ISSN : 2394-2975 (Online)
ISSN : 2394-6814 (Print)

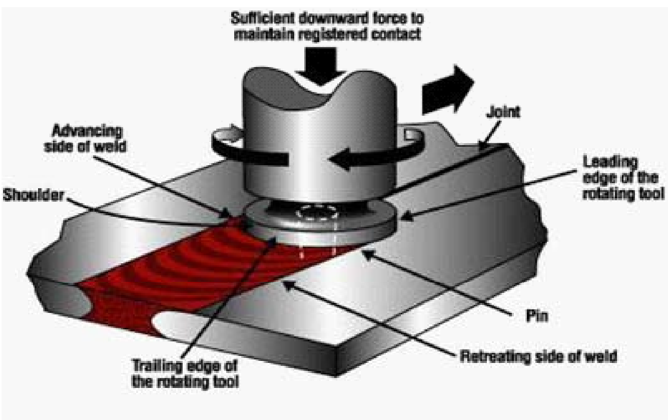
To Optimize Maximum Tensile Strength & Analysis of Microstructure of FSW on Magnesium Alloy by ANOVA Techniques

[I]Krishan Kant, [II]Lalit Kumar, [III]Kanika Verma, [IV]Umesh Gupta, [V]Naveen Kumar
[I,II,III,IV,V]Assistant Prof. in Mechanical Engineering Department, Chandigarh University, Gahuran, Mohali

Abstract
In this paper, Friction Stir Welding is a solid-state process, which means that the objects are joined before reaching the melting point.A good quality friction stir weld requires a proper tool material selection for the desired application. After conducting the pilot experimentation it has been observed that input parameters like tool rotational speed, tool feed rate and tool pin profiles have some significant effect on the mechanical properties of the weld samples. For the optimization of process, design of final experiments was made according to Taguchi's L9 orthogonal array. The S/N ratios available depending on type of characteristic: lower is better (LB), nominal is best (NB), larger is better (LB). Larger is better S/N ratio was used here. Analysis of variance (ANOVA) test was performed to identify the average performance of process parameters that are statistically significant and The joining of magnesium alloy was successfully carried out using FSW technique. The samples were characterized by mechanical properties like tensile strength, impact strength, Vicker hardness. The following conclusions were made from the present investigation. Observed that the speed is 500 R.P.M and Feed is 50 mm/min with a cylindrical threaded tool was best to maximize the tensile strength, The fine structure in the weld may be divided into three regions: fine re-crystallized grains around the weld centre, the grains in the base metal highly elongated and pancake shaped and grain having great deformation in TMAZ. Compared with the BM, very fine grains were present in the SZ, due to dynamic recrystalization.

Keyword
FSW, Mg Alloy, DOF, Analysis Of Variance (ANOVA)

Introduction
Friction Stir Welding is a solid-state process, which means that the objects are joined before reaching the melting point.A good quality friction stir weld requires a proper tool material selection for the desired application. All friction stir tools contain features desired for specific function. The tool material used for friction stir welding should have following characteristics if the tool wear is excessive it changes the shape of the tool thus changing the weld quality and the probability of defects is also increased. During the friction stir welding process tool wear can occur by adhesive, abrasive or chemical wear mechanisms.



Tool fracture toughness plays a significant role during tool plunge and dwell. The local stresses and strain produced when the tool touches the work piece are sufficient to break a tool. Therefore the material of the tool used for friction stir welding should have high fracture toughness. The surface properties of the tool get changed if the tool reacts with the work piece or the environment. Titanium is well known for its reaction at elevated temperature and reaction of titanium with the tool material will change the tool properties. Therefore material of the tool is selected in such a way that it must not react with work piece or the environment in order to maintain its properties. If pin and shoulder material has a large difference in coefficient of thermal expansion it leads to either expansion of the shoulder relative to pin or expansion of pin relative to shoulder. In both of the situations there is an increase in the stresses between the pin and shoulder which can lead to failure of the tool. Tools consist of a shoulder and a probe which can be integral with the shoulder or as a separate insert possibly of a different material. The design of the shoulder and of the probe is very important for the quality of the weld. The probe of the tool generates the heat and stirs the material being welded but the shoulder also plays an important part by providing additional frictional treatment as well as preventing the plasticised material from escaping from the weld region..

Final Experimentation
After conducting the pilot experimentation it has been observed that input parameters like tool rotational speed, tool feed rate and tool pin profiles have some significant effect on the mechanical properties of the weld samples. For the optimization of process, design of final experiments was made according to Taguchi's L9 orthogonal array.

Taguchi's L9 orthogonal array

SR. NO.	TOOL ROTATION	WELDING SPEED	TOOL PIN PROFILE
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Tensile Test

Observation table for tensile test

Sr. No	Tool rotation (RPM)	Welding Speed (mm/min)	Tool pin profile	Tensile strength (TS) (MPa)		
				TS1	TS2	TS3
1	400	50	Taper threaded	87.40	89.40	86.50
2	400	60	Cylindrical threaded	148.90	147.28	145.36
3	400	70	Grooved threaded	106.40	105.20	104.10
4	500	50	Cylindrical threaded	172.10	169.17	170.40
5	500	60	Grooved threaded	114.80	112.54	111.74
6	500	70	Taper threaded	101.143	102.20	102.27
7	600	50	Grooved threaded	118.85	117.93	119.13
8	600	60	Taper threaded	141.9	143.01	142.02
9	600	70	Cylindrical threaded	128.92	131.56	130.40

Results and Discussions

ANALYSIS OF TENSILE STRENGTH

S/N Ratio Analysis

The term "Signal" represents the desirable value (mean) for the output characteristics and the term "noise" represents the undesirable value for the output characteristic. The S/N ratio is uses to measure the quality characteristic deviating from the desired value in Taguchi method.

Experimental results for tensile strength, S/N ratios, mean ratio of FSW welds

Sr. No.	Tool rotational speed (RPM)	Tool feed rate (MM/MIN)	Threaded tool pin profile	Tensile strength	S/N Ratio	Mean ratio
1	400	50	Taper	87.8	38.87	87.77
2	400	60	Cylindrical	147.2	43.36	147.18
3	400	70	Grooved	105.2	40.44	105.23
4	500	50	Cylindrical	170.6	44.64	170.56
5	500	60	Grooved	113.0	41.06	113.03
6	500	70	Taper	101.9	40.16	101.87
7	600	50	Grooved	118.6	41.48	118.64
8	600	60	Taper	142.3	43.06	142.31
9	600	70	Cylindrical	130.3	42.30	130.29

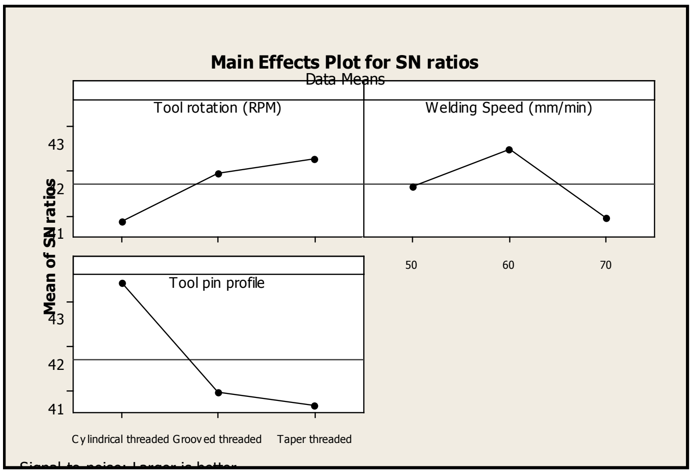
From the above signal to noise ratios of each level of factor it is concluded that the optimum factor level to achieve Optimum tensile strength is 170.6 MPa which are having maximum s/n ratios and maximum mean ratio i.e. speed is 500 R.P.M and Feed is 50 mm/min with a cylindrical threaded tool

Response table for S/N ratio Larger is better

Level	Tool rotational speed (RPM)	Tool feed rate (MM/MIN)	Tool pin profile
1	40.89	41.66	43.43
2	41.95	42.50	41.00
3	42.28	40.97	40.70
DELTA	1.39	1.53	2.73
RANK	3	2	1

ISSN : 2394-2975 (Online)
ISSN : 2394-6814 (Print)

The S/N ratios available depending on type of characteristic: lower is better (LB), nominal is best (NB), larger is better (LB). Larger is better S/N ratio was used here. From the delta values it assigns the rank to each factor which are having more influence on the mean of percentage of elongation, from the results of S/N ratio also it is observed that tool pin profile is the dominant factor for tensile behaviour.



Main effects plot for S/N ratio

Based on the above graph, the optimum conditions for the tensile strength are (a) 600 rpm speed (b) 60 mm/min feed (c) cylindrical threaded

Response table for mean Larger is better

Level no	Tool rotational speed(RPM)	Tool feed rate (MM/MIN)	Tool pin profile
1.	113.4	125.7	149.3
2.	128.5	134.2	112.3
3.	130.4	112.5	110.6
DELTA	17.0	21.7	38.7
RANK	3	2	1

From the delta values it assigns the rank to each factor which are having more influence on the mean of % of elongation, from the results of mean ratio also it is observed that tool pin profile is the dominant factor for tensile strength.

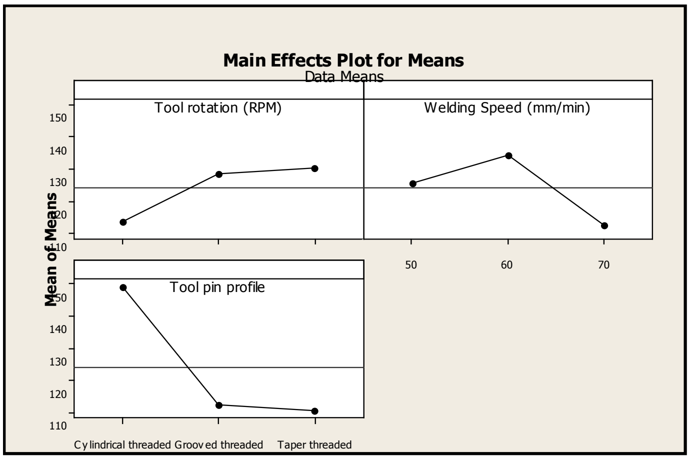


Fig 5.2 : Main effects plot for mean ratio

Based on the above graph, the optimum conditions for the tensile strength are (a) 600 rpm speed (b) 60 mm/min feed (c) cylindrical threaded

5.1.2 Analysis Of Variance (ANOVA)

Analysis of variance (ANOVA) test was performed to identify the average performance of process parameters that are statistically significant

Table 5.4 : One-way ANOVA: Tensile strength versus Tool rotation

Source	DOF	SS	MS	F	P
Tool rotation (rpm)	2	521	261	0.32	0.037
Error	6	4862	810		
Total	8	5384			

S=98.47 R-Sq. = 96.68% R-Sq. (adj.) = 95.97%

Table 5.5 : One-way ANOVA: Tensile strength versus Welding speed

Source	DOF	SS	MS	F	P
Welding Speed(mm/min)	2	59.4	29.7	0.46	0.04
Error	6	389.6	64.9		
Total	8	449.0			

S=98.058 R-Sq. = 93.22% R-Sq.(adj.)=96.54%

Table 5.6 : One-way ANOVA: Tensile strength versus Tool pin Profile

Source	DOF	SS	MS	F	P
Tool pin					
Profile	2	521	261	0.32	0.034
Error	6	4862	810		
Total	8	5384			

S=98.47 R-Sq. = 94.68% R-Sq. (adj.)=95.056%

DOF—Degrees of freedom,SS—Sequencial sum of squares,SS—Adjusted sum of square,MS—Adjusted mean square,SS'—Pure sum of squares, F—Fisher ratio, P—Probability that exceeds the 95 % confidence level. In addition, larger F-value indicates the variation of process parameters makes big change on performance. The Smaller p-value, P<0.05(1-0.95), greater the significance of the process parameter. The purpose of the ANOVA test is to investigate the significance of the process parameters which affect the tensile strength of FSW joints. The ANOVA results for tensile strength v/s tool rotation, welding speed, tool pin profile of means and S/N ratio are given in Tables 5.4, 5.5 and 5.6 respectively. In addition, the F-test named after Fisher can also be used to determine which process has a significant effect on tensile strength. The results of ANOVA indicate that the considered tool pin profile are highly significant factors affecting the tensile strength of FSW joints in the order of rotational speed, traverse speed.

Confirmation Experiment

Results show that the confirmation result is between 5% of the calculated value of tensile strength i.e 165.7 MPa and the confirmed

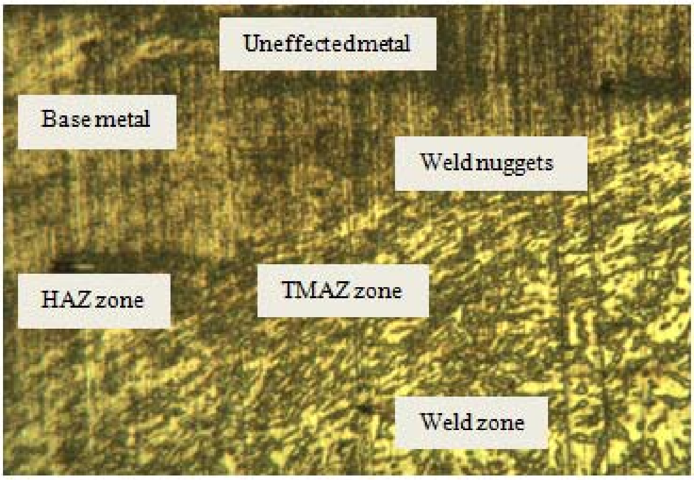
ISSN : 2394-2975 (Online)
ISSN : 2394-6814 (Print)
Vol. 3, Issue 2 (April - June 2016)
International Journal of Advanced Research in Education & Technology (IJARET)

value is 169.4 MPa.

5.4 Analysis of Microstructure Testing

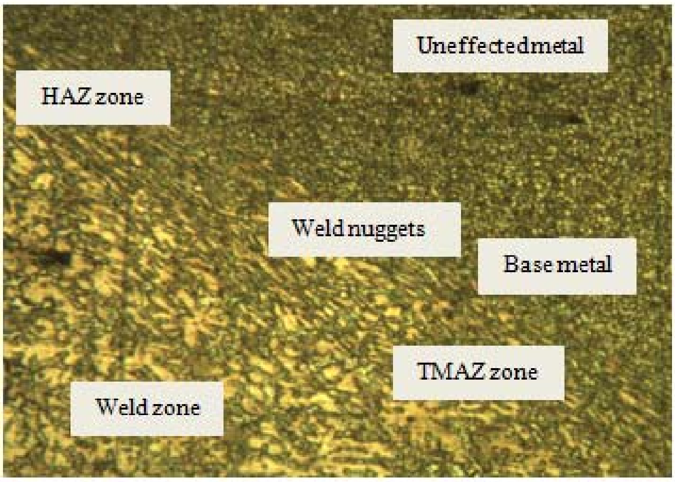
Picral etchant was used to etch AZ 91 Mg alloy of the weld. A solution of 1.5 g picric acid, 1.25 ml acetic acid, 2.5 ml distilled water,25 ml ethnol was used to bring out the lamellar-like shear bands and fine microstructure in the intercalated weld zone. Shows an overview of the cross-section of joint, and the microstructure in the base metal (BM), thermo mechanically affected zone (TMAZ) and stir zone (SZ) are shown in Figs. 8.1–8.9, respectively. The BM exhibits a typical solidification microstructure formed in the casting process. The grains in the TMAZ were greatly deformed due to the friction heat and mechanical deformation, and the grains have an obvious orientation along the metal-flow direction induced by stirring. The SZ contains fine recrystallized grains instead of dendritic ones, and the intermetallic compound seems to be uniformly dispersed in the SZ.

Weld sample 1



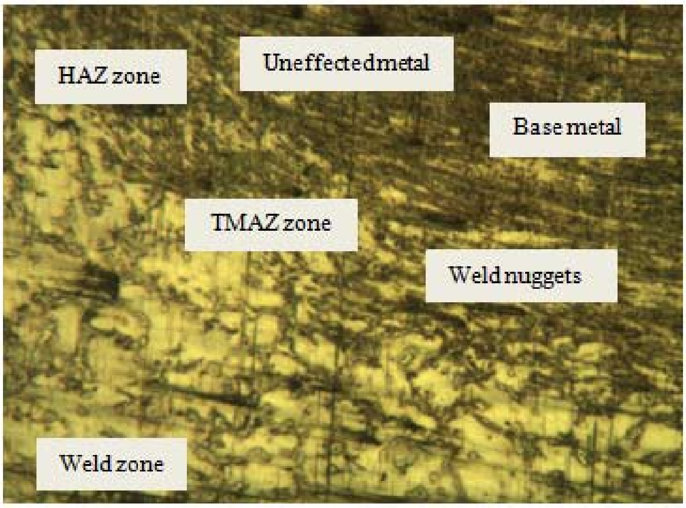
Microstructure of fusion zone(100X)

Weld sample 2



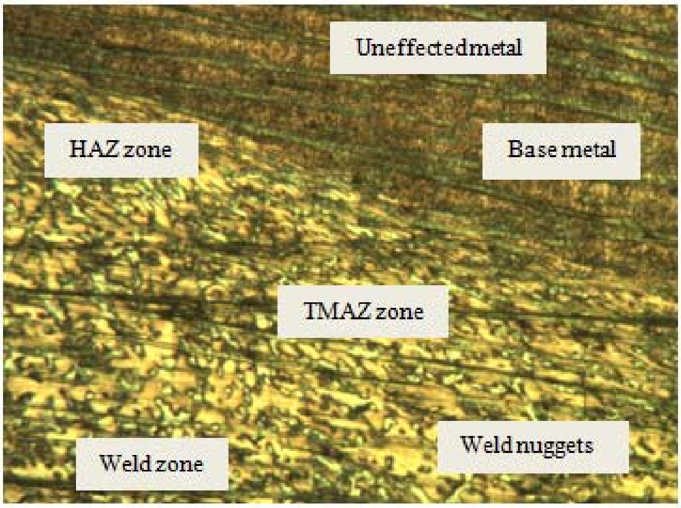
Microstructure of fusion zone(100X)

Weld sample 3



Microstructure of fusion zone(100X)

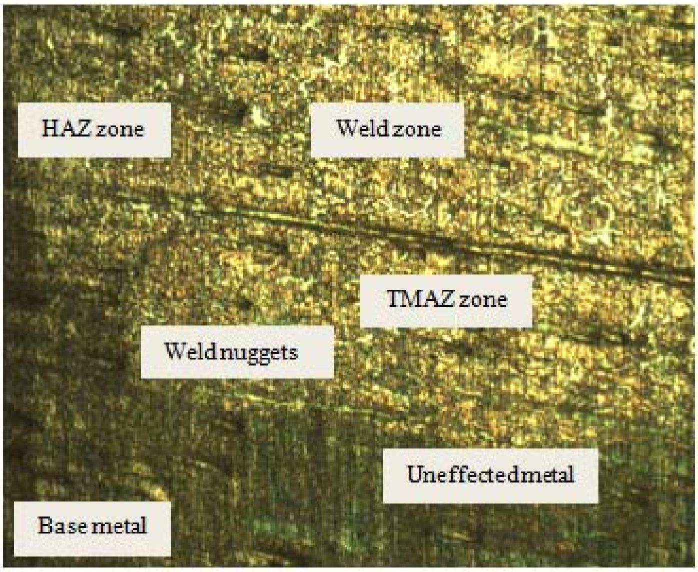
Weld sample 4



Microstructure of fusion zone(100X)

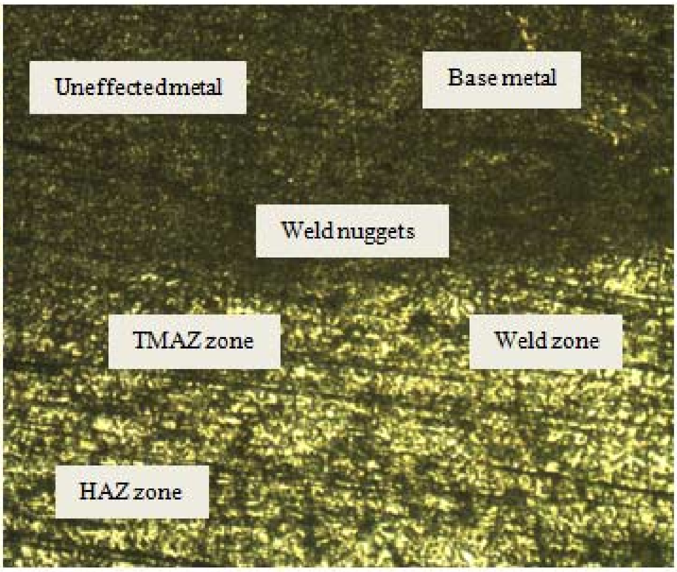
Vol. 3, Issue 2 (April - June 2016)
ISSN : 2394-2975 (Online)
ISSN : 2394-6814 (Print)

Weld sample 5



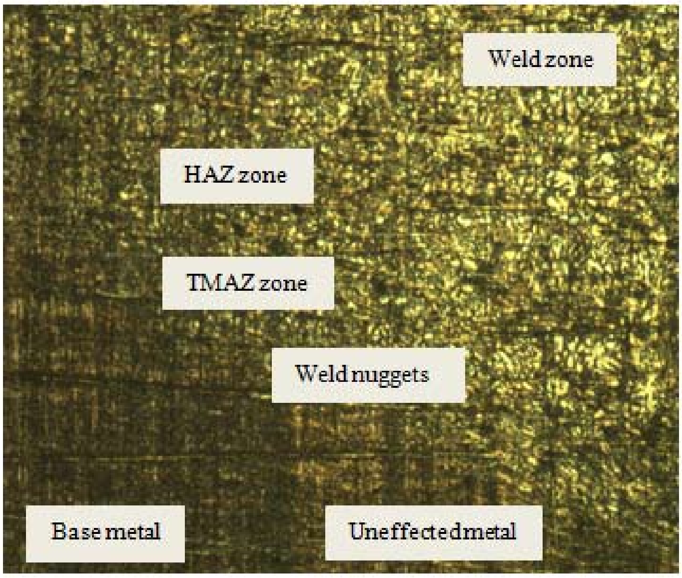
Microstructure of fusion metal (100X)

Weld sample 6



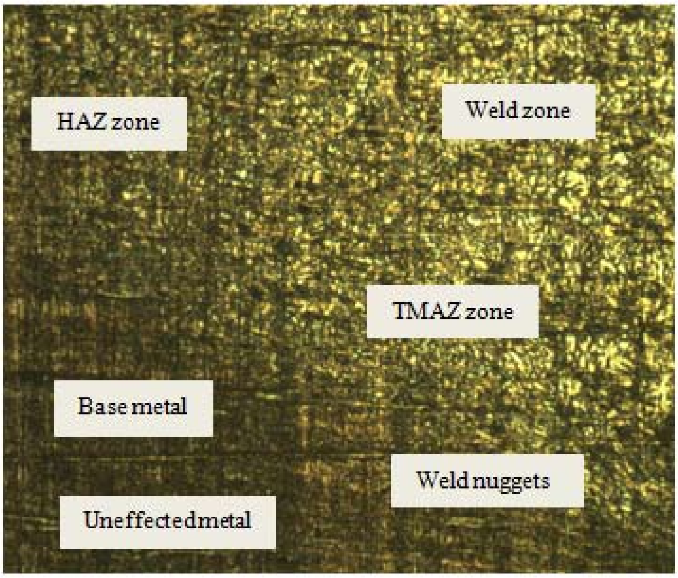
Microstructure of fusion zone(100X)

Weld sample 7



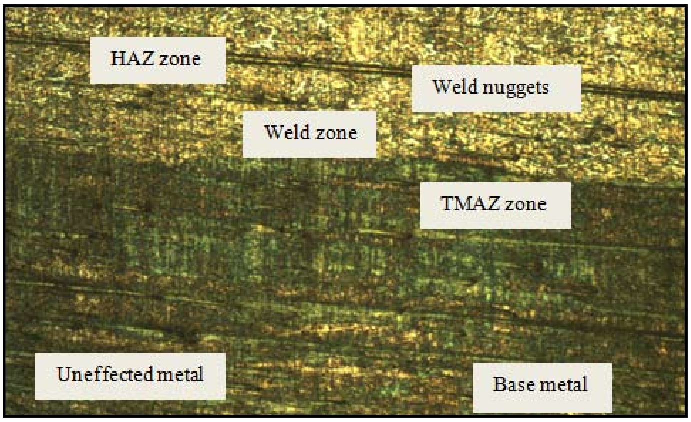
Microstructure of fusion metal (100X)
Fig. 5.13

Weld sample 8



Microstructure of fusion zone(100X)
Fig. 5.14

Weld sample 9



Microstructure of fusion metal (100X)

After FSW, the microstructures of the SZ, consisting almost entirely of dynamically recrystallized Mg grains and intermetallic compounds, tend to disappear, due to their dissolution at elevated temperature.

Conclusion

The joining of magnesium alloy was successfully carried out using FSW technique. The samples were characterized by mechanical properties like tensile strength, impact strength, Vicker hardness. The following conclusions were made from the present investigation

1. Observed that the tool pin profile having more influence on the mean of tensile strength, impact strength, vicker Hardness.
2. Observed that the speed is 500 R.P.M and Feed is 50 mm/min with a cylindrical threaded tool was best to maximize the tensile strength.
3. The fine structure in the weld may be divided into three regions: fine re-crystallized grains around the weld center, the grains in the base metal highly elongated and pancake shaped and grain having great deformation in TMAZ. Compared with the BM, very fine grains were present in the SZ, due to dynamic recrystalization.

Rferences

[1]. Ahmadi H, Arab M.N.B, Ghasemi F.A, Farsani R.E (2012), "Influence of Pin Profile on Quality of Friction Stir Lap Welds in Carbon Fiber Reinforced Polypropylene Composite". International Journal of Mechanics and Applications, Vol.2, pp. 24-28.

[2]. Bahemmat P, Rahbari A, Haghpanahi M, Besharati M.K (2008), "Experimental Study on the Effect of Rotational Speed and Tool Pin Profile on AA2024 Aluminium Friction Stir Welded Butt Joints". ASME Early Career Technical Conference, pp. 1.1-1.7.

[3]. Balamurugan K.G, Mahadevan K, Pushpanathan D.P (2012), "Investigations on the Effect of Tool Types on the Mechanical Properties of Friction Stir Processed AZ31B Magnesium Alloy".Journal of Mechanical and Civil Engineering, Vol. 2, pp. 44-47.

[4]. Bilici M.K, (2012), "Effect of Tool Geometry on Friction Stir Spot Welding of Polypropylene Sheets." Express Polymer Letters, Vol.6, pp. 805–813.

[5]. Bishnoia R.N, Saprab P.K, Bhambhu (2013), "Effect of Tool Pin Profile on Mechanical Properties of Single and Double Sided Friction Stir Welded Aluminium Alloy AA19000." International Journal of Current Engineering and Technology, Vol.3, pp.138-1341.

[6]. Choi D H, Ahn B.W, Lee C.Y, Yeon Y.M, Song K , Jung S.B (2010), "Effect of Pin Shapes on Joint Characteristics of Friction Stir Spot Welded AA5J32 Sheet Materials Transactions". Vol. 51, pp. 1028- 1032.

[7]. Dalu S.G, Shete M. T (2013), "Effect of Various Process Parameters on Friction Stir Welded Joint a Review." International Journal of Research in Engineering and Technology, Vol.2, pp.555-558.

[8]. Ding R.J, Athens, Oelgoetz P.A, Huntsville (1998), "Auto-Adjustable Pin Tool for Friction Stir Welding". United States Patent, patent number 5,893,507, pp.1-7.

[9]. Devana R.J, Anilkumar S.H, Biju S (2015),"Numerical studies on effect of welding tool geometry and welding force on friction stir welding of AL2221."pp. 1-9.

[10]. Elangovan K, Balasubramanian V, Valliappan M (2008), "Influences of tool pin profile and axial force on the formation of friction stir processing zone in AA6061 aluminum alloy". International Journal Advanced Manufacturing Technology, Vol. 38, pp.285–295.