research and Science*, *4*(3), 22–28. https://doi.org/10.22161/ijaers.4.3.4

Ilman, M. N., Widodo, A., & Triwibowo, N. A. (2022). Metallurgical, mechanical and corrosion characteristics of vibration assisted gas metal arc AA6061-T6 welded joints. *Journal of Advanced Joining Processes*, *6*(July), 100129. https://doi.org/10.1016/j.jajp.2022.100129

Mandal, N. R. (2005). *Aluminum Welding.* (Second). Narosa Publishing House Pvt. Ltd. https://doi.org/10.1201/9780203912591.ch9

Mishra, R. S., & Ma, Z. Y. (2005). Friction stir welding and processing. *Materials Science and Engineering R: Reports*, *50*(1–2), 1–78. https://doi.org/10.1016/j.mser.2005.07.001

Ravikumar, S., Seshagiri Rao, V., & Pranesh, R. V. (2014). Effect of Process Parameters on Mechanical Properties of Friction Stir Welded Dissimilar Materials between AA6061-T651 and AA7075-T651 Alloys. *International Journal of Advanced Mechanical Engineering*, *4*(1), 101–114.

Riswanda, & N. Ilman, M. (2012). Studi Komparasi Sambungan Las Dissimilar AA5083 - AA6061-T6 Antara TIG dan FSW. *Jurnal Industrial Research Workshop and National Seminar*, 75–79.

Selamat, N. F. M., Baghdadi, A. H., Sajuri, Z., & Kokabi, A. H. (2016). Friction stir welding of similar and dissimilar aluminium alloys for automotive applications. *International Journal of Automotive and Mechanical Engineering*, *13*(2), 3401–3412. https://doi.org/10.15282/ijame.13.2.2016.9.0281

Venkat Ramana, G., & Sanke, N. (2019). Effect of tool rotational speed and feed rate on similar and dissimilar Friction Stir welded joints of Al 5082 and Al 6061. *Materials Today: Proceedings*, *19*, 870–874. https://doi.org/10.1016/j.matpr.2019.08.228

Venkat Ramana, G., Yelamasetti, B., & Vishnu Vardhan, T. (2021). Effect of FSW process parameters and tool profile on mechanical properties of AA 5082 and AA 6061 welds. *Materials Today: Proceedings*, *46*, 826–830. https://doi.org/10.1016/j.matpr.2020.12.801

Wahid, M. A., Siddiquee, A. N., & Khan, Z. A. (2020). Aluminum alloys in marine construction: characteristics, application, and problems from a fabrication viewpoint. *Marine Systems and Ocean Technology*, *15*(1), 70–80. https://doi.org/10.1007/s40868-019-00069-w