IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

EFFECT OF DIFFERENT TOOL PIN PROFILE ON THE MECHANICAL PROPERTIES OF MAGNESIUM BASED ALLOY AZ91 BY FRICTION STIR WELDING

Naveen Kumar *, Manjit Singh
[*1]M.Tech Research Scholar, RIMT College of Engineering & Technology, Mandigobindgarh, Punjab, India
[*2]Associate Professor, RIMT College of Engineering & Technology, Mandigobindgarh, Punjab, India

ABSTRACT
The usage of magnesium in automotive applications is also assessed for the impact on environmental conservation. Recent developments in coating and alloying of Mg improved the creep and corrosion resistance properties of magnesium alloys for elevated temperature and corrosive environments. The results of the study conclude that reasonable prices and improved properties of Mg and its alloys will lead to massive use of magnesium. Compared to using alternative materials, using Mg alloys results in a 22% to 70% weight reduction. The joining of magnesium alloy was successfully carried out using FSW technique. . In this paper effect of different tool pin profile on mg az 91 alloy is calculated by using FSW Welding. The samples were characterized by mechanical properties like tensile strength, impact strength, Vicker hardness and microstructure. The nominal chemical composition of AZ-91 magnesium alloy is 9% Aluminium (Al) and 1 % Zinc (Zn) and balance Mg. The FSW was carried out using CNC vertical milling machine .The optimum results by taguchi L9 method are carried out at a rotational speed of 500 RPM and feed is 50 mm/min with a cylindrical threaded tool was best to maximize the tensile strength and Observed that the 600 rpm, 70 mm/ min feed and cylindrical threaded was best to maximize the impact strength. The best to minimize the vicker hardness at rotational speed the 600 rpm and 60 mm/ min feed and taper threaded. 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.

Keywords: **:** Magnesium alloys, Friction stir processing, tensile strength, impact strength, vicker hardness and taguchi L9 method.

INTRODUCTION
The Welding Institute in Cambridge, England has developed a method of joining materials by friction stir welding. This method employs a tool having a pin which is plunged into and stirs the material to be joined to a plastic state. The pin preferably has threads for forcing the plasticized material downward and backward. When the pin is moved along the laying surface the plasticized material flows from the front of the pin downward and to the rear of the pin as the pin translates the faying surface. A shoulder at the top of the pin keeps plasticized material from leaving the joint region [Holt et al.].A rapidly rotating cylindrical pin tool is then slowly plunged into the centerline of the joint until the shoulder of the pin tool comes into contact with the work piece surface. Heating causes the material yield strength to decrease and, as the pin tool moves along the joint, material moves around the pin tool closing the joint behind the tool. As a solid state welding method, FSW can avoid all the welding defects caused by the melting and solidification in fusion welding and has more versatility than traditional friction welding which normally is limited to small axis symmetric parts [Melendez et al.(2001)].

ISSN: 2277-9655
(I2OR), Publication Impact Factor: 3.785

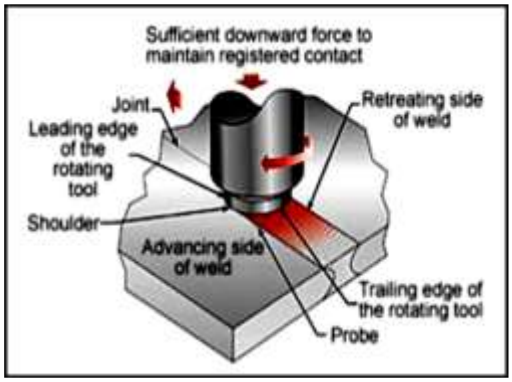

Fig. 1.1 Two metal plates butted together, along with the tool [Leal et al.(2010)].

Magnesium alloys are the most attractive materials in recent transportation industries where weight reduction is of prime importance. Magnesium alloys are 35% lighter than aluminum alloys and 78% lighter than steel. However, the mechanical properties of magnesium alloys are not commendable. This limitation restricts the usage of magnesium alloys in many end applications.. Alloying magnesium with aluminum, manganese, rare earths, thorium, zinc or zirconium increases the strength to weight ratio making them important materials for applications where weight reduction is important, and where it is imperative to reduce inertial forces. Because of this property, denser material, not only steels, cast iron and copper base alloys, but even aluminum alloys are replaced by magnesium-based alloys. The requirement to reduce the weight of car components as a result of legislation limiting emission has created renewed interest in magnesium. Auto manufacturing companies have made the most of research and development on Mg and its alloys. Volkswagen was the first to apply magnesium in the automotive industry on its Beetle model, which used 22 kg magnesium in each car of this model. Porsche first worked with a magnesium engine in 1928 .Magnesium average usage and projected usage growth per car are given as 3 kg,20 kg, and 50 kg for 2005, 2010 and 2015, respectively . In the past aluminum and some plastic have been used as the preferred material for some auto parts. In recent years magnesium applications in the auto sector have been increasing. Recent research and development studies of magnesium and magnesium alloys have focused on weight reduction, energy saving and limiting environmental impact [Balamurugan et al.(2012)].

EXPERIMENTAL PROCEDURE

A. Welding tools used during friction stir welding.

The tools used for FSW were made of High speed steel tool . The design of the tool is a critical factor as a good tool can improve both the quality of the weld and the maximum possible welding speed.

Fig. 2.1 Cylindrical Threaded Tool

The high speed steel raw material has been taken the tool materials. The tool was designed based on the chuck of the radial drilling machine. Then the tool was heat treatment applied to increase the hardness. Improvements in tool design have been shown to cause substantial improvements in productivity and quality.

Fig. 2.2 Grooved Threaded Tool

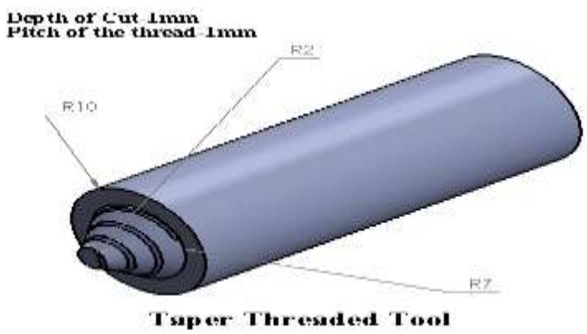

Fig. 2.3 Taper Threaded tool

TWI has developed tools specifically designed to increase the depth of penetration and so increase the plate thickness that can be successfully welded.

B. Experimental Material

The material used for the experimental work was magnesium AZ 91 plates with dimensions (300mmx50mmx7mm).

Fig. 2.4 Magnesium AZ 91 plates

C. Equipment Used For Conducting The Experimental Work

Equipment Used For Conducting The Experimental Work The CNC vertical milling machine was used for making the weld joints which available at CTR Ludhiana with following specifications such as type of machine - CNC milling machine, Travel capability of x = 1600, y = 800, z = 750, Running speed limit of 30 – 7500 rev/min and load application of 1800 kg. A fixture is generally used to hold the work piece firmly during the welding process. The various forces acting on the work piece are the transverse force that acts parallel to the tool motion, downward and upward forces due to the plunging, torque due to the rotation of the tool and lifting of the tool during welding process respectively.

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FINAL EXPERIMENTATION

A. ANALYSIS OF TENSILE STRENGTH

S/N Ratio Analysis

ISSN: 2277-9655
(I2OR), Publication Impact Factor: 3.785

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.

Table 3.1 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.

Table 3.2 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

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 % of elongation, from the results of S/N ratio also it is observed that tool pin profile is the dominant factor for tensile behaviour.

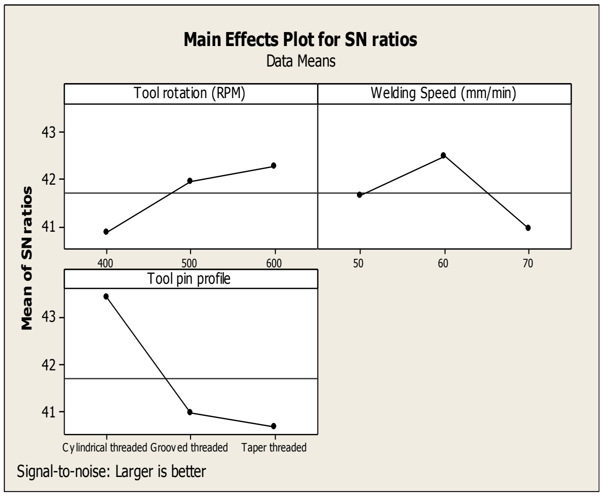

Fig 3.1 Main effects plot for S/N ratio

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

Table 3.3 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.

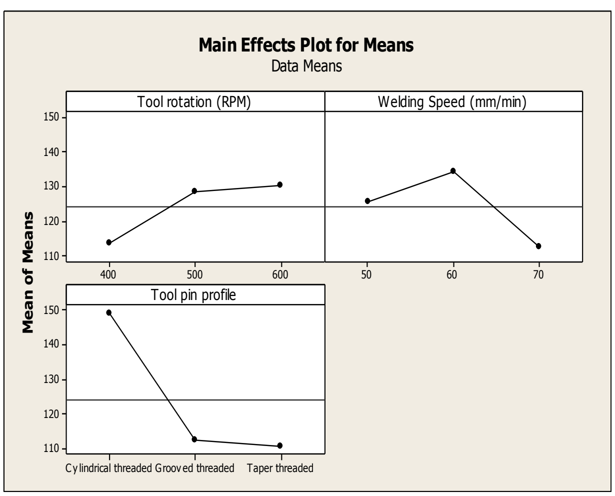

Fig 3.2 Main effects plot for mean ratioBased on the above graph, the optimum conditions for the tensile strength are (a) 600 rpm speed (b) 60 mm/min feed (c) cylindrical threaded

Analysis Of Variance (ANOVA)

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

Table 3.4 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 3.5 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 3.6 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%

DF─Degrees of freedom, Seq SS─Sequencial sum of squares, Adj SS─Adjusted sum of square, Adj 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.

B. ANALYSIS OF IMPACT 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.

Table 3.7 Experimental results for impact strength, S/N ratios

Sr. no.	Tool rotational speed (RPM)	Tool feed rate (MM/MIN)	Threaded tool pin profile	Impact strength	S/N ratio	Mean ratio
1	400	50	Taper	35.33	30.96	35.33
2	400	60	Cylindrical	44.67	33.00	44.67
3	400	70	Grooved	26.67	28.52	26.67
4	500	50	Cylindrical	32.67	30.28	32.67
5	500	60	Grooved	26.00	28.30	26.00
6	500	70	Taper	31.33	29.92	31.33
7	600	50	Grooved	34.00	30.63	34.00
8	600	60	Taper	26.00	28.30	26.00
9	600	70	Cylindrical	46.00	33.26	46.00

From the above signal to noise ratios of each level of factor it is concluded that the optimum factor level to achieve Optimum impact strength is 46 J/m2 which are having maximum s/n ratios and maximum mean ratio i.e. speed is 600 R.P.M and Feed is 70 mm/min with a cylindrical threaded tool.

Table 3.8 Response table for S/N ratio larger is better

Level no.	Tool rotational speed (RPM)	Tool feed rate (MM/MIN)	Tool pin profile
1	30.83	30.63	32.18
2	29.50	29.87	29.15
3	30.73	30.56	29.73
DELTA	1.33	0.76	3.03
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 S/N ratio also it is observed that tool pin profile is the dominant factor for tensile behaviour.

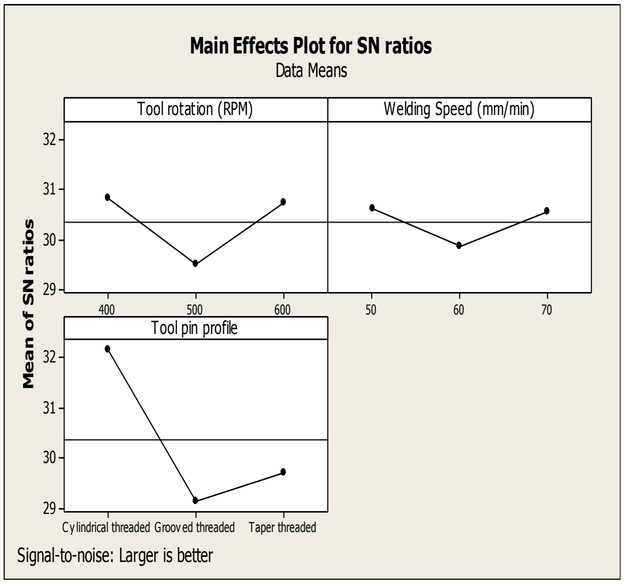

Fig 3.3 Main effect Plot for SN ratios

Based on the above graph, the optimum conditions for the tensile strength are (a) 600 rpm speed (b) 70 mm/min feed (c) cylindrical threaded.

Table 3.9 Response table for Mean ratio larger is better

Level no.	**Tool rotational speed (RPM)**	**Tool feed rate (MM/MIN)**	**Tool pin profile**
1	35.56	34.00	41.11
2	30.00	32.22	28.89
3	35.33	34.67	30.89
DELTA	5.56	2.44	12.22
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.

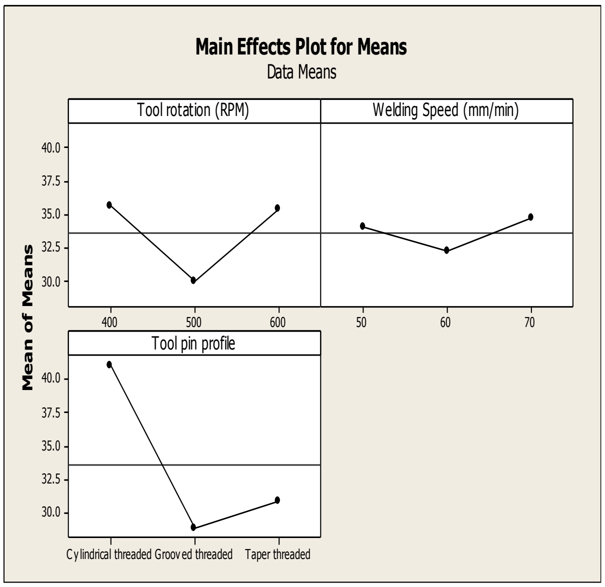

Fig 3.4 Main effect plot for Means

Based on the above graph, the optimum conditions for the tensile strength are (a) 600 rpm speed (b) 70 mm/min feed (c) cylindrical threaded

Analysis Of Variance (ANOVA)

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

Table 3.10 One-Way ANOVA: Tensile Strength Versus Tool Rotation

Source	**DOF**	**SS**	**MS**	**F**	**P**
Tool rotation (RPM)	2	59.4	29.7	0.46	0.024
ERROR	6	389.6	64.9		
TOTAL	8	449			

S=98.0587 R-Sq. = 93.22% R-Sq.(adj.)=97.11%

Table 3.11 One-way ANOVA: Tensile strength versus Welding speed

Source	**DOF**	**SS**	**MS**	**F**	**P**
Tool rotation (RPM)	2	9.6	4.8	0.07	0.037
ERROR	6	439.4	73.2		
TOTAL	8	449			

S=98.558 R-Sq. = 92.13% R-Sq. (adj.) = 96.52%

Table 3.12 One-way ANOVA: Tensile strength versus Tool pin profile

Source	**DOF**	**SS**	**MS**	**F**	**P**
Tool rotation (RPM)	2	257.9	128.9	4.05	0.047
ERROR	6	191.1	31.9		
TOTAL	8	449.0			

S=95.644 R-Sq. = 97.44% R-Sq.(adj.)=93.25%

DF─Degrees of freedom, Seq SS─Sequencial sum of squares, Adj SS─Adjusted sum of square, Adj 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 5.10,5.11and 5.12 respectively..The results of ANOVA indicate that the rotational speed are highly significant factors affecting the impact strength of FSW joints in the order of, traverse speed and Tool pin profile.

C. ANALYSIS OF VICKER HARDNESS

Analysis of Vicker Hardness

Table 3.13 Response table for S/N ratios

Level no.	**Tool rotational speed (RPM)**	**Tool feed rate (MM/MIN)**	**Tool pin profile**
1	-40.22	-40.32	-40.93
2	-40.25	-40.12	-39.86
3	-40.06	-40.08	-39.72
DELTA	0.91	0.23	1.20
RANK	3	2	1

From the above signal to noise ratios of each level of factor it is concluded that the optimum factor level to achieve.

Optimum impact strength is 96 Hv which are having minimum s/n ratios and minimum mean ratio i.e. speed is 600 R.P.M and Feed is 60 mm/min with a Taper threaded.

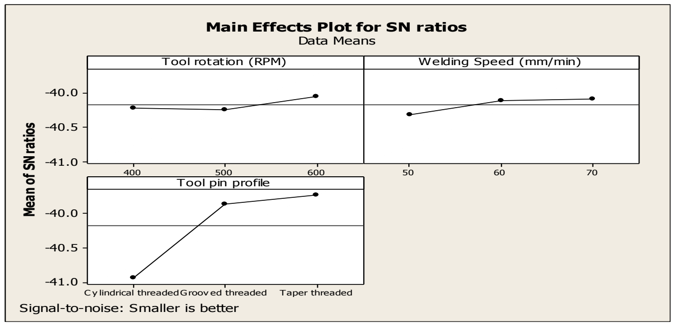

Fig 3.5 Main effects plot for S/N ratio

Based on the above graph, the optimum conditions for the vicker hardness are (a) 400 rpm speed (b) 50 mm/min feed (c) cylindrical threaded.

Table 3.14 Experimental results for vicker strength,S/N ratios and mean ratio

Sr. no.	**Tool rotational speed(RPM)**	**Tool feed rate (MM/MIN)**	**Threaded tool pin profile**	**Vicker hardness**	**S/N ratio**	**Mean ratio**
1	400	50	Taper	98.67	-39.88	98.67
2	400	60	Cylindrical	110.33	-40.85	110.33
3	400	70	Grooved	99.00	-39.91	99.00
4	500	50	Cylindrical	115.33	-41.24	115.33
5	500	60	Grooved	98.33	-39.85	98.33
6	500	70	Taper	96.00	-39.65	96.00
7	600	50	Grooved	98.00	-39.82	98.00
8	600	60	Taper	96.00	-41.65	96.00
9	600	70	Cylindrical	108.33	-40.70	108.33

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 s/n ratio also it is observed that tool pin profile is the dominant factor for Vicker hardness.

Table 3.15 Response table for mean ratio

Level no.	**Tool rotational speed (RPM)**	**Tool feed rate (MM/MIN)**	**Tool pin profile**
1	102.67	104.00	111.33
2	103.22	101.56	98.44
3	100.78	101.11	96.89
DELTA	2.44	2.89	14.44
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 Vicker hardness.

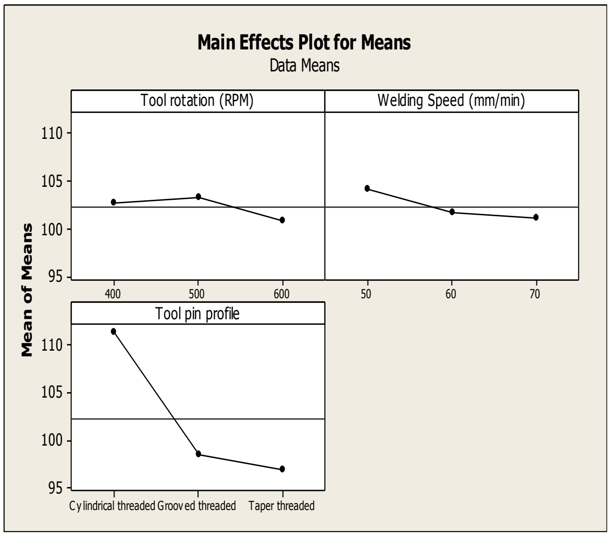

Fig. 3.6 Response table for mean

Based on the above graph, the optimum conditions for the vicker hardness are (a) 600 rpm speed (b) 50 mm/min feed (c) Taper threaded.

Analysis Of Variance (ANOVA)

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

Table 3.16 One-way ANOVA: Tensile strength versus Tool rotation

SOURCE	**DOF**	**SS**	**MS**	**F**	**P**
Tool rotation (RPM)	2	9.9	4.9	0.07	0.05
ERROR	6	398.6	66.4		
TOTAL	8	408.4			

S=98.151 R-Sq. = 92.41% R-Sq.(adj.)=96.85%

Table 3.17 One-Way Anova: Tensile Strength versus Welding Speed

Source	**DOF**	**SS**	**MS**	**F**	**P**
Tool rotation (RPM)	2	14.5	7.3	0.11	0.047
ERROR	6	393.9	65.7		
TOTAL	8	408.4			

S=98.103 R-Sq. = 93.55% R-Sq. (adj.)=97.23%

Table 3.18 One-way ANOVA: Tensile strength versus Tool pin profile

Source	**DOF**	**SS**	**MS**	**F**	**P**
Tool rotation (RPM)	2	377.19	188.59	36.20	0.001
ERROR	6	31.26	5.21		
TOTAL	8	408.44			

S=92.283 R-Sq. = 92.35% R-Sq.(adj.)=89.88%

DF─Degrees of freedom, Seq SS─Sequencial sum of squares, Adj SS─Adjusted sum of square, Adj 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 ANOVA results for vicker hardness v/s tool rotation, welding speed, tool pin profile of means and S/N ratio are given in Tables 5.15, 5.16 and 5.17 respectively. The results of ANOVA indicate that the tool pin profile are highly significant factors affecting the tensile strength of FSW joints in the order of rotational speed, traverse speed.

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. Observed that the 600 rpm, 70 mm/ min feed and cylindrical threaded was best to maximize the impact strength.
4. Observed that the 600 rpm and 60 mm/ min feed and taper threaded was best to minimize the vicker hardness.
5. 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.

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