MECHANICAL BEHAVIOUR OF METALS UNDER FRICTION STIR WELDING

P. SHEKAR VARMA
M.Tech, Production Engineering,
Ellenki engineering college of siddipet,
E-mail: shekarvarma39@gmail.com

G.VINOD REDDY,
Assistant Professor,
Dept. of Mechanical,
Ellenki engineering college of siddipet.

ABSTRACT

Friction stir welding (FSW) is a relatively new solid-state joining process that can be beneficially used for various transportation and defence applications. This joining technique is energy efficient, environment friendly, and versatile. In particular, it can be used to join high-strength aerospace aluminium alloys and other metallic alloys that are hard to weld by conventional fusion welding. FSW is considered to be the most significant development in metal joining in a decade. Understanding the microstructure evolution and properties of friction stir welded components is necessary to use this new process in critical structural applications. In this project we put forth the knowledge base regarding friction stir welding under static load which is performed on three different AL alloys namely Al-3003(H18), Al-6082(H30) and commercial grade. The effects of critical FSW process parameters were also studied. The resulting micro structural changes, micro hardness profiles and tensile testing have been reported. Comparison of micro hardness values has also been performed. The findings from these investigations will be presented and discussed.

INTRODUCTION

Friction stir welding (FSW) is a significant manufacturing process for producing welded structures in solid state [1]. This process offers several advantages compared to the conventional welding methods including higher mechanical properties and lower residual stresses as well as reduced occurrence of defects [2]. In FSW process, a rotating tool having a shoulder moves along the welding line. Rotational motion of the shoulder generates frictional heat leading to a softened region around the pin while the shoulder prevents deforming material from being expelled. In fact, a weld joint is produced by the extrusion of material from the leading side to the trailing side of the tool[3].

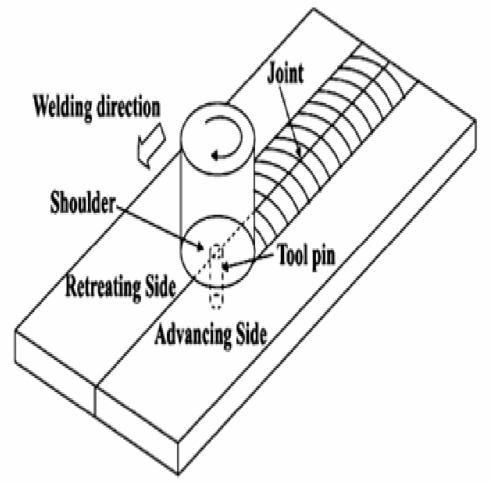


Figure-1.1: diagram shows friction stir welding process and terminology.

Frictions stir welding: Stir friction welding is a solid-state joining process (the metal is not melted) and is used when the original metal characteristics must remain unchanged as much as possible. It mechanically intermixes the two pieces of metal at the place of join, then softens them so the metal can be fused using mechanical pressure. It is primarily used on aluminium, aluminium alloys, and most often on large piece that cannot be easily heat-treated after welding to recover temper characterises. FSW can be a slower process than other forms of welding, such as arc or laser welding. This is because the cylindrical tool must turn to generate heat on the joint, and then traverse the length of the joint transmitting that heat.

Project objectives: The objective of this project was to build the knowledge base regarding static performance of friction stir welded joints. Achievements in this area would contribute to the viability of using the FSW process in this alloy in the transportation industry, leading to significant improvements in component strength and cost of production over traditional joining methods used with the alloy. This project has another objective of the micro structural characteristics resulting from different sets of variables in the FSW process, micro hardness profiles generation and flow of heat.

Approach to the problem: In industrial applications, joints are subjected to compound forces and moments as well as a large variety of environmental conditions. In addition to complex loading scenarios, friction stir welded joints have highly variable microstructures that affect the performance of the material. If all loads and environmental conditions were combined in a single test, isolation of factors that determine failure would be difficult. In order to approximate the behaviour of friction stir welds in actual applications, tests for static loading are used.

Achievements: This project investigates static properties of FSW in Al3003 (H18), Al6082 (H30) and commercial grade (H14) and the microstructure of the FSW joint. Determining the microstructure and micro hardness profiles of the joint is imperative in understanding methods for improving the process. Using information gathered from static load testing of sample butt joints, links between micro structural features and processing parameters that affect the static performance of the joints are identified.

Principle of operation: A constantly rotated cylindrical-shouldered tool with a profiled nib is transversely fed at a constant rate into a butt joint between two clamped pieces of butted material. The nib is slightly shorter than the weld depth required, with the tool shoulder riding atop the work surface. Frictional heat is generated between the wear-resistant welding components and the work pieces. This heat, along with that generated by the mechanical mixing process and the adiabatic heat within the material, cause the stirred materials to soften without melting.

Weld creation: Welds were created in 100mm weld lengths in Aluminium alloy stock 0f 3mm thick. In each weld, the base material was formed so that the rolling direction was perpendicular to the welding direction. Welds were created for six sets of parameters. The result of the FSW procedures was six sets of welds on each alloy with individual time-temperature histories and differing resultant microstructures.

Weld creation: - material composition: - The materials on which the job has carried out are Aluminium-3003 (H18), Commercial grade (H14), Aluminium-6082 (H30). The chemical composition of these alloys plays a significant role in the weld creation gives the chemical composition of these alloys.

Data Sheet: **Aluminum 3003**

Chemical Composition Limits						
Weight %	Al	Cu	Si	Fe	Mn	Zn
3003	Remainder	0.20 Max	0.60 Max	0.70 max	1.0 - 1.5	0.10 Max

CHEICAL COMPOSITION OF H18 AL ALLOY

Element	% Present
Manganese (Mn)	0.0 - 0.05
Iron (Fe)	0.0 - 0.40
Copper (Cu)	0.0 - 0.05
Magnesium (Mg)	0.0 - 0.05
Silicon (Si)	0.0 - 0.25
Zinc (Zn)	0.0 - 0.07
Titanium (Ti)	0.0 - 0.05
Aluminium (Al)	Balance

CHEMICAL COMPOSITION OF COMMERCIAL GRADE AL ALLOY

Data Sheet: **Aluminium Alloy 6082**

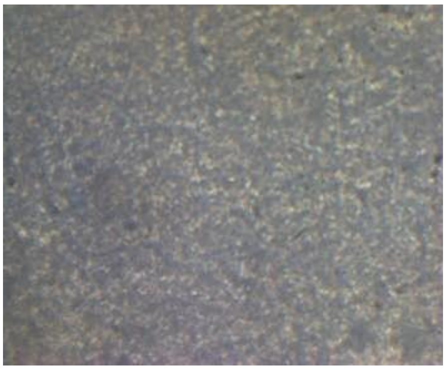
Chemical Composition Properties											
Weight %	Al	Si	Fe	Cu	Mn	Cr	Mg	Zn	Ti	Others Each	Others Total
Alloy 6082	Bal	0.7-1.3	0.50 max	0.10 max	0.40-1.00	0.25 max	0.06-1.20	0.20 max	0.10 max	0.05 max	0.15 max

CHEMICAL COMPOSITION OF H30 AL ALLOY

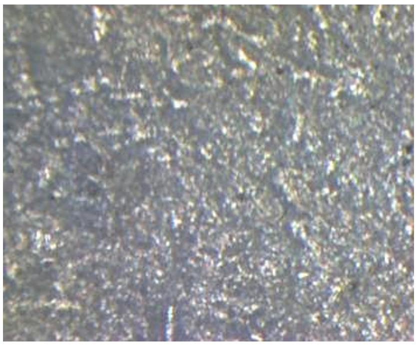
RESULTS AND DISCUSSIONS:

micro structure: The microstructures of welds produced for this project demonstrated all the characteristics of friction stir welds found in reviewed literature. All welds had a distinct DXZ, TMAZ, and HAZ that were clearly defined by the standard FSW geometries.

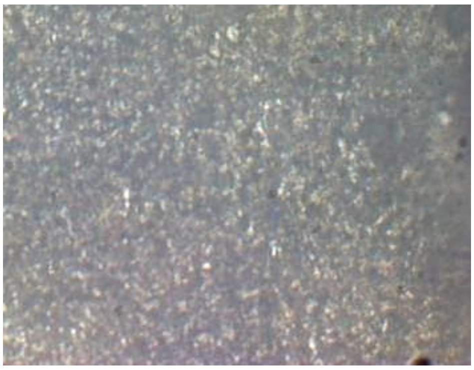
Aluminium- 3003(H18), Alluminium-6082(H30) & Commercial grade(H14) were used as the base material in this study. The material is readily available and was acquired from a local provider. An image micro structure of Aluminium-6082(H30) with different weld parameters can be seen in the following figures.



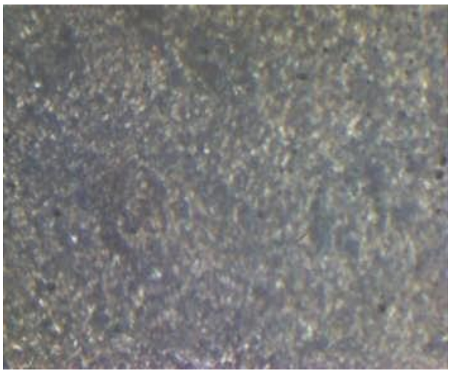
Al-6082(H30), Speed-1400rpm, Feed-6mm/min



Aluminium-6082(H30), Speed-1400rpm, Feed-8mm/min

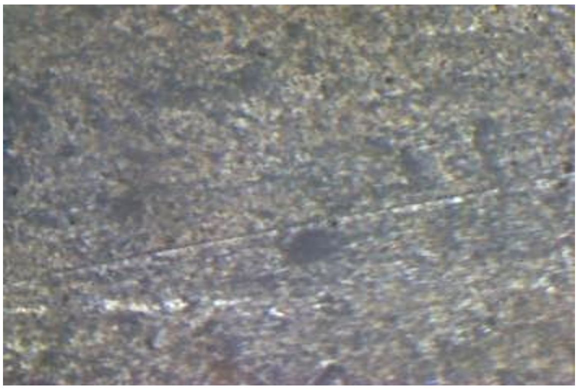


Aluminium-6082(H30), Speed-2000rpm, Feed-4mm/min

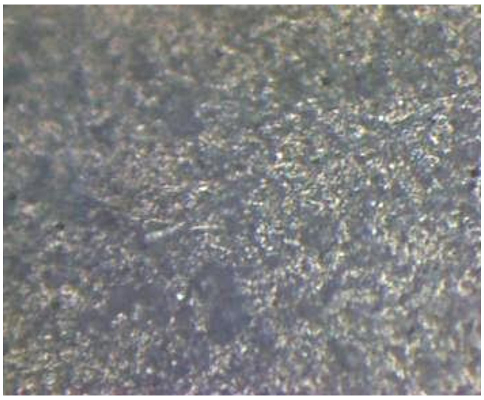


Aluminium-6082(H30), Speed-2000rpm, Feed- 6mm/min

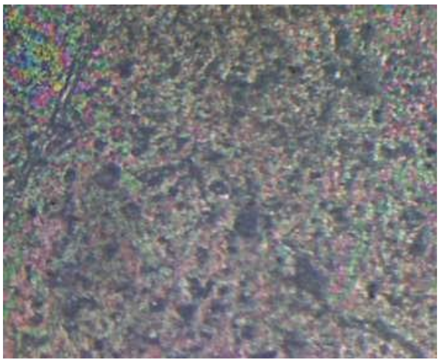
An image micro structure of Commercial Grade (H14) with different weld parameters can be seen in the following figures.



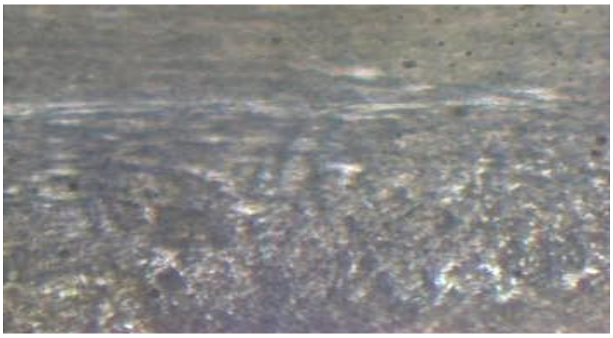
Commercial Grade (H14), Speed-1400rpm, 1400rpm, Feed-4mm/min



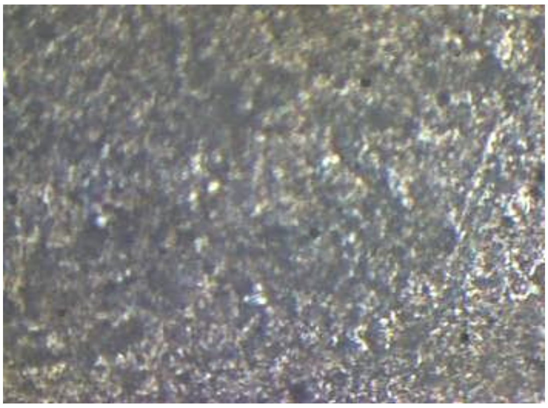
Commercial Grade(H14), Speed- Feed-8mm/min



Commercial Grade (H14), Speed-2000rpm, Feed-4mm/min



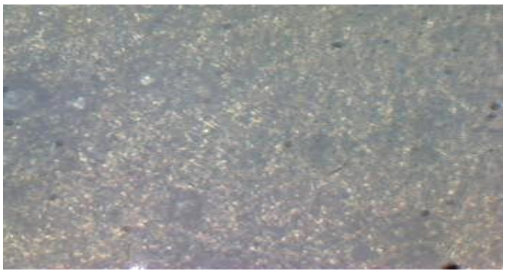
Commercial Grade (H14), Speed-2000rpm, Feed-6mm/min



Commercial Grade (H14), Speed-2000rpm, Feed-8mm/min

Comparison of micro structure with wrought Aluminium micro structure

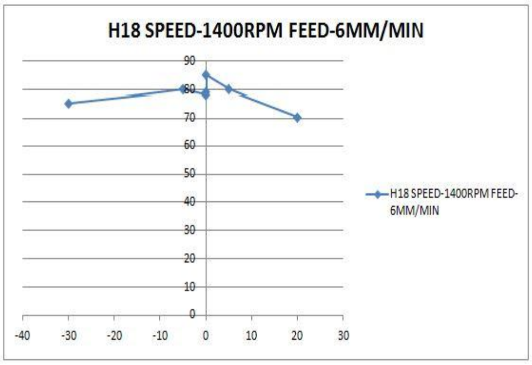
Wrought (H30)



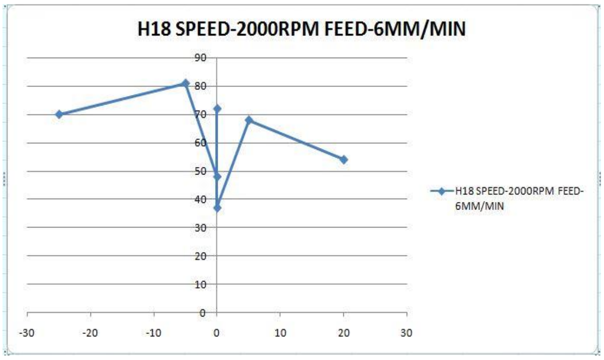
Wrought (Commercial Grade)

The band spacing of onion rings was also measured in order to verify that the FSW process was extruding a shell roughly every tool revolution. In this baseline weld, the band spacing was calculated to be approximately 140µm, which corresponds roughly to the linear distance travelled by the tool per rotation for this set of parameters. The theoretical value for this spacing would be 120µm, calculated by dividing the tool traverse rate by the tool rotational rate following the equation$spacing(\mu m) = \frac{traverse\ rate\ \left(\frac{mm}{s}\right)}{rotational\ rate\left(\frac{rpm}{60}\right)} * 100$. The small deviation of 20µm may be due to viscous effects and inconsistencies in the welding process. This finding is consistent with those on onion rings in the literature (Krishnan, 2002).

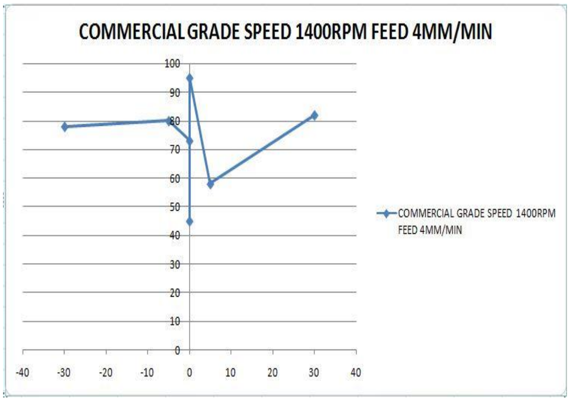
Micro Hardness Profiles



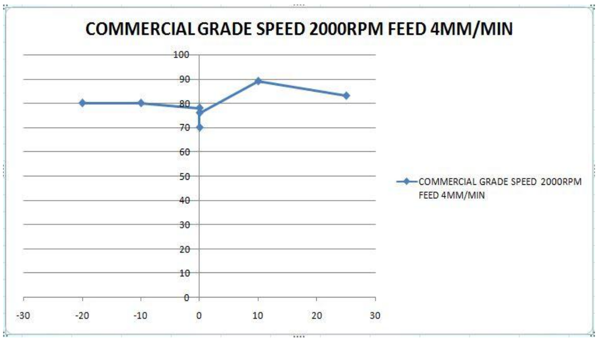
Aluminium-3003 speed-1400rpm, feed-6mm/min.



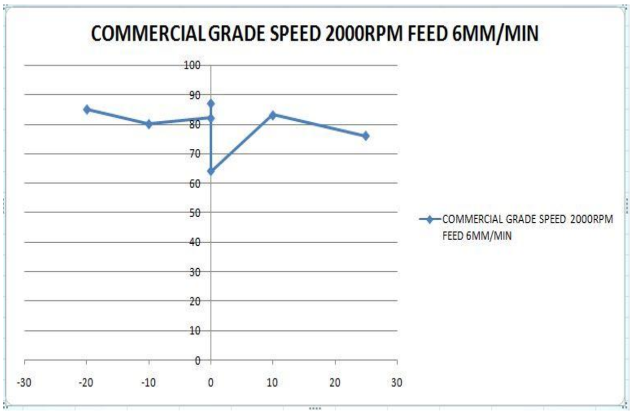
Aluminium-3003 speed-2000rpm, feed-6mm/min.



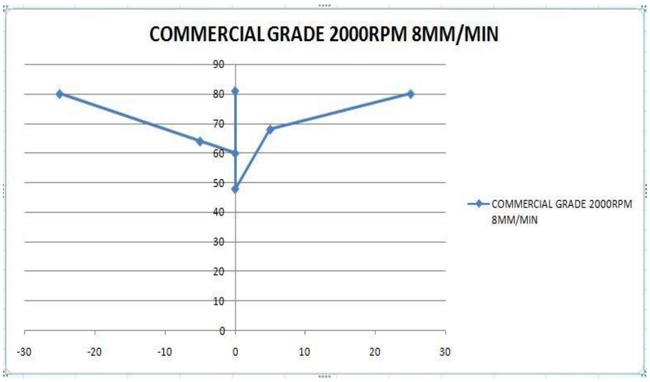
Commercial Grade Speed-1400rpm, feed-4mm/min.



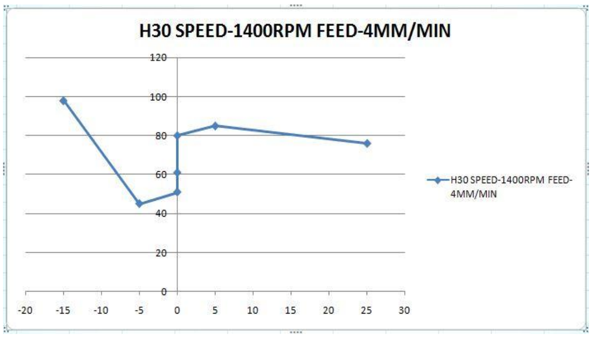
Commercial Grade Speed-2000rpm, Feed-4mm/min.



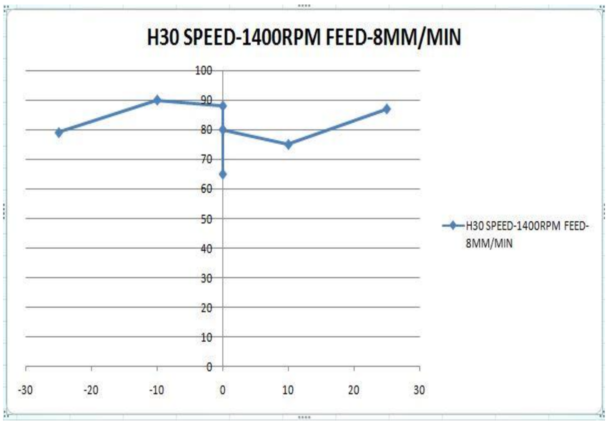
Commercial Grade Speed-2000rpm, Feed-6mm/min.



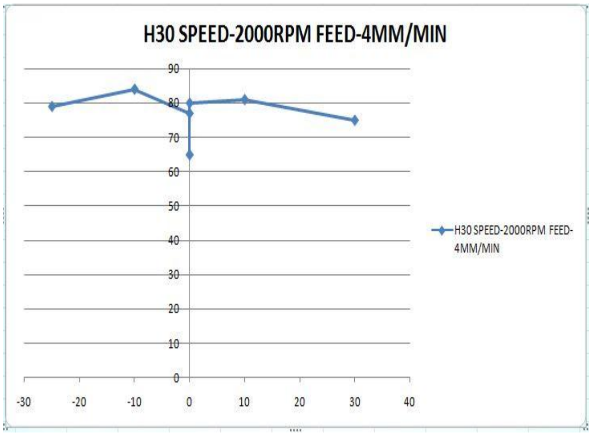
Commercial Grade Speed-2000rpm, Feed-8mm/min.



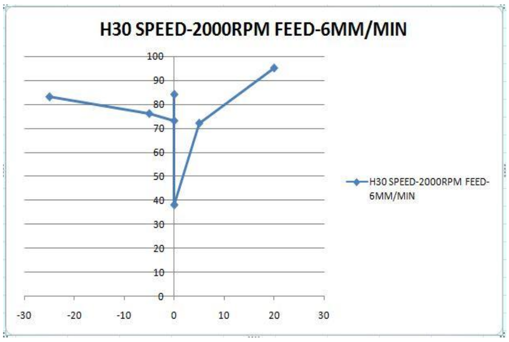
Aluminium-6082 (H30), Speed-1400rpm, Feed-4mm/min



Aluminium-6082 (H30), Speed-1400rpm, Feed-8mm/min.

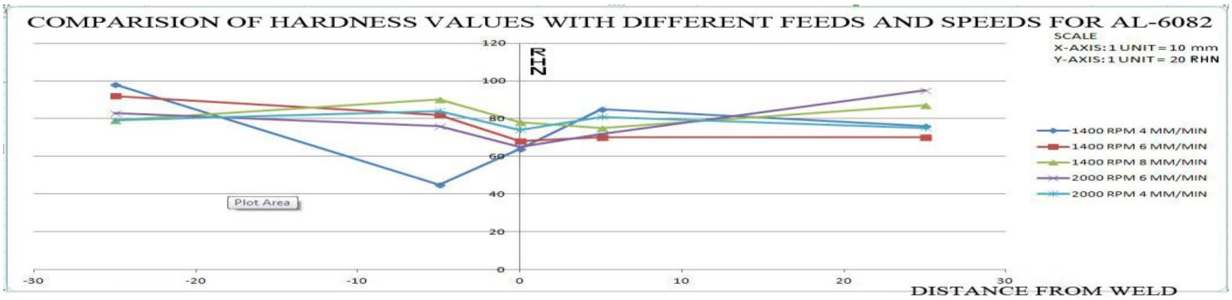


Aluminium-6082 (H30), Speed-2000rpm, Feed-4mm/min.

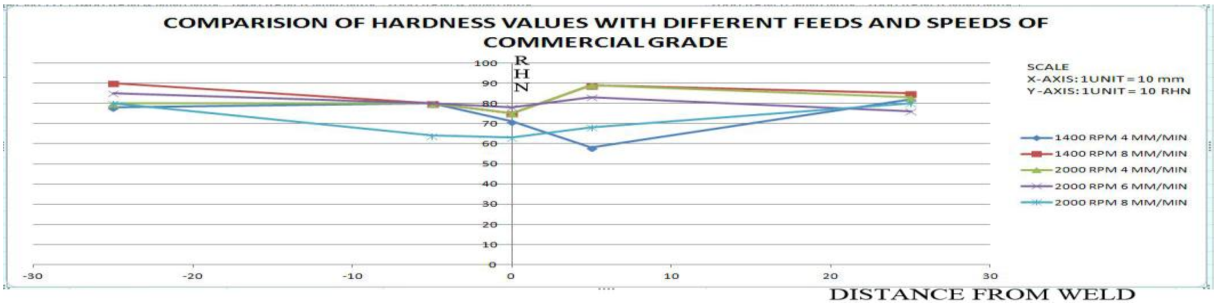


Aluminium-6082, Speed-2000rpm, Feed-6mm/min.

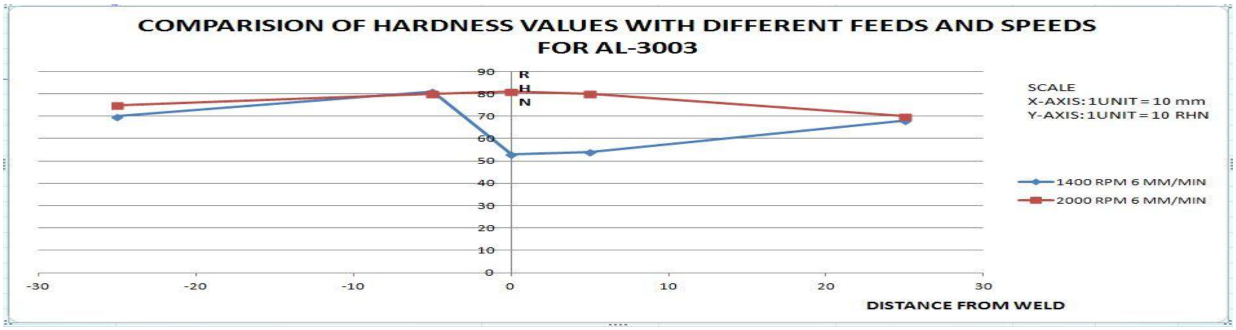
A micro hardness profile are taken for the baseline weld to determine degradation in properties on a localized scale This micro hardness profile takes the typical "W" shape for precipitation strengthened alloys described in the literature. The outer edges of this distribution would be expected to continue to increase in micro hardness until reaching the unaffected base material value; at no point is the hardness greater than that of the unaffected base material. It is apparent that the ultimate low point of micro hardness occurs somewhere between the TMAZ and HAZ for all sets of welding parameters. It is likely that the relatively high hardness of the DXZ is due to the small grain size, while the low hardness of the TMAZ is due to dissolution of strengthening precipitates and the low hardness of the HAZ is due to coarsening and clustering of precipitates (Lim et al., 2004; Liu, Fujii, Maeda, & Nogi, 2003). The flattening of the hardness profile is a result of the smaller thermal inputs and thermal gradients in this weld. These less intense thermal conditions do not coarsen or cluster precipitates as significantly as more intense thermal interactions. The micro hardness profile maintains a relatively consistent shape with smaller changes in hardness across the TMAZ and HAZ pictured in Figure (Lim et al., 2004). Additionally, this micro hardness profile suggests that a large section of the DXZ as well as areas in the HAZ on both sides of the weld have higher hardness than can be found in the unaffected base material. The literature suggests that this is a result of finer grains in the DXZ and compressive residual stresses in the HAZ (Bussu & Irving, 2003; John, Jata, & Sadananda, 2003; Prime & Hill, 2002). The ultimate low point of micro hardness for this weld is in the HAZ of the advancing side, similar to that found in the baseline weld.



Comparison of hardness values with different feeds and speeds for Al-6082.



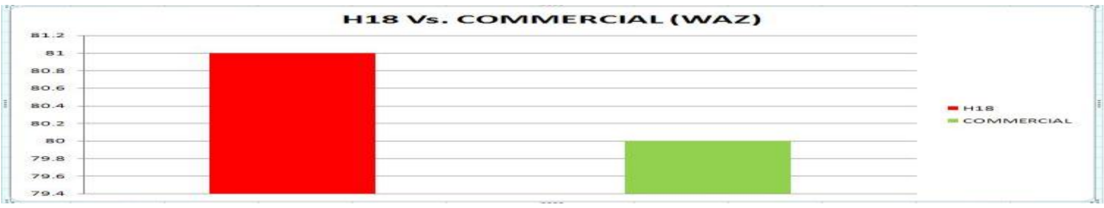
Comparison of hardness values with different feeds and speeds for commercial grade.



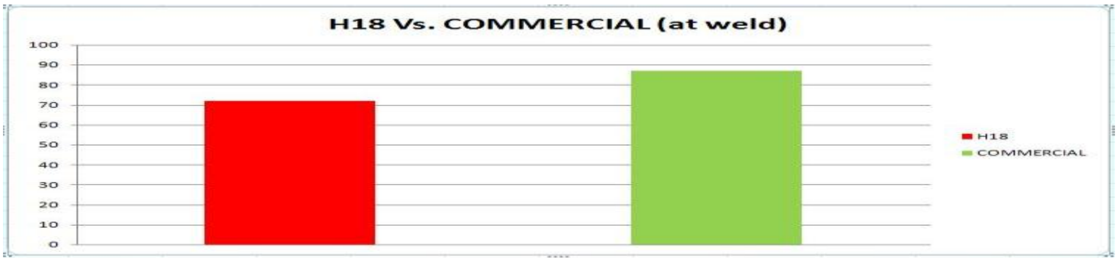
comparision of hardness values with different feeds and speeds for Al-3003

COMPARISION OF MICRO HARDNESS VALUES
COMMERCIAL GRADE vs. AL-3003 (H18):

H18 VS. COMMERCIAL GRADE AT WROUGHT



H18 VS. COMMERCIAL GRADE AT WAZ

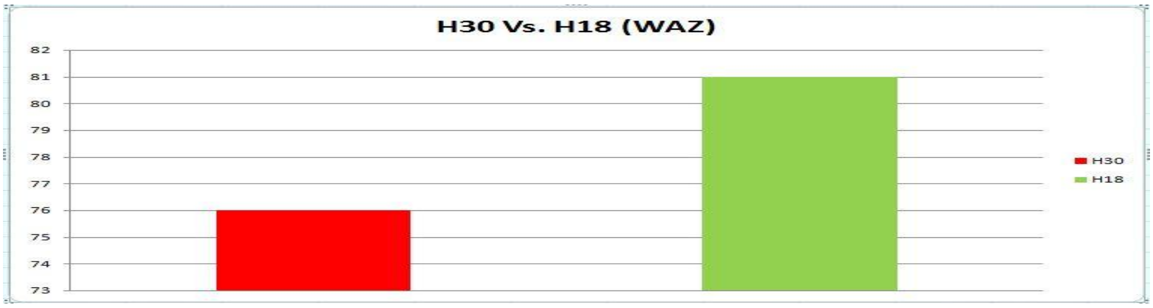


H18 VS. COMMERCIAL GRADE AT WELD

At wrought zone and at weld the micro hardness values of commercial grade aluminium are comparatively more to that of al-3003 (H18) but at WAZ (weld affected zone) the micro hardness value of al-3003 (H18) is more than that of commercial grade aluminium.

AL-6082 (H30) Vs. AL-3003 (H18):

H30 vs. H18 AT WROUGHT



H30 vs. H18 AT WAZ

H30 vs. H18 AT WAZ

H30 vs. H18 AT WELD

TENSILE TESTING METHODOLOGY:

TENSILE TEST SAMPLES: Tensile samples were cut from sections of the 100mm X 100mm weld. Cohesive sections of weld were selected of dimension 10mm X 100mm in the tool traverse direction. All samples were produced with minimal defects and conformed to specified dimensions with a tolerance of 0.01". Figure ……. shows a dimensioned image of the tensile samples used in testing.

Sample before tensile testing.

Tensile testing procedure-Tensile bars were tested on a UNIVERSAL TESTING MACHINE (UTM). All samples were checked visually during testing to ensure that no abnormal failures or sample slippage occurred. Elongation at fracture was recorded. Tensile bars were made for three weld samples, of these three weld samples all were ruptured and their respective yield point was noted with elongation.

Fig: Sample after tensile testing.

Alloy	Speed (rpm)	Feed (mm/min)	Tensile Strength At breaking point (N/mm²)	Elongation (mm)
Commercial Grade	2000	4	80	7
AL-6082	2000	4	93.34	6
AL-6082	1400	8	66.67	6

Results of Universal testing machine

CONCLUSIONS AND FUTURE WORK:

The analyses performed on the microstructure, microhardness, tensile testing, in Al6082 (H30), Al-3003 and commercial grade alloy demonstrate relationships between material properties and the response of welds to static loading. Comparison of microstructure analysis, micro hardness profiles, and sample responses to static loading for the three sets of welding parameters confirms that tensile properties are governed primarily by the micro hardness profile but may be influenced by micro structural features. The results demonstrate that the micro hardness profile of a sample is a result of the welding parameters selected, and therefore tensile strength and elongation are also determined by the welding parameters. Conclusions from the analysis of material response to static loading are:

1. Micro hardness profiles determine tensile properties
2. UTS is a function of the minimum micro hardness.
3. Ductility is determined by continuous sections of low micro hardness, not points.
4. Fracture location may also be affected by microstructure.

In general, the coincidence of tensile strength and low micro hardness indicates that the inner HAZ is the critical area of the WAZ for applications of static loading in cross-weld scenarios.

FUTURE SCOPE:

The conclusions presented in this section may be used to develop methods to enhance specific properties for industrial applications. The selection of the welding parameters used fully determines the tensile behaviour of the material. Accordingly, specific parameter combinations may be chosen for industrial applications in order to develop enhanced properties of frictions stir welds in the Al-3003, Al- 6082, and Commercial Grade Alloy.

There are several suggestions for future work to build upon this study. These include further tests and analysis of sample response to both static and dynamic loads:

- Perform tensile testing on a larger set of welding parameters with multiple tests for each set of welding parameters.
- Perform tensile tests on samples made entirely of the DXZ, in order to determine tensile and ductile properties of this weld zone alone.
- Analyze the residual stress distribution for several sets of welding parameters using the accurate methods to determine how residual stresses change with welding parameters.

REFERENCES

[1] W. Thomas, E. Nicholas, J. Needham, M. Murch, P. Templesmith, C. Dawes, 1995, Patent-Friction stir butt welding, I.P.N.PCT/GB92/02203, Editor, GB Patent No. 9125978.8, US Patent No.5.460.317. (1991).

[2] Yeong-Maw Hwang , Zong-Wei Kang , Yuang – Cherng Chiou , Hung – Hsiou Hsu, "Experimental study on temperature distributions within the workpiece during friction stir welding of aluminium alloys", International journal of machine tools & manufacture, vol. 48, pp.778- 787, 2008.

[3] Hua-Bin Chen, Keng Yan, Tao Lin, Shan-Ben Chen, Cheng-Yu Jiang, Yong Zhao, "The investigation of typical welding defects for 5456 aluminium alloy friction stir welds", Material science and engineering A, vol. 433, pp. 64-69, 2006.

[4] K. Elangovan, V. Balasubramanian, "Influences of post weld heat treatment on tensile properties of friction stir-welded AA6061 aluminium alloy joints", Material characterization vol. 59, pp.1168- 1177, 2008.

[5] P.M.G.P. Moreira, T. Santos, S.M.O. Tavares, V. Richter-Trummer, P. Vilaca, P.M.S.T.de Castro, "Mechanical and metallurgical characterization of friction stir welding joints of AA6061-T6 with AA6082-T6", Materials and design, vol. 30, pp. 180-187, 2009. [6] C. Leitao, R.M.Leal, D.M. Rodrigues, A. Loureiro, P. Vilaca, "Mechanical behaviour of similar and dissimilar AA5182-H111 and AA6016-T4 thin friction stir welds, Materials and design", vol. 30, pp. 101-108, 2009.

[7] W. Gan, K. Okamoto, S. Hirano, K. Chung, C. Kim, R.H. Wagoner, "Properties of friction-stir welded aluminium alloys 6111 and 5083", Journal of engineering materials and technology, vol. 130, pp. 031007- 1 – 031007-15, 2008.

[8] W.B. Lee, Y.M. Yeon, S.B. Jung, "The improvement of mechanical properties of friction-stir-welded A356 Al alloy", Material science and engineering A, vol. 355, pp.154-159, 2003. [9] Yutuka S. Sato, Hideki Takauchi, Seung Hwan C. Park, Hiroyuka Kokawa, "Characteristics of the kissing-bond in friction stir welded Al alloy 1050", Material science and engineering A, vol. 405, pp. 333-338, 2005.

[10] William D. Lockwood, Borislav d, A.P. Reynolds, "Mechanical response of friction stir welded AA2024: experiment and modeling", Material science and engineering A, vol. 323, pp. 348-353, 2002.

[11] Dr. Richard Johnson, Dr. Philip Threaddill, "Friction stir welding of magnesium alloys", Magnesium technology 2003, Edited by Howard I. Kaplan TMS (The minerals, metals & material society), pp.147-152, 2003.

[12] Naiyi, Li, Tsung-Yu Pan, Ronald P.Cooper, Dan Q. Houston, Zhili Feng and L. Santella, "Friction stir welding of magnesium AM60 alloy", Magnesium technology 2004, Edited by Alan A. Luo TMS (The minerals, metals & material society), pp.19-23, 2004.

[13] T.J. Lienert, W.L. Stellwag, JR., B.B. Grimmett, and R.W. Warke, "Friction stir welding studies on mild steel", Welding research, Supplement to the welding journal, pp.1s-9s, January 2003.

[14] Ling Cui, Hidetoshi Fujii, Nobuhiro Tsuji and Kiyoshi, Nogi, "Friction stir welding of a high carbon steel", Scripta Materialia, vol. 56, pp. 637-640, 2007.