INVESTIGATION ON MECHANICAL PROPERTIES OF FRICTION STIR WELDING OF MAGNESIUM ALLOY (AZ31) BY USING BORON POWDER

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Abstract - *The present work investigates on mechanical properties of friction stir welding of magnesium alloy AZ31 by using boron powder. In this work 100x50x5mm dimensioned plates of magnesium AZ31 alloy are fabricated by FSW process by the boron powder addition into welding process is carried out. Tool geometry depends on probe length, shoulder size and pin shape which influences the heat generation and material flow in the solid state. The shoulder produces maximum heat which plasticizes the material and the welded joint is formed effectively in the solid state. Here the welding tool with triangular taper pin is used effectively, which improves mixing of boron powder in the stir zone. As it is clear from the literature the strength of the friction stir welding joint is higher than the conventional fusion welding process. The strength of the welded joint in FSW depends on the process parameters like rotational speed, welding speed, axial load and tilt angle. The FSW weld part is during the wire cut machined to Further various tests for tensile test, charpy impact test, and micro hardness test measurements were carried out. In this study the mechanical properties are evaluated for the welded joints.*
A comparison has been made between the experimental values and prior journal papers. The maximum peak stress obtained was 172.27 MPa at 1200 RPM, welding speed at 40 mm/min and tilt angle of 1^0 . The maximum Izod impact value obtained was 4.5 joules weld4, maximum Microhardness of 80.20 VH average at weld1.

Key Words**:** Friction stir welding, magnesium AZ31, UTM machine, semi-automated milling machine, boron powder, triangular taper pin profile tool, mechanical properties, EDM wire cut machine.…

1. INTRODUCTION

The friction stir welding (FSW) is a new welding technique in welding. It is solid form weld method and initially started by the welding institute (TWI) of Cambridge, England in 1991. This method is simple, environment friendly, power able and becomes major serviceable for an marine, aircraft, automobile and aerospace industries its gives to the high strength of the FSW weld samples joints, as close to as base metal. It allows significant weight consumption in light weight production compared to conventional welding joints technologies. In dissimilarity to conventional welding joining process, there is no fluid condition for the weld joints during FSW, the welding takes place in the solid stage at below the melting point of the materials to be joined in this FSW. Thus, all the trouble related to the solidification of a fused material are avoided. Materials which are different to fusion weld similar to the high strength in the aluminium alloys can be joined with small loss in strength.

In friction stir weld a non-consumable revolving tool with a particularly profiled threaded/ unthreaded pin of tool and shoulder is turning at a continuous speed. The tool plunges into the two samples of plate material and through frictional high temperature it locally plasticized the joint in the weld region. The tool then certified to stir the weld joint surface next to the welding joining direction. Throughout tool plunge, the revolving tool undergoes only revolving motion at one place till the shoulder attack on the surface of the work material. During this step of tool plunge can generates lateral force orthogonal to the welding joining way. The following figure depicts the procedures of friction stir welfing.

The upper surface of the welding pieces consists of material that is carry by the shoulder from the retreating face of the weld, and put down on the advancing face. After the get the weld, the tool arrived at to termination stage where it is withdrawn from the work part. This is shown in fig. 1.1. During the welding method the piece have to be clamped strictly onto a support bar in a mode that avoid the adjoining joint faces from organism forced separately. The tool pin length is slightly less than the weld tickness required and the tool shoulder have to be in contact with the work surface.

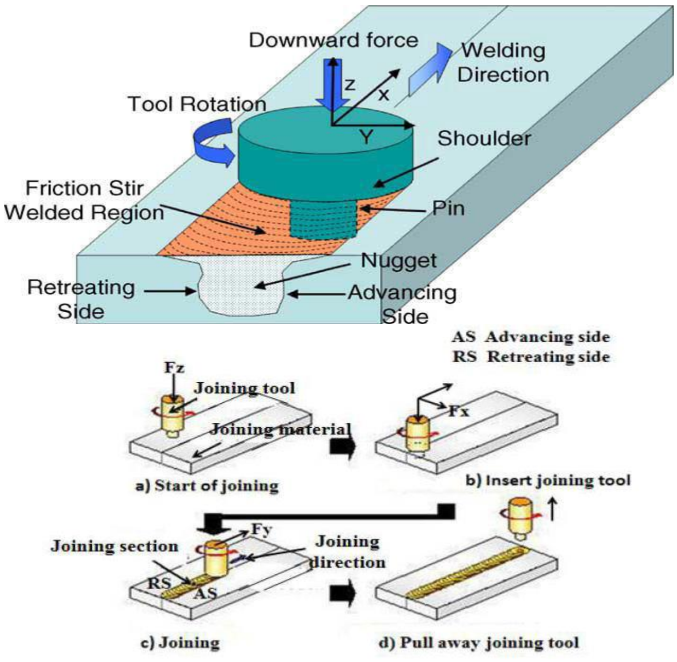


Fig. 1.1: Schematic representation of FSW

In recently, five investigators had studied the achieved of nanoparticles and powder addition to during welding joining of similar and different metals on friction stir welding procedure. The inserting of reinforcements during friction stir welding processing yield developed properties were also been founded by many researchers. **Tabasi** et al. performed AZ31 and AA7075 different pieces joint on FSW by addition the SiC nano particles & obtained out that the pin result take place in nugget zone. They carried that the inter combination of two alloys were increasing by raise the rotary motion speed & falling the journey speed. **Bahrami** et al. examined the influences of SiC nano particles adding at find mechanical properties of AA7075 similar alloys weld joint. They reported a considerable increase in tensile strength & elongation which were credited to the pinning result, more nucleation sites and contravention of major grains connected with strengthening nanoparticles. **Mirjavadi** et al. studied the effects of TiO2 nanoparticles addition on microstructure and tribological, mechanical properties of AA5083 aluminum alloy FSW butt joints. They declared that the augmentation of mechanical and wear properties was mainly due to the condensed grain size. **Baridula** et al., also reported the influence of rein forcements on the mechanical properties and microstructure of friction stir welded joints. as of this writing examination, it is obvious that the authority of reinforcement nano particles addition influences the mechanical properties, micro structural characteristics of welded joint. **K Venkat** et al., studied the mechanical and metallurgical properties of friction stir welded dissimilar aluminum AA2014 & AA6082 alloy by adding the TiO2 nanoparticles and simulation analysis in ansys software. They reported a Tensile Test the Maxi, Peak stress carried out was 151.1MPa going on a digitally Automated UTM machine, parameter at 900 rpm, 16mm/min and tilt angle of 1.5^0 by using hexagonal tool pin. The maximum impact value 10.5 joules on a digitally Automated impact tester machine, parameter at weld eld sample 01. Tilt angle 1.5^0 and speed 900rpm and feed rate 16 mm/min speed using Hexagonal tool pin. Micro hardness 95.5HV in nugget zone at 900Rpm and weld speed 16mm/min & tilt angle1.5^0. & micro structure of FSW welded joints is clear that the authority of reinforcement nano particles addition influences the mechanical properties, micro structural characteristics of welded joint. Thus the present study aims to understand the behavior of Boron powder addition into welding process and its influence on mechanical properties during joining of magnesium alloy AZ31 similar alloy butt joint form by Friction Stir Welding which was not studied adequately.

2. MATERIALS AND EXPERIMENTAL PROCEDURE

This chapter includes the details of the experiments that were carried out to complete the purpose of this examination by using friction stir welding process. The welding tool used in the welding process has triangular pin which was specially designed to advance the material flow in the weld zone. The boron powders were adding in to the groove of size 2mm × 5mm throughout the welding process. The welded joints are carried by different welding process parameters by stirring the welding tool over the work pieces. The mechanical properties like tension test, impact test and micro hardness test of welded joints were studied.

2.1 Materials

The material of magnesium alloy AZ31 of 5mm thickness plates and boron powder are used in this study purchased from Andhra steel and chowdary chemical supplier, Fathe Nagar, Hyderabad-500018. The materials when purchased were appearing in flat rectangle shape, the plate of dimension is 5mm thickness & 100x50 mm. The Chemical, physical & thermal composition of Magnesium AZ 31 work material as given below table 2.1 and table 2.2, boron powder supplied to inserting into the each plate groves before welding process for weld joints by laxmi chemical laboratory from Ramkoti. Table 2.3 and Fig 2.1 show the chemical composition and boron powder properties and scanning electron microscopy of the as-received powder respectively. Welding Tool has triangular pin profile and is made tool steel HSS. HSS tool steel consists of tungsten, chromium & molybdenum and vanadium and is identified for its high hardness and good toughness. Below figure 2.2 .

Table 2.1: Nominal chemical composition of AZ 31

Element	Mg	Al	Zn	Si	Mn	Cu	Fe	O
%(Wt)	90.2	8.7	0.95	0.003	0.05	0.03	0.01	0.05

Table 2.2: Physical & Thermal composition of AZ 31

Properties	Strength
Ultimate Tensile strength	230MPa
Yield strength	160MPa
% of Elongation	3
Thermal Conductivity	72 W/m-°K
Melting Temperature	533°C

Figure 2.1: Boron powder

Table 2.3: Properties of Boron powder

Molecular Weight	10.811(gm/mol.)
Appearance	Metalloid
Melting Point	2079 °C
Boiling Point	2550 °C
Density	2.08 g/cm3
Specific Heat	0.125 Cal/g/K
Thermal Conductivity	27.4 W/(m·K)
Vickers Hardness	50-58 MPa

Figure 2.2: HSS Triangular taper pin tool

Process Parameters

There were totally 4 different process parameters used in the experimental procedure and 4 experiments were conducted with boron powder. The parameters are listed in the below table.

Table 2.4: parameters used for welding joints

Experiment No.	Tool Speed(RPM)	Feed (mm/min)	Tilt angle (^{o})
1	900	25	1^{o}
2	900	40	1.5^{o}
3	1200	25	1.5^{o}
4	1200	40	1^{o}

2.2 MECHANICAL JOINING OF SIMILAR AZ31 BY FSW

Friction stir wending is a solid state welding process with no spark produced for welding commercially used for joining types of alloys of aluminum, magnesium, copper light and weighty ferrous and nonferrous material and etc. The setup has been installed over this semi automated milling machine knee type vertical milling machine. This has a capability of rpm ranges from 50 to 1800 rpm and welding speed ranges from 16 to 800 mm/min which made achievable to do number of experiments by varying welding speed and rotational speed and tool holding spindle can be rotated either direction maximum traverse length of machine table is 500 mm over which work piece is kept For conducting actual experiments it requires a fixture which can hold the welding plates firmly and prevents the rotary and translator motions. Fixture has been correctly installed on milling machine bed is as shown in below picture.

The FSW of AZ31 on semi-automated milling machine. The FSW is on totally on 4 pairs of similar AZ31 and boron particle powder. Out of 4 pairs of welding plate's 1-4 pair and boron powder are FSW with triangular taper pin tool. Butt joint formation has been prepared to fabricate FSW joints. Single way welding procedure has been used to fabricate the joints with friction stir welding tool with boron powder and attempt has been made to find out effect of difference on mechanical properties of FSW joints. AZ31 being the hard metal was placed on the both advancing side and retreating side and the weld was carried out using the required parameters. For the joints made with boron powder a groove was made from the centre of the plates. the boron powder was filled into the grooves manually and then the plates were fixed on to the fixture using the backing plate and fastened using bolts.

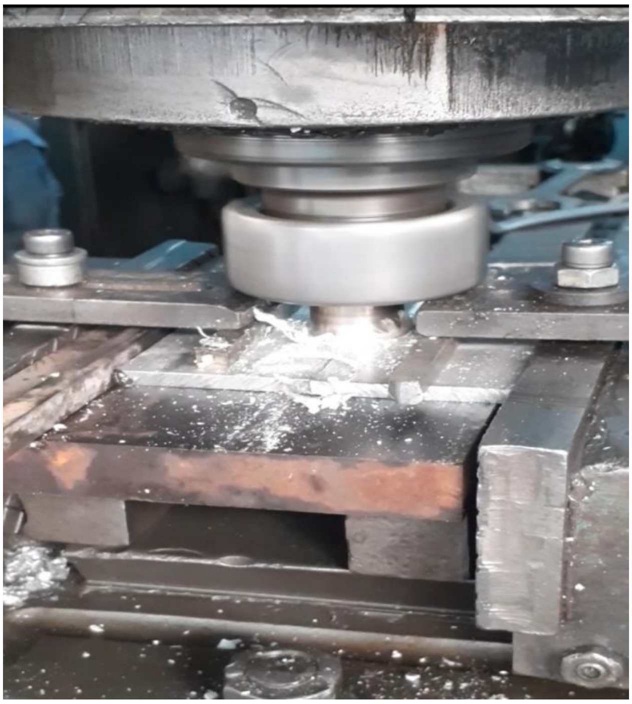


Figure 2.3: FSW process onAZ31 plates being welded with Boron powder

Welded joints are obtained with different process parameters. The process parameters used are 900rpm and 1200rpm, welding speed of 25 mm/min and 40mm/min and tilt angle of 1^{0} and 1.5^{0} respectively.

Weld joints:

The weld joints produced using these parameters are shown in the below figure.

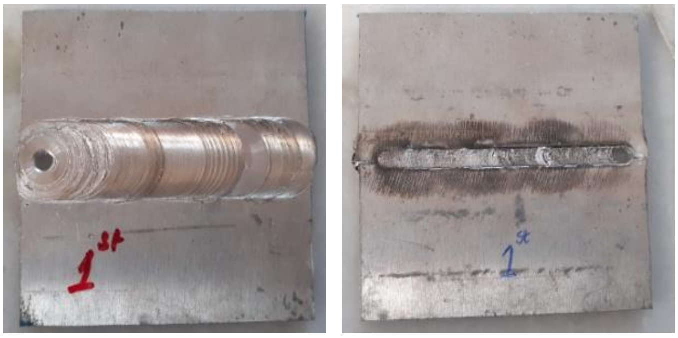


Figure 2.4: Welded sample 01 of AZ31 at vertical milling machine

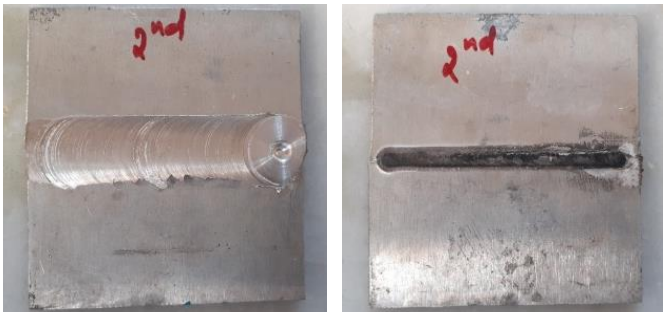


Figure 2.4a: Welded sample 02 MgAZ31

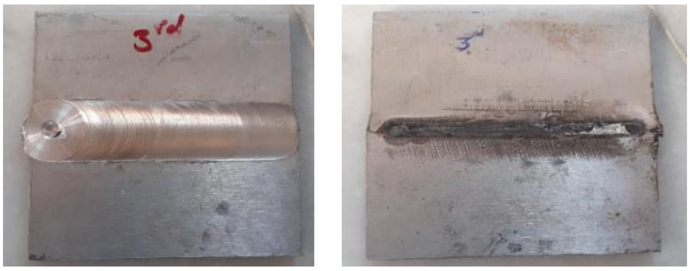


Figure 2.5: Welded Samples 03 of AZ31

Figure 2.6: Welded sample no.4 of AZ31

The tensile test was conducted on UTM-Universal Testing Machine as need the work piece is of ASTM E8-15 is obtained by EDM wire cut machine. ASTM E8-15 Tensile test sample (Dog Bone Shape) was obtained from the FS welded sample having depth of 5mm, Gauge length as 56mm, Fillet radius as 10mm and shoulder length 35mm as shown in the Figure 2.8. The friction stir welded tensile test specimens are shown in the figure 2.9.

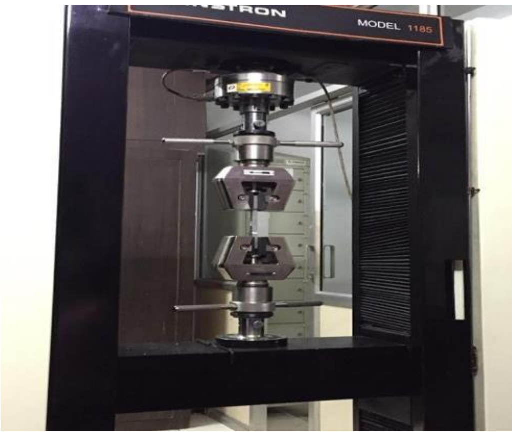


Figure 2.7: specimen mounted over the universal testing machine

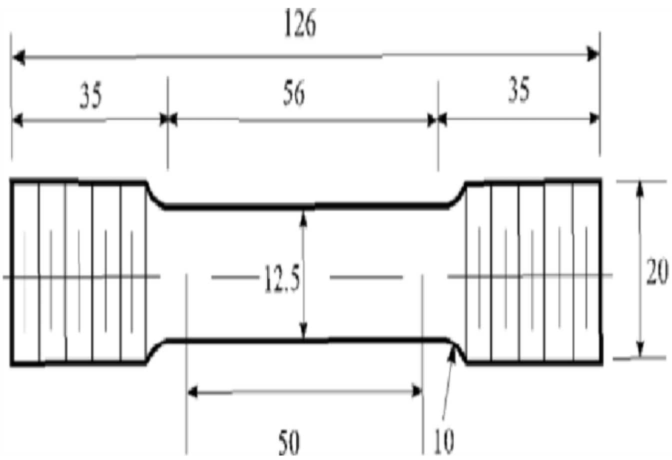


Figure 2.8: tensile specimen

Figure 2.9: samples for tensile test after EDM wire cut machine

The charpy impact test was conducted by using impact testing machine, the test specimen are shown in the figure 2.10 and 2.11. The energy engrossed by the weld piece is calculated from the height the arm swings to after striking the sample. A notched job is commonly used to conclude impact energy and notch sensitivity. The ASTM370 specimen is having dimensions of 5X10X55mm. ASTM370 standard to EDM wire cut for charpy impact test shown the below figure.

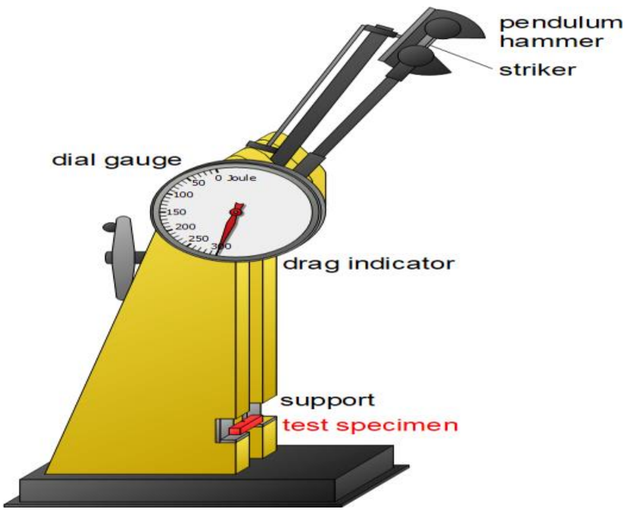


Figure 2.10: Charpy impact test machine

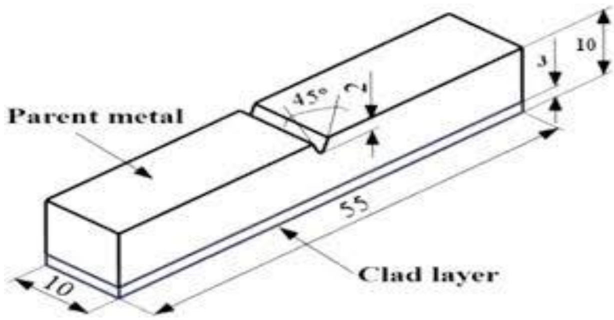


Figure 2.11: ASTM370 for charpy impact test

Similarly the Micro hardness test is conducted by Vickers hardness testing machine as shown in the figure 2.12. The specimen with smooth surface finish was prepared properly for micro hardness test. Current practice divides hardness testing into two categories: macro hardness and micro hardness. Macro hardness refers to testing with applied loads on the indenter of more than 1 kg and covers, for example, the testing of tools, dies, and sheet material in the heavier gages. In micro hardness testing, applied loads are 1 kg and below, and material being tested is very thin (down to 0.0125 mm, or 0.0005 in.). Applications include extremely small parts, thin superficially hardened parts, plated surfaces, and individual constituents of materials.

micro hardness test usually refers to static indentations made with loads not exceeding 1 kgf. The indenter is either the Vickers diamond pyramid. The procedure for testing is very similar to that of the standard Vickers hardness test, except that it is done on a microscopic scale with higher precision instruments. ASTM e384-17 standard to EDM wire cut for micro Hardness.

Figure 2.12: digital micro hardness tester

Figure 2.13: micro hardness test samples from EDM wire cut

3. RESULTS AND DISCUSSION

In the present investigation the results of friction stir welded aluminium alloys by the addition of reinforcements are given below along with the simulation analysis. It has been observed that the process parameters play an important function during of metals by FSW process.

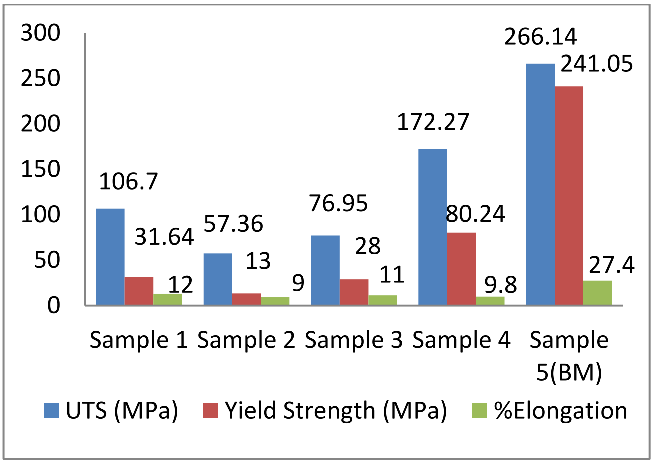
3.1 TENSILE TEST

Tensile test was conducted by using UTM and the results are given in following table 3.1. The parameter range of tool rotational speed 1200 rpm and welding speed of 40 mm/min and tilt angle 1^0 can gives the high range of Tensile Strength than other parameters. The tensile samples after the test are shown in the figure 3.1 below.

The reading obtained while performing the tensile test are shown below in table3.1

Table 3.1: Showing Reading Recorded while the tensile test

Weld Sample No	Tool speed (RPM)	Feed rate (mm/min)	Tilt angle (0^o)	Tensile test	
				UTS (MPa)	Yield Strength (MPa)
W 1	900	25	1	106.7	31.64
W 2	900	40	1.5	57.36	13.26
W 3	1200	25	1.5	76.95	28.65
W 4	1200	40	1	172.2	80.24
(BM)	-	-	-	266.1	241.05



Graph 3.1: UTS and yield strength and %elongation graphs

- From the above data we can clearly notice that Highest peak stress is 172.27 MPa for Hexagonal Tool pin profile at 900 rpm , 40mm/min weld speed, 1^0 tilt angle on UTM.

Figure 3.1: Tensile Test specimen after Break.

3.2 CHARPY IMPACT TEST

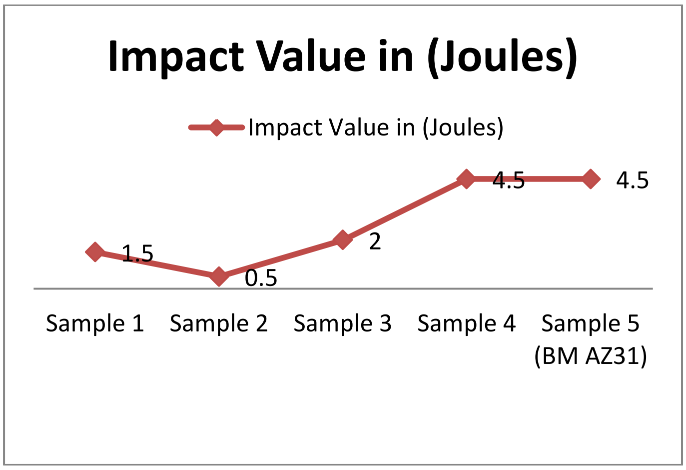
Charpy impact test was conducted by using impact tester machine and the results are given in following table 3.2. The parameter range of tool rotational speed 1200 rpm and welding speed of 40 mm/min and tilt angle 1^0 etc. can gives the high range of impact value than other parameters. The impact samples after the test are shown in the figure.

- The reading obtained while performing the charpy impact test are shown below in table 3.2:

Table 3.2: Showing Reading Recorded while the charpy impact test

Observed Values in Joules	
Sample ID	**Impact Value in (Joules)**
Sample 1	1.5
Sample 2	0.5
Sample 3	2.0
Sample 4	4.5
(Base Material)	4.5

Figure 3.2: Impact test specimen after break



Graph 3.2: Graph of charphy Impact Value

3.3 MICROHARDNESS TEST

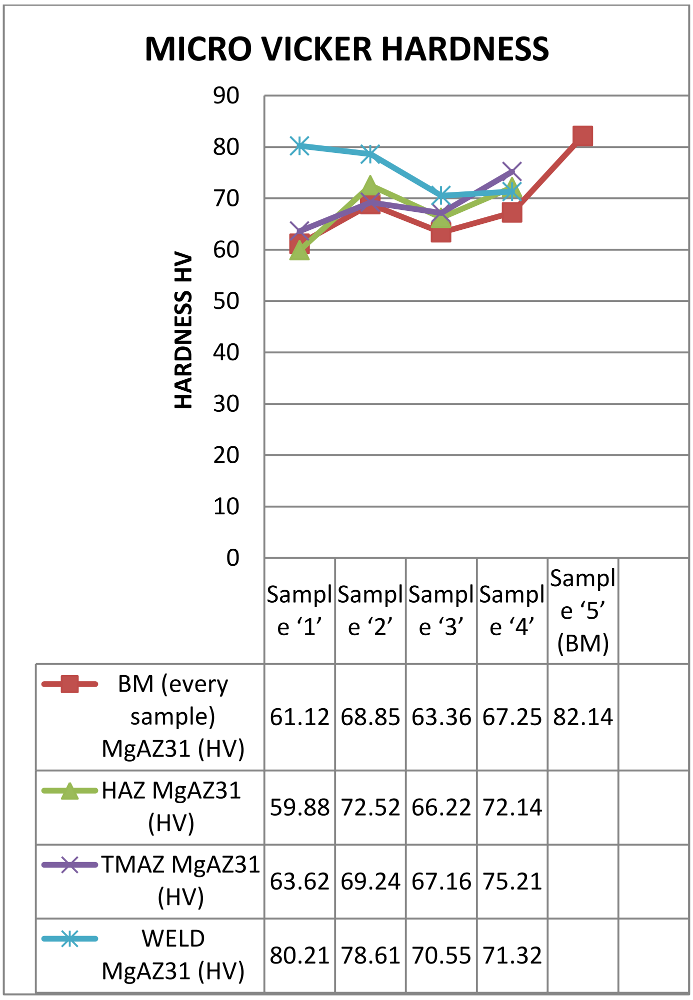
The micro hardness test conducted on Vickers hardness tester to the welded specimen was measured using pyramid diamond intender for various welded specimens with varying rotational speed and transfer speed were prepared and tested. Hardness values consider under micro scale. Form the Vickers hardness 80.21HV at the welding speed of 25 mm/min and the tool rotational speed of 900 RPM & tilt angle 1^o is given good range of hardness value 80.21 HV.

Micro hardness test is carried in four different zones:

a.) Weld zone or Nugget Zone b) TMAZ c) HAZ zone and finally the d) parent material Zone.

Table 3.3: Reading is recorded while the micro hardness tester

Weld No.	BM AZ31 (HV)	HAZ AZ31 (HV)	TMAZ AZ31 (HV)	WELD AZ31 (HV)	Load Applied (gram force)
W'1'	61.12	59.88	63.62	80.21	100gf
W'2'	68.85	72.52	69.24	78.61	
W'3'	63.36	66.22	67.16	70.55	
W'4'	67.25	72.14	75.21	71.32	
BM'5'	82.14,				



Graph 3.3: Graph hardness test report.

Figure 3.3: Vicker hardness sample after the test

4. CONCLUSIONS

In this investigation an attempt has been made to study the effect of boron powder in the weld joint of similar magnesium alloy AZ31. The tensile properties, hardness, impact properties have been obtained, it is concluded that

- The tensile strength is higher in the joints made with boron powder.
- By using boron powder in the friction stir weld joints only the hardness has also been improved and the other properties of the weld joint have reduced.
- The optimums parameter that was observed in the investigation are at 1200RPM, feed rate of 40 mm/min and tool angle 1^0 degrees.
- The maximum tensile stress obtained is 172.27 KN and elongation% of 9.84%.
- The maximum impact value obtained is 4.5 joules at 1200Rpm and welds speed 40 mm/min & tilt angle 1^0.
- The maximum Vicker hardness obtained is 80.21HV in nugget zone (weld zone or stir zone) at 900Rpm, weld speed 25mm/min and tilt angle 1^0.

REFERENCES

[1] R.S. Mishra, Z.Y. Ma, "Friction stir welding and processing" Materials Science and Engineering" Volume 50, Issues 1-2, 31 August 2005, Pages 1-78.
[2] V.PARADISO,F.RUBINO 2007. Dissimilar friction stir welded joints between2024-T3 aluminium alloy and AZ31 magnesium alloy. Mater. Trans. 48,2501–2505.
[3] GALVAO et.al. Microstructure evolution and mechanical properties of friction stir welded dissimilar joints of Mg–Zn–Gd and Mg–Al Zn alloys,2016, Material Science and Engineering, A664(2016)103–113.
[4] COLEGROVE et.al, Dissimilar friction stir welding between 5052 aluminum alloy and AZ31 magnesium alloy,2010,Transaction of nonferrous metals society of china 20.
[5] K VENKAT et, al. Study of mechanical and metallurgical properties of friction stir welded aluminium alloys AA2014 & AA6082 by the addition titanium dioxide nanoparticles and its simulation analysis, Volume: 07 Issue: 11 | Nov 2020 www.irjet.net p-ISSN: 2395-0072.
[6] CAVALIERE et.al ,Softening behavior of friction stir welded Al 6061-T6 and Mg AZ31B alloys,2011, Science and Technology of Welding and Joining 2011 vol 16 no 3.
[7] Yan J, Xu Z, Li Z, Li L, Yang S. Microstructure characteristics and performance of dissimilar welds between magnesium alloy and aluminum formed by friction stirring. Scripta Materialia. 2005;53:585-9.
[8] Kwon, Y.J., Shigematsu, I., Saito, N., 2008. Dissimilar friction stir welding between magnesium and aluminum alloys. Mater. Lett. 62, 3827–3829.
[9] P.VENKATESWARAM, 2010a. Al-to-Mg friction stir welding: effect of material position, travel speed, and rotation speed. Metall. Mater. Trans. A 41, 2914–2935.
[10] A.FORCELLESE Experimental Analysis of Friction Stir Welding of Dissimilar Alloys AA6061 and Mg AZ31 Using Circular ButtJoint Geometry,2016 Procedia Technology 23 ,pp 566 – 572.
[11] Y. Zhao et.al, Effect of travel speed on the microstructure of Al- to-Mg FSW joints,2016, Material science and Technology.volume32 issue 10.
[12] M.TABASI Dissimilar friction stir welding of 7075 aluminum alloy to AZ31 magnesium alloy using SiC nanoparticles,2015, TheInternational Journal of Advanced Manufacturing Technology, Volume 86, Issue 1, pp 705–715.
[13] FUJII et.al. Joining of AZ31 and AZ31 Mg alloys by friction stir welding, 2015, Journal of Magnesium and Alloys 3 ,pp 330–334.
[14] Ravinder Reddy Baridula, Ramgopal Varma Ramaraju, Che Ku Mohammad Faizal Bin Che Ku Yahya and Abdullah Bin Ibrahim. Effect Of Groove Size On Mechanical Properties and Microstructures Due To Reinforcement Addition In FSW Dissimilar Alloys. ARPN Journal of Engineering and Applied Sciences VOL. 12, NO. 20, OCTOBER 2017.
[15] Satish V. Kailas, Satyam Suwas,, Effect of Mechanical Mixing in Dissimilar Friction Stir Welding of Aluminum to Titanium with Zinc Interlayer.
[16] M. Dadashpour a,n, A.Mostafapour b, R.Yeşildal a, S.Rouhi, Effect of process parameter on mechanical properties and fracture behaviorofAZ91C/SiO2 composite fabricated byFSP Materials Science & Engineering A655(2016)379–387.
[17] *Ravinder Reddy* Baridula1*, *Che Ku Mohammad* Faizal Bin Yahya1, *Ramgopal Varma,* Ramaraju2 and *Abdullah Bin* Ibrahim1, Effect of Welding Speed on Microstructure and Mechanical Properties due to The Deposition of Reinforcements on Friction Stir Welded Dissimilar Aluminium Alloys[AA2014-AA7075], MATEC Web of Conferences **135**, 00039 (2017) DOI: 10.1051/matecconf/201713500039.
[18] Ravinder Reddy Baridula, Abdullah Bin Ibrahim and Mohammad Faizal Bin Che Ku, Effect of Rotational speed on mechanical properties and microstructure due to the addition of reinforcements on friction stir welded dissimilar aluminium alloys [AA5052 –AA6063], The National Conference for Postgraduate Research 2016, University Malaysia Pahang

[19] Ravinder Reddy Baridula1 Ramgopal Varma Ramaraju2 Abdullah Bin Ibrahim1 Mohammad Faizal Bin Che Ku Effect of Nano Particle Deposition on Mechanical Properties of Friction Stir Welded Dissimilar Aluminium Alloys by Taguchi Technique Trans Indian Inst Met (2017) 70(4):1005–1017
[20] S Ravikumar, V Seshagiri Rao and RV Pranesh, 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, 2014, 4(1), 101-114.
[21] A Pradeep and S Muthukumaran, An Analysis to Optimize the Process Parameters of Friction Stir Welded Low Alloy Steel Plates, International Journal of Engineering, Science and Technology, 2013, 5(3), 25-35.
[22] Dr. Ch.S.Naga Prasad, Experimental Investigation and Finite Element Analysis of Fristion Stir Welding of Two Disimilar Materias, IJRMET Vol. 7, IssuE 2, May - ocT 2017.
[23] Takashi Nakamura, Toshiyuki Obikawa, Eitaro Yukutake, Satoru Ueda, Itaru Nishizaki, Tool Temperature and Process Modeling of Friction Stir Welding, Modern Mechanical Engineering, 2018, 8, 78-94.
[24] Dr.M.Chandra Sekhar Reddy, B.Eswaraiah,Anthati Naveen Kumar,Experimental Investigations and finite element analysis of friction stir welding of various aluminium alloys,IJERT:2278-0181,2017.

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