International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8 Issue-6, March 2020

Experimental Examination of Weld Hardness Profile with Various Tool Pin Probes using Friction Stir Welding of AA 6082-T6 Aluminium Alloy

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***Abstract:** In the present research work, an attempt was made to evaluate the weld hardness profile on the weldments along the weld traverse direction fabricated using various tool pin probes (Concave triangular threaded probe, Inner rake angle probe, Flats on edges of probe and Scroll threaded flute probe) at three different rotational speeds 1000 rpm, 1200 rpm, 1400 rpm at single weld traverse speed 25 mm/min. Hardness profiles are useful for establishing interpretation on microstructure and weld mechanical properties, micro hardness was performed in order to outline the weld hardness profile in the vicinity of weld affected areas like Nugget zone, Thermo-mechanically affected zone, Heat affected zone and Boundary zone in the weldments. From the hardness profiles it was found that higher hardness value of 106 VHN_{1kg} (Vicker's Hardness Number at 1kg load) was obtained with the weldment fabricated using Scroll threaded flute probe at 1400 rpm and 25 mm/min i.e 15 mm distance away from the weld centreline on the advancing side of the weldment , besides lower hardness value of 49.8VHN_{1kg} was obtained with weldment fabricated using concave triangular threaded probe at 1200 rpm and 25 mm/min at nugget zone i.e at the centerline of the weldment*.

***Keywords:** Hardness profiles, VHN, FSW, Tool pin probes.*

I. INTRODUCTION

Steel as structural material has progressively reinstated by non-ferrous, particularly aluminium grade alloys, in many industrial applications. Some aluminium alloys grade has combination of less weight coupled with high strength when compared with structural steels. Anyhow, the weld joining of such type of materials find frequently very ambiguous. High tensile strength coupled with specific strength and excellent resistance to corrosion make aluminium grade alloys as essential structural material employed for different structural elements in ship-building, aviation and other industries. In the present days, one of the effective and common method for fabricating the metallic structures is fusion-based welding [1].

In order to avoid the weld defects formed during fusion welding process, the solid state form of joining process, known as friction stir welding (FSW) has been developed by TWI (The Welding Institute), in the late 1990's at Cambridge.

The schematic operation of FSW is shown in Fig.1. FSW can be employed for joining both similar and dissimilar metals for this reason FSW played a predominant role in industrial applications for joining aluminium grade alloys. The joining process is very simple: a non-consumable rotating tool fabricated with a uniquely created probe and tool shoulder is plunged between the two abutting surfaces of the materials to be welded and is traversed along the weld line. Frictional heat generated due to orbital forging pressure during welding deforms the base material in to plastic state thereby softening the material allowing the probe to traverse along weld length. During welding the base material undergoes severe plastic deformation in solid form of joining involves formation of DRX (Dynamic Recrystallization) during welding leading to the formation of substantial state of grain refinement in the weld zone [1].

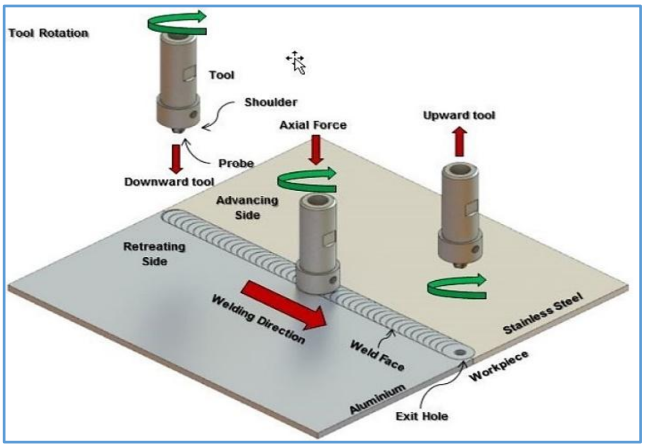

Fig. 1. Schematic operation of FSW [2]

The present aim of the study, is to evaluate the impact of various tool pin probes and welding parameters on the hardness profiles of FSW fabricated butt joints of AA 6082-T6.

Manuscript received on February 10, 2020.
Revised Manuscript received on February 20, 2020.
Manuscript published on March 30, 2020.
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II. EXPERIMENTAL WORK

Ilangovan et.al [2] performed FSW using three different tool pin profiles namely straight, tapered and threaded cylindrical on AA 6061 and AA 5086 from the experimental investigation high hardness of 106 HV was obtained near boundary zone i.e on the AS of weldment (AA 6061) and low hardness of 62 HV was near TMAZ zone near the AS of the weldment AA 6061. Raghubabu et.al [3] performed FSW on AA 6082-T6 using taper threaded tool pin profile observed high hardness of 125 HV was observed near TMAZ on the AS of the weldment, low hardness of 65 HV was observed near nugget zone on the RS of the weldment.

III. FSW EXPERIMENTAL PROCEDURE

AA 6082-T6 aluminium alloy was shear cut and milling is performed in order to obtain required dimensions 200×80×6 mm. The abutting surfaces of the material is welded using four different tool pin probes as shown in the Fig. 2 namely: 2.a) Concave triangular threaded probe, 2. b) Flats on edges of probe, 2. c) Scroll threaded flute probe and 2 d). Inner rake angle probe.

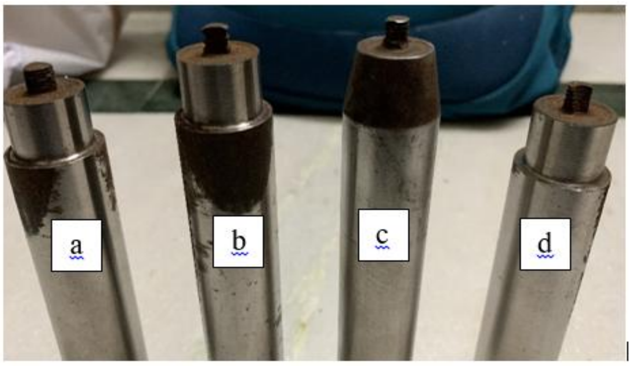


Fig. 2. FSW tool pin probes

The weldments fabricated using Concave triangular threaded probe (CTTP) at three different rpm's namely 1000 rpm, 1200 rpm and 1400 rpm at single traverse speed 25 mm/min are shown in Fig. 3. (a), (b) and (c) respectively. Similarly the weldments fabricated using Inner rake angle probe (IRAP), Flats on edges of probe (FEP) and Scroll threaded flute probe (STFP) three different rpm's namely 1000 rpm, 1200 rpm and 1400 rpm at single traverse speed 25 mm/min are shown in Fig. 4 (a), (b) and (c), 5 (a), (b) and (c) and 6 (a), (b) and (c) respectively.

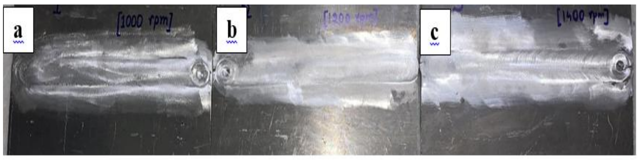


Fig. 3. 3(a) CTTP weldment at 1000 rpm 3 (b) CTTP weldment at 1200 rpm 3 (c) CTTP weldment at 1400 rpm

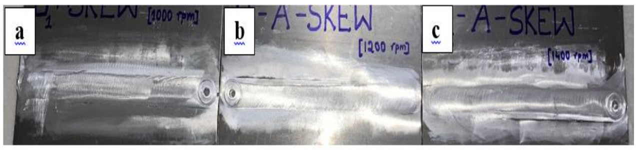


Fig 4. 4(a) IRAP weldment at 1000 rpm 4 (b) IRAP weldment at 1200 rpm 4 (c) IRAP weldment at 1400 rpm

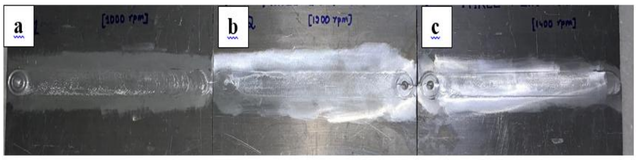


Fig. 5. 5(a) FEP weldment at 1000 rpm 5 (b) FEP weldment at 1200 rpm 5 (c) FEP weldment at 1400 rpm

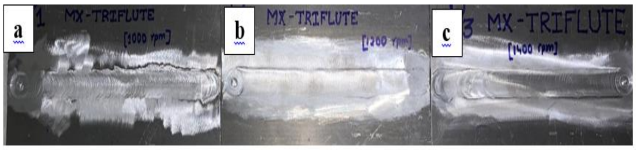


Fig. 6. 6(a) STFP weldment at 1000 rpm 6 (b) STFP weldment at 1200 rpm 6 (c) STFP weldment at 1400 rpm

IV. EXAMINATION OF WELD HARDNESS PROFILES

The weld hardness test was conducted as per ASTM E92-80(2003)e2 standard and pyramid shaped 136^0 diamond indenter probe as per ASTM E384-05a was employed for examination of hardness on the weldments. Chennai make Metco Micro-Vickers hardness testing machine has been employed for examining hardness on the weldments as shown in Fig. 7. The specifications of the micro-vickers tester is given in Table. 1. The dotted line in Fig. 8 represents weld center line and dots represents places where hardness is examined on the weldments.

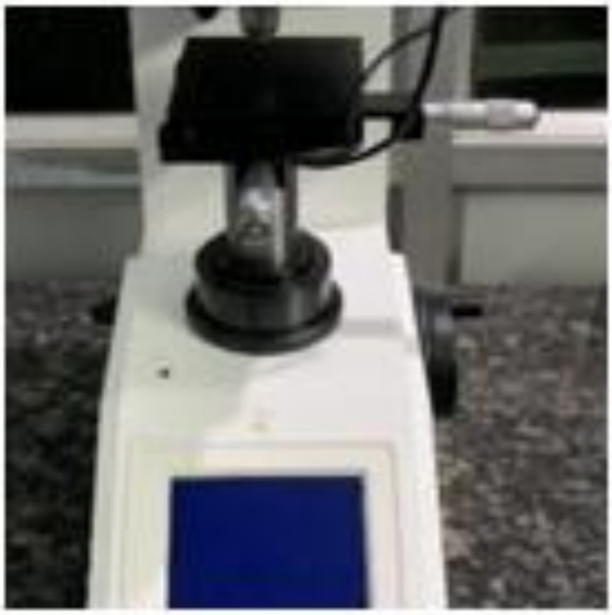


Fig. 7. Micro-Vickers hardness testing instrument

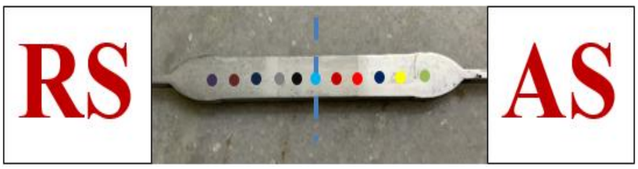


Fig. 8 Specimen employed for examination of hardness on the weldment

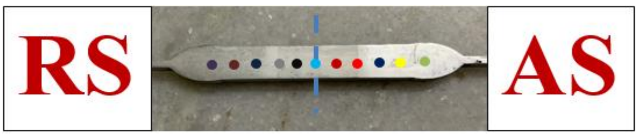
TABLE 1. Specifications of Micro-Vicker's hardness tester

Specification	Value
Load range	10 grams – 1 Kilogram
Magnification	100 x – 2000 x
Make and model	Chennai Metco

Micro-Vickers hardness was conducted test was conducted on weld center line at various regions on the weldments with weld spacing of 5 mm on both advancing side (AS) and retreating side (RS) of the weldments. The hardness test was performed with a test load range of ten grams to one kilogram and vernier calipers least count of 0.01 mm. The test was performed at 11 different places on the weldments. The applied load in 0.5 kg and dwell time of 10 seconds. From the hardness results high 126 VHN_{1kg} was obtained at CTTP at 1400 rpm near boundary zone on the retreating side of the weld, besides low 49.8 VHN_{1kg} was obtained at CTTP at 1200 rpm at the nugget zone of the weldment. Low hardness of 49.8 VHN_{1kg} was due to decrease in cooling rates at low traverse speed resulting in the formation of coarse secondary phase dissolute transformation at the weld nugget zone. This transformation also reduces the solutes quantity during welding thereby reducing the strengthening in the solid state solution. The knockdown of hardness is due to coarsening of particle precipitates during welding. Increase of weld hardness is observed by increasing in tool rotational speed increases the strength due to spatial refinement of grain size. Whereas, on the other zones fluctuation of the hardness values substantial increase in the degree of precipitate formation due to rapid cooling and heating cycles during FSW lead to increase in weld hardness surrounding the weld nugget zone. Table. 2 represents micro-hardness of various regions of the weldments fabricated using CTTP at 1000, 1200 and 1400 rpm respectively. Micro-hardness distribution across the weld cross-section is shown in Fig. 9 [4].

TABLE 2. Micro-hardness values at different regions

	Distance in mm										
	-25	-20	-15	-10	-5	0	5	10	15	20	25
VHN_{1kg} CTTP at 1000 rpm	110	92	81.2	74.2	69.1	52	59.3	66.1	86	100	125
VHN_{1kg} CTTP at 1200 rpm	130	98	85.8	70.7	67	49.8	70.2	74.8	81.5	95	105
VHN_{1kg} CTTP at 1400 rpm	126	97.6	92.8	87.6	66	53.1	60.2	77.2	85.2	96.7	100



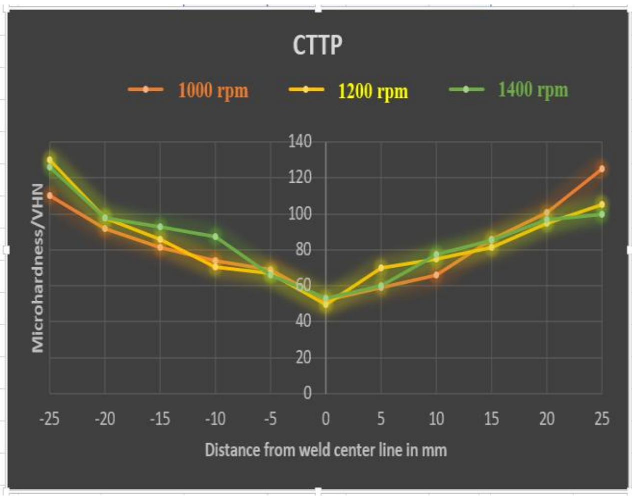
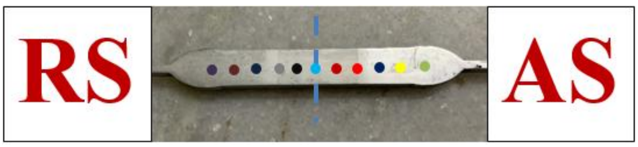


Fig. 9. Micro-hardness distribution across the weld cross-section using CTTP at different rpm's

Similarly Micro-Vickers hardness test was conducted on weld center line at various regions on the weldments with weld spacing of 5 mm on both advancing side (AS) and retreating side (RS) of the weldments. The hardness test was performed with a test load range of ten grams to one kilogram and vernier calipers least count of 0.01 mm. The test was performed at 11 different places on the weldments. The applied load in 0.5 kg and dwell time of 10 seconds. From the hardness results high 127 VHN_{1kg} was obtained at IRAP at 1400 rpm near boundary zone on the retreating side of the weld, besides low 53 VHN_{1kg} was obtained at IRAP at 1000 rpm at the nugget zone of the weldment. Low hardness of 53 VHN_{1kg} was due to presence of voids at the WN zone. The knockdown of hardness is likely associated with the degree of stirring during welding. Table. 3 represents micro-hardness of various regions of the weldments fabricated using IRAP at 1000, 1200 and 1400 rpm respectively. Micro-hardness distribution across the weld cross-section is shown in Fig. 10 [5].

TABLE 3. Micro-hardness values at different regions

	Distance in mm										
	-25	-20	-15	-10	-5	0	5	10	15	20	25
VHN_{1kg} IRAP at 1000 rpm	123	99.6	98.4	87.3	84.7	53	81.2	88.6	90.8	94.1	107
VHN_{1kg} IRAP at 1200 rpm	115	97.6	94.1	77.2	71.6	54.9	74.4	82.9	83.2	91.6	103
VHN_{1kg} IRAP at 1400 rpm	127	102.3	91.2	81.2	71.9	54.7	77.69	86.5	89.2	95.4	116



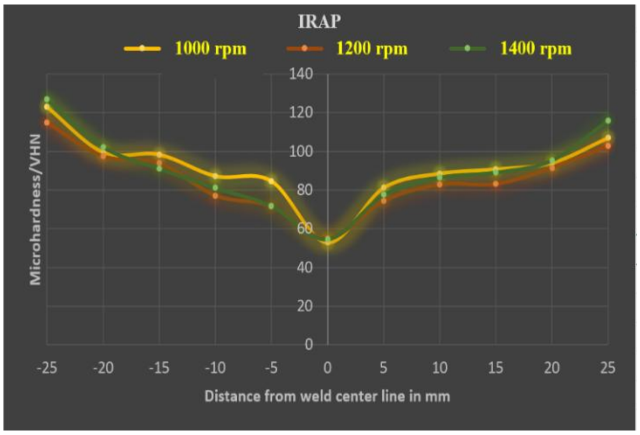
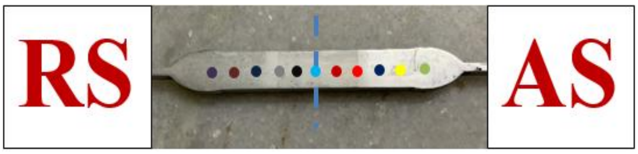


Fig. 10. Micro-hardness distribution across the weld cross-section using IRAP at different rpm's

Similarly Micro-Vickers hardness test was conducted on weld center line at various regions on the weldments with weld spacing of 5 mm on both advancing side (AS) and retreating side (RS) of the weldments. The hardness test was performed with a test load range of ten grams to one kilogram and vernier calipers least count of 0.01 mm. The test was performed at 11 different places on the weldments. The applied load in 0.5 kg and dwell time of 10 seconds. From the hardness results high 106 VHN_{1kg} was obtained at FEP at 1400 rpm near boundary zone on the retreating side of the weld, besides low 57 VHN_{1kg} was obtained at FEP at 1000 rpm at the nugget zone of the weldment. Low hardness of 53 VHN_{1kg} was due to presence of voids at the WN zone. The knockdown of hardness is due to formation of plasticized material around the weld region lead to dissolution of precipitates strength and coarsening observed by thermal cycles which are formed mainly due to over-aging of solidus precipitates observed during FSW. Table. 4 represents micro-hardness of various regions of the weldments fabricated using FEP at 1000, 1200 and 1400 rpm respectively. Micro-hardness distribution across the weld cross-section is shown in Fig. 11 [6].

TABLE 4. Micro-hardness values at different regions

	Distance in mm										
	-25	-20	-15	-10	-5	0	5	10	15	20	25
VHN_{1kg} FEP at 1000 rpm	100	97.6	92.8	89.2	77.2	57	74.5	78.2	94.2	104.6	99
VHN_{1kg} FEP at 1200 rpm	105	102.2	85.8	72.4	63.8	60.6	75.7	92.8	93.6	97.1	100
VHN_{1kg} FEP at 1400 rpm	106	102.8	98.5	90.8	78.2	55.9	74.2	92.4	93.8	98.6	104



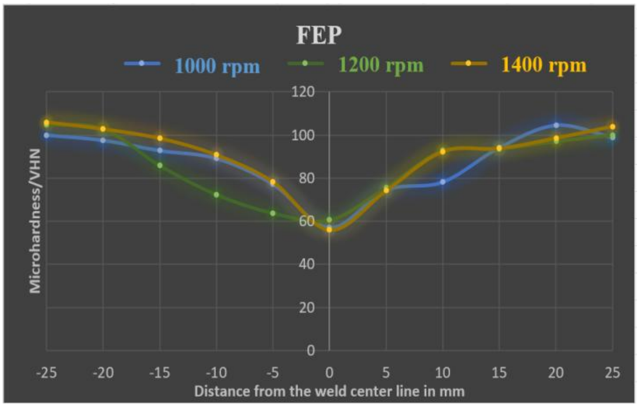
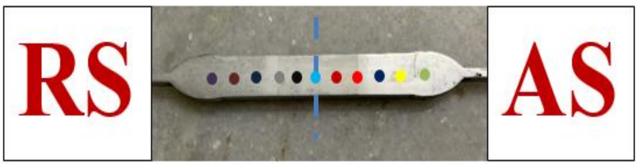


Fig. 11. Micro-hardness distribution across the weld cross-section using FEP at different rpm's

Similarly Micro-Vickers hardness test was conducted on weld center line at various regions on the weldments with weld spacing of 5 mm on both advancing side (AS) and retreating side (RS) of the weldments. The hardness test was performed with a test load range of ten grams to one kilogram and vernier calipers least count of 0.01 mm. The test was performed at 11 different places on the weldments. The applied load in 0.5 kg and dwell time of 10 seconds. From the hardness results high 127 VHN_{1kg} was obtained at STFP at 1400 rpm near boundary zone on the retreating side of the weld, besides low 53 VHN_{1kg} was obtained at STFP at 1000 rpm at the nugget zone of the weldment. Low hardness of 53 VHN_{1kg} was due to presence of voids at the WN zone. The knockdown of hardness is likely associated with the degree of stirring during welding. Table. 5 represents micro-hardness of various regions of the weldments fabricated using STFP at 1000, 1200 and 1400 rpm respectively. Micro-hardness distribution across the weld cross-section is shown in Fig. 12 [7].

TABLE 5. Micro-hardness values at different regions

	Distance in mm										
	-25	-20	-15	-10	-5	0	5	10	15	20	25
VHN_{1kg} STFP at 1000 rpm	102	97.6	94.9	94.1	78.5	52	73.6	88.4	89.2	97.8	103
VHN_{1kg} STFP at 1200 rpm	103	97.6	83.2	72.7	63.4	53.3	70.5	81.2	92.4	94.9	99
VHN_{1kg} STFP at 1400 rpm	115	106.4	96.7	90.4	77.2	59.1	72.1	88.8	94.9	104.1	110



Retrieval Number: F8521038620/2020©BEIESP
DOI:10.35940/ijrte.F8521.038620
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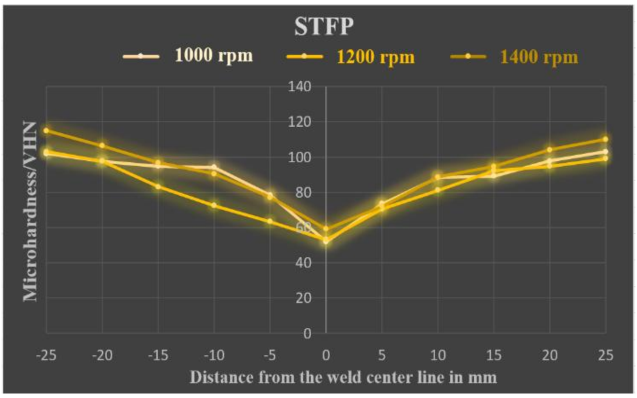

Fig. 12. Micro-hardness distribution across the weld cross-section using STFP at different rpm's

V. CONCLUSIONS

Based on the experiment results, the following conclusions are made:

- High hardness of 130 VHN_{1kg} was obtained with the weldment fabricated using concave triangular threaded probe at 1200 rpm at retreating side boundary zone.
- Low hardness of 49.8 VHN_{1kg} was obtained with the weldment fabricated using concave triangular threaded probe at 1200 rpm at weld nugget zone.
- The knockdown in hardness is due to low peak temperatures observed during welding and formation of secondary precipitates and voids at the weld zone.

ACKNOWLEDGEMENT

The authors are thankful to Mr. M. Rama Raju G.M METCO ASIA PVT.LTD, Dr. N. Murthy Raju, Director IIRM, Dhanbad, Prof. K. Suryanarayana Raju, Director Sigma Metallurgical Services, Mr. Naresh, lab Assistant RSML, Dr. Shivababa Senior Metallurgical Engineer LMF, Ms. N. Lakshmi, AEE TSGENCO, Prof. Laxmipathiraju, BECT, Bhimavaram, Mr. .M.S Venkateswara Raju, Plant Head ESSAR STEELS PVT.LTD.

REFERENCES

1. Krasnowski K, Hamilton C, Dymek S, " Influence of the tool shape and weld configuration on microstructure and mechanical properties of the Al 6082 alloy FSW joints", *Archieves of Civil and Mechanical Engineering*, ACME-193 2014, pp. 1-9.
2. Ilangovan M, Rajendra Boopathy S, Balasubramanian V, "Effect of tool pin on microstructure and tensile properties of friction stir welded dissimilar AA6061-AA5086 aluminium joints", *Defence Technology*, Volume 11, 2015, pp. 174-184.
3. Raghu Babu G, Murti K.G.K, Ranga Janardhana G, "An experimental study on the effect of welding parameters on mechanical and microstructural properties of AA6082-T6 friction stir welded butt joints", *APRN Journal of Engineering and Applied Sciences*, Volume 3, No 5, 2008, pp. 68-74.
4. Ravikumar, S., Seshagiri Rao, V., Pranesh, R.V., " 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, Volume 4, No 1 (2014), pp. 101-114.
5. Izabela Kalemba-Rec, kopyscianski M, Damian M, Krasnowski, K., "Effect of process parameters on mechanical properties of friction stir welded dissimilar 7075-T651 and 5082-H111 aluminium alloys", *International Journal of Advanced Mechanical Engineering*, 2018, pp. 2767-2779.
6. Mishras R.S, Ma Z.Y, "Friction stir welding and processing". *Materials Science and Engineering*, 18 August, 2005, pp. 1-78.
7. Chen, Y., Huijie, L., Feng, J., " Friction stir welding characteristics of different heat-treated-state 2219 aluminium alloy plates", *Materials Science and Engineering*, 2006 , pp. 21-25.

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