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## An experimental approach to study the effect of welding parameters on similar friction stir welded joints of AZ31B-O Mg alloy

Inderjeet Singh<sup>a</sup>, Gurmeet Singh Cheema<sup>b\*</sup>, Amardeep Singh Kang<sup>b</sup><sup>a</sup>Chandigarh Engineering College, Landran, Mohali, India<sup>b</sup>Bhai Gurdas Institute of Engineering & Technology, Sangrur 148001, Punjab, India

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### Abstract

In this investigation an attempt has been made to study the effect of friction stir welding parameters on mechanical and metallurgical properties of AZ31B-O Mg alloy joints. The selected material was welded using combination of different parameters i.e. tool rotational speed, welding speed and tool shoulder diameter. The effect of weld pitch i.e. ratio of welding speed to tool rotational speed (0.0020 mm/rev to 0.05 mm/rev) was examined on the mechanical and micro structural properties of friction stir welded joints of AZ31B-O Mg alloy. The linear relationship between tensile strength and weld pitch was observed. The maximum value of tensile strength i.e. 187.8 N/mm<sup>2</sup> was obtained at weld pitch of 0.05 mm/rev using 20 mm tool shoulder diameter. Most of the tensile test specimens fractured in the area between Stir Zone (SZ) and Thermo Mechanical Affected Zone (TMAZ) towards the advancing side. The fine and equiaxed grains were observed due to dynamic recrystallization at higher value of weld pitch.

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**Keywords:** Magnesium alloy; Friction stir welding; Mechanical and Metallurgical properties

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### 1. Introduction

The magnesium alloy is the lightest structural alloy, has low density, high strength to weight ratio, good castability, excellent sound damping capabilities and excellent machinability [1]. Magnesium alloy is considered as

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\* Corresponding author. Tel.: +91-981-560-3024; fax: 01672278529.

E-mail address: [gcheema\\_80@yahoo.com](mailto:gcheema_80@yahoo.com)

advanced material in terms of electromagnetic shielding, energy conservation and environment pollution regulation [2]. But the welding of magnesium alloy is difficult with fusion welding process, due to high thermal conductivity. Fusion welding results in formation of coarse microstructure, porosity, severe deformation and high residual stresses. To expand the applications of magnesium alloy, effective welding techniques are required. The solid welding process would be more suitable process for solving the problems associated with fusion welding process. The friction stir welding process is used to achieve high performance joints of magnesium alloys. Varieties of magnesium alloys have been successfully welded by a solid state joining process in which the heat is generated by a rotating, non-consumable tool that plunges into the base material and moves forward [3]. Friction stir welding has many potential applications in major industries, i.e ship building, aerospace, automobile, railway and many industrial applications [4]. The major advantages of the FSW over convention fusion welding process are high joining speed, autogenous welding, reduced human skill and improved mechanical and metallurgical properties of the weld [5]. The friction stir welding process is not limited to welding alone, it can be used in the processing applications for the grain refinement of wrought and cast alloys [6]. Due to many advantages of the friction stir welding process over the fusion welding process, the friction stir welding process creates the attention in the industrial world. So the objective of this study was to investigate the effect of FSW process parameters on Mechanical and Metallurgical properties of friction stir weldments of AZ31B-O magnesium alloy.

## 2. Experimentation

The material selected for the study was AZ31B-O Mg alloy which has better strength to weight ratio than that of high strength steel. Chemical composition and mechanical properties of the original alloy are presented in Table 1 Table 2 respectively. The material received from supplier was 5 mm thick sheet and the specimen having dimensions 150 mm x 75 was prepared for friction stir welding. Sixteen plates of size 150 mm x 75 mm were prepared to obtain eight friction stir welded joints of size 150 mm x 150 mm with different welding parameters. The milling operation was performed so that interfaces can be properly matched. The vertical milling machine was used for friction stir welding. The setup of process is shown in Figure 1. In the present study trial experimentation was conducted using the different parameters to select the range of the welding parameters. A proper selection of tool material and tool design plays a vital role to achieve good mechanical as well as microstructural properties with friction stir welding process. It has been observed from the Literature that the tool material has a great influence on weld appearance and joint quality [7]. The FSW tool affects the heat generation, material flow, power input, and weld quality. A downward material flow close to the pin surface was observed with left hand thread tool pin due to which the welding porosity located near the bottom surface of the joint was eliminated [8]. The tool used in present work was left handed thread tool pin and the material of tool was high carbon high chromium steel. The tool configuration is presented in Table 3. The appropriate clamps were used to hold the fixture on machine table. The welded joints were made perpendicular to the rolling direction. The experiments were performed as per the parameters mentioned in Table 4. Two welding tools with different shoulder diameters of 18 mm and 20 mm were used, keeping pin diameter and pin length of 7 mm and 4.8 mm respectively.

Table 1 Chemical composition of AZ31B-O Mg alloy

Elements	Si	Fe	Cu	Mn	Zn	Al	Ni	Co	Mg
Wt%	<0.1	<0.005	0.05	0.2-0.5	0.5-1.5	2.5-3.5	0.05	<0.05	Balance

Table 2 Mechanical Properties of AZ31B-O Mg alloy

Material	Tensile Strength (N/mm <sup>2</sup> )	% elongation	Micro hardness (Hv)
AZ31B-O	206	20	50

Table 3 Tool configuration

S.NO	Parameters	Dimensions (mm)
1	Shoulder Diameter	18 and 20
2	Pin Diameter	7
3	Pin Length	4.8
4	Left hand thread	1 mm (pitch)
5	D/d ratio of tool	2.56 and 3

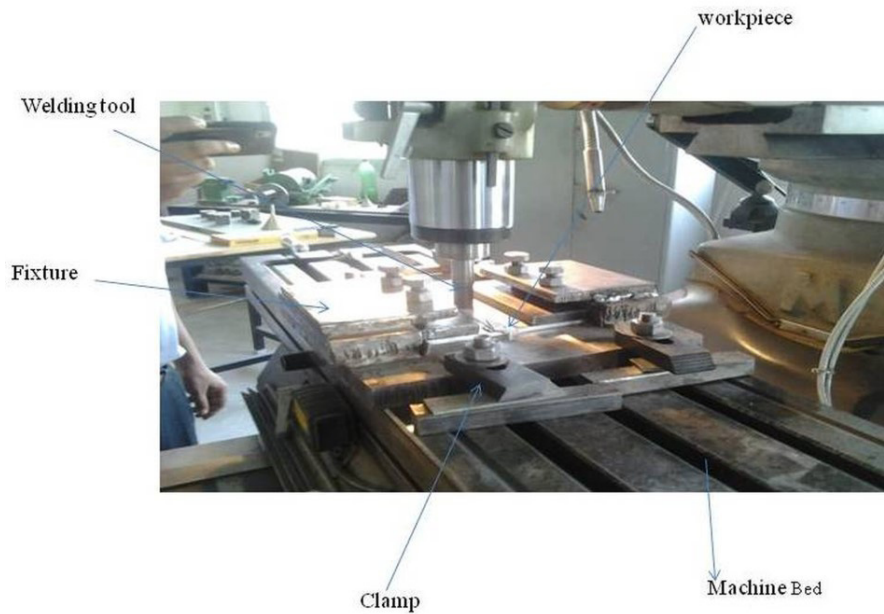


Figure 1 Setup of fixture on Milling Machine Table

Table 4 Process parameters

Specimen No	Welding Speed (S) (mm/min)	Tool Rotational Speed (N) (rpm)	Weld Pitch (mm/rev.)	Tool Shoulder Dia.(mm)
1	40	1950	0.0020	18
2	60	1950	0.0308	18
3	40	1200	0.0333	18
4	60	1200	0.0500	18
5	40	1950	0.0020	20
6	60	1950	0.0308	20
7	40	1200	0.0333	20
8	60	1200	0.0500	20

Note: weld pitch was carried out by dividing welding speed to tool rotational speed.

Visual inspection of all the specimens was carried out and it was observed that specimens welded with tool shoulder diameter of 20 mm shows, better surface texture as compared to other joints welded with 18 mm shoulder diameter. Tensile test specimens were prepared from each weld in accordance with ASTM E-8M-08 specifications [9]. The tensile test specimens, before and after tensile test, are shown in Figure 2 and Figure 3 respectively. Most of the tensile tested specimens have  $45^{\circ}$  shear fracture as shown Figure 4 and  $<$  type fractures were also observed [10].

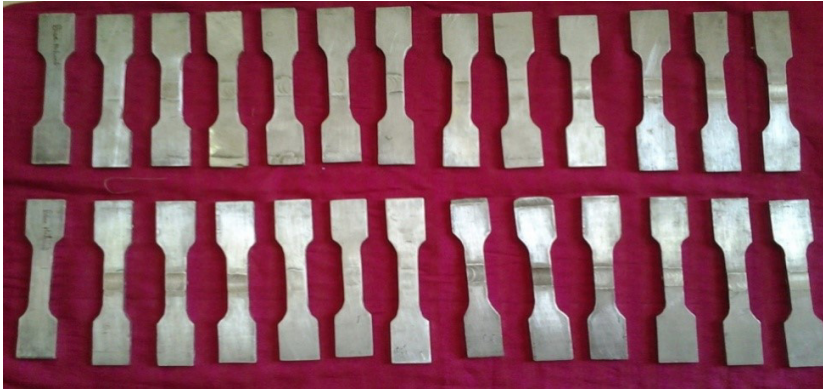


Figure 2 Tensile specimens before tensile testing



Figure 3 Tensile Specimens after testing



Figure 4 Fracture location

The impact test specimens were prepared according to ASTM-23-08 standard guidelines and five impact test specimens for each parameter were tested [11]. The maximum and minimum value of the impact test was ignored and the average of three results was taken and which are presented in Table 5. Standard metallurgical procedure was followed to prepare the metallurgical specimens. All polished specimens were etched by dipping in a standard reagent known as acetic-picral [10 ml acetic acid (99%), 4.2 gram picric acid, 10 ml H<sub>2</sub>O, 70 ml ethanol (95%)] for about 40 seconds and then dried in blast of air after rinsing in ethanol. Specimens were snapped at 200 X and 400 X magnification at stir zone and thermo-mechanical affected zone. Micro indents were made on both directions from center i.e. towards Advancing Side and Retreating Side, at a successive distance of 6 mm. Twelve indents were made on either side excluding the center indent at a load of 0.5 kg for 15 s. Values for the micro hardness of each specimen were calculated and average of the results is presented in Table 5.

Table 5 Experimental results

Specimen No.	Tensile strength (MPa)	Percentage elongation	Impact toughness (J)	Grain size ( $\mu\text{m}$ )	Micro hardness (Hv)
1	140.8	13.77	6	18.4	46.91
2	150.4	13.32	4	17.7	54.20
3	153.9	15.4	5	14.5	64.26
4	159.4	17.03	5	12.4	64.25
5	143.4	12.47	5	15.2	44.02
6	157.5	12.02	7	14.3	51.72
7	170.4	15.32	6	10.3	61.07
8	187.8	16.73	7	9.2	64.77

### 3. Results and Discussion

After experimentation it is very important to describe the results so that they can be generalized. In results and discussion all the findings regarding mechanical properties and micro structural properties observed during the research are discussed in detail. The effect of selected FSW process parameters on all above mentioned properties was analyzed along with their responding reasons of occurrence of such characteristics in Friction stir welded AZ31B-O Mg alloy joints.

#### 3.1. Effect of weld pitch or combined effect of welding speed and tool rotational speed on tensile strength

The specimens were tensile tested, transverse tensile strength and percentage elongation were evaluated for each parameter. Three specimens were tested at each condition and average of the results is presented in Table 5. Variations in tensile strength with welding speed and tool rotational speed have also been observed by various researchers [12]. The combined role of both parameters could be better represented by weld pitch. The relationship between tensile strength and weld pitch is presented in Figure 5. The tensile strength increases significantly as the weld pitch increases with both the shoulder diameters but the tool shoulder diameter 20 mm having higher impact on tensile strength as shown in Figure 5. The maximum tensile strength of 187.8 N/mm<sup>2</sup> and 159.8 N/mm<sup>2</sup> for weld pitch of 0.050 mm/rev. was observed with tool shoulder diameter of 20 mm and 18 mm respectively. All the tensile test specimens fractured between SZ and TMAZ of the advancing side. With increase in the weld pitch, tensile strength of the joints enhanced due to the sufficient heat generation during FSW which led to the formation of fine and equiaxed grains with average grain diameter of 9  $\mu\text{m}$  as observed from the micro graphs (Figure 7 and Figure

8). The grain size decreases with increase in weld pitch, with both the shoulder diameters as presented in Table 5. Due to the appropriate heat input, the cooling rate become slow and ample time was available for grains to grow in size, as a result the grains with smaller average diameter were formed [8]. At the lower weld pitch, heat input was high, the coarse grain with average grain diameter of  $18.4 \mu\text{m}$  was observed, that was the reason of deterioration in the tensile strength. The relationship between the percentage elongation and weld pitch is presented in Figure 6. No large variation, in the percentage elongation was observed with the change in weld pitch. But as compared to the base material elongation, large decrease in elongation was observed.

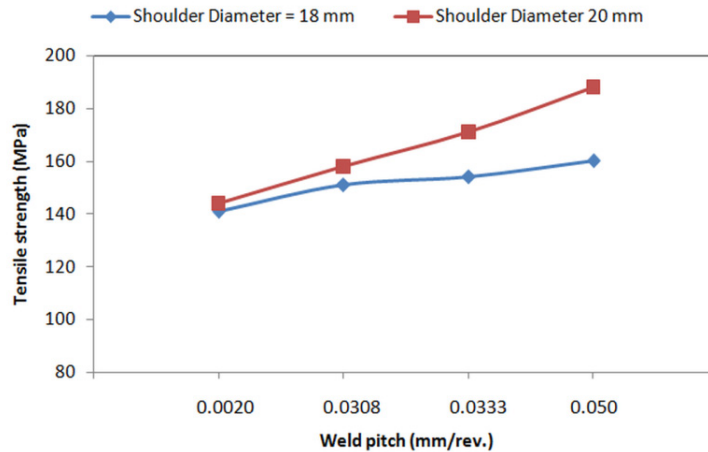


Figure 5 Tensile strength and weld pitch relationship

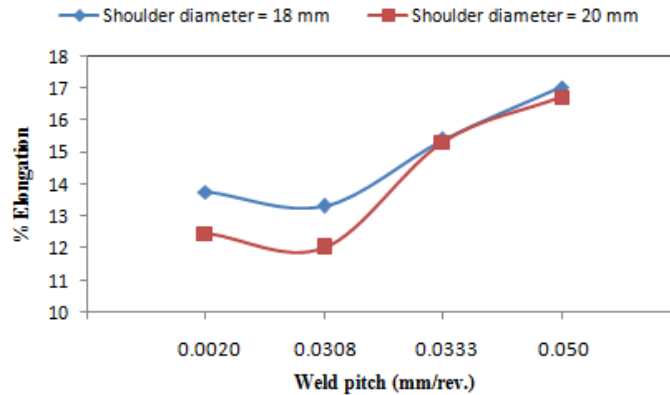


Figure 6 % elongation and weld pitch relationship

### 3.2. Effect of FSW process parameters on Impact toughness

Impact toughness represents resistance of a material, in presence of notch and high strain rate loading. Friction stir welds, in this research work, showed a very interesting trend on impact toughness. In contrast to most of the mechanical properties of weld joints, that were either not altered or slightly deteriorated during FSW of magnesium alloy, impact toughness was the property which improved slightly. The measured value of impact toughness base material was 4 Joules. Welds made by FSW process showed impact toughness values greater than those of the base material (in the range of 4 to 7 Joules). Ductile failures occurred in all the specimens and the failure location of all

the joints was at the notch which was provided at the stir zone. As shown in Figure 7, with increase in the weld pitch, impact toughness of weld joints improved, reaching maximum at the weld pitch of 0.050 mm/rev. When the weld pitch was decreased, the heat input within the stir zone increased due to the higher friction. Higher heat generation causes slow cooling rate and this led to the formation of coarse grains in the SZ, which may be the reason of lower impact toughness at lower weld pitch.

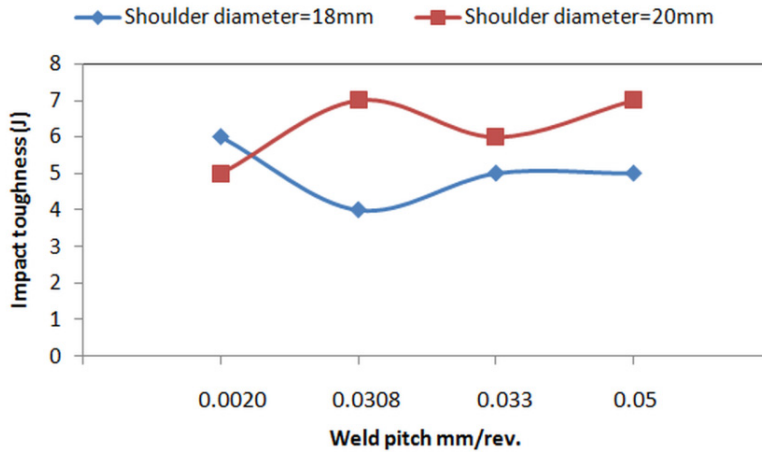


Figure 7 Impact toughness and weld pitch relationship

3.3. Effect of FSW weld pitch and shoulder diameter on microstructural properties

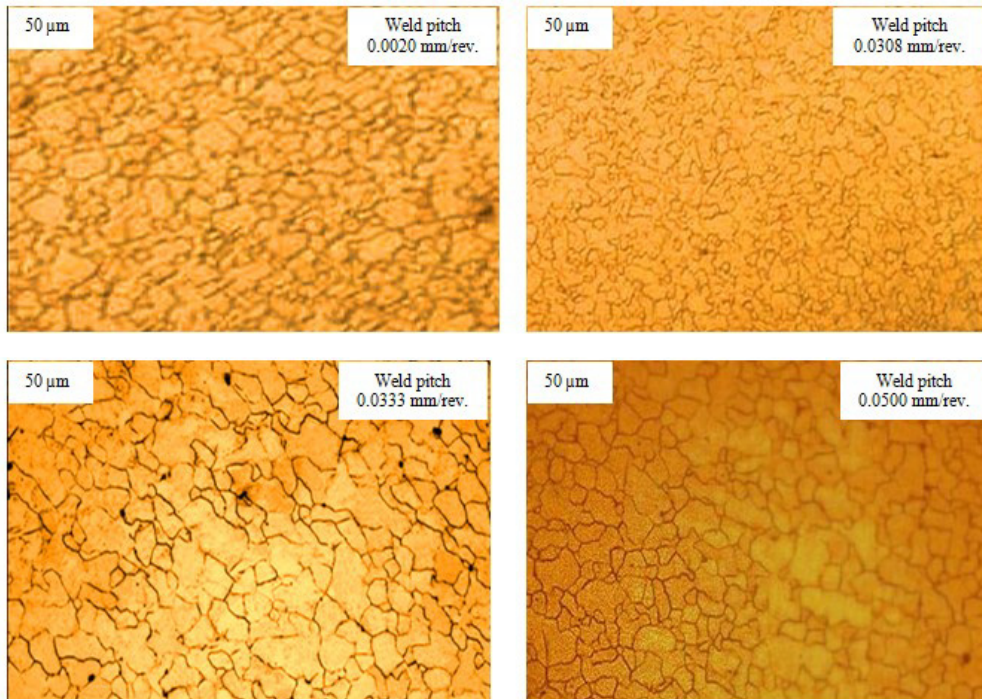


Fig 8 Microstructure of friction stir welded joints at SZ with 18 mm tool shoulder diameter at 200X

The effect of weld pitch on microstructure at Stir Zone of Friction stir welded joint with 18 mm and 20 mm shoulder diameter is presented in Figure 8 and Figure 9 respectively. The base material contains elongated grains as shown in Figure 10. The lighter areas of Figure 8 and Figure 9 represent the grain (crystal) which consists of a space occupied by a continuous crystal lattice. The dark lines surrounding the grains are the grain boundaries. The average size of the grain is an important feature for determining the mechanical and metallurgical properties. A larger grain size increases creep, the permanent deformation that increases with time under a constant load. But at the optimized parameters, fine and equiaxed recrystallized grain structure was observed in SZ due to dynamic recrystallization [13]. In the present study at the weld pitch of 0.050 mm/rev., fine grains having average grain diameter of 9.2  $\mu\text{m}$  were observed with tool shoulder diameter of 20 mm. The microstructure of TMAZ and HAZ towards AS of the specimen No. 4 is illustrated in Figure 11. Recrystallization phenomenon was also observed in the TMAZ even though this was not as noticeable in the HAZ where there was no significant difference in grain structure with respect to base material. It was also observed that grain size increases with decrease in shoulder diameter.

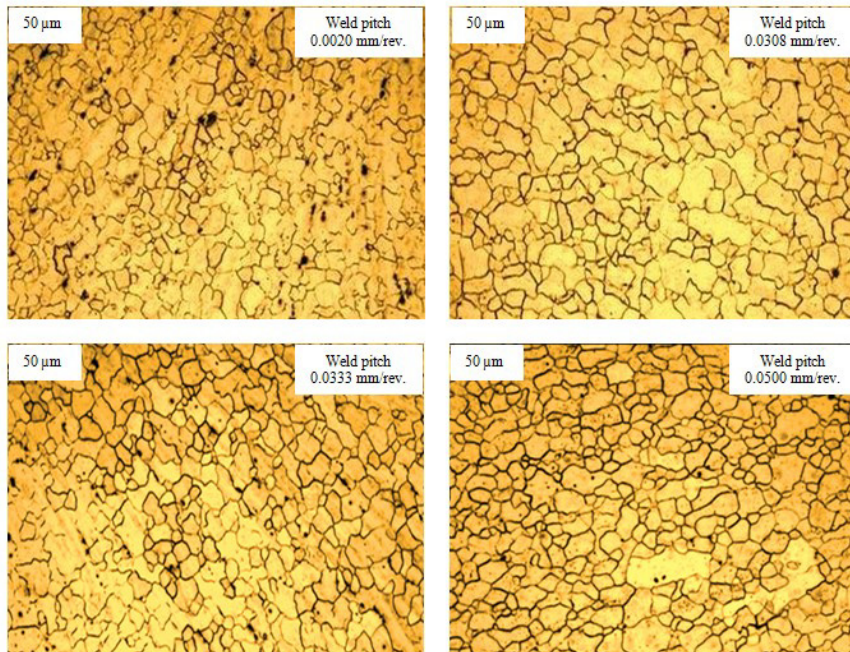


Figure 9 Microstructure of friction stir welded joints at SZ with 20 mm tool shoulder diameter at 200X



Figure 10 Microstructure of Base material AZ31B-O Mg alloy at 200X



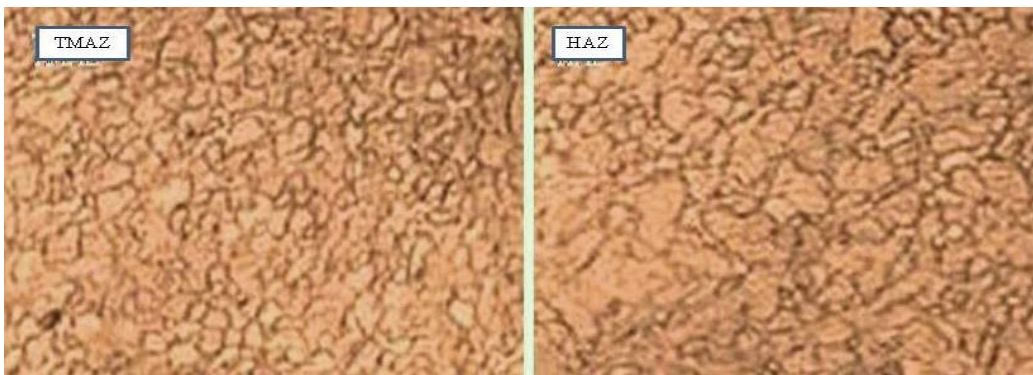


Figure 11 Microstructure of TMAZ and HAZ towards AS at 200X

### 3.4. Effect of weld pitch and tool shoulder diameter on micro hardness

The effect of weld pitch on micro hardness of friction stir welded joints of magnesium alloy with 18 mm and 20 mm shoulder diameter is illustrated in Figure 12. The high value of micro hardness 67.25 Hv was achieved at weld pitch of 0.050 mm/rev with 20 mm tool shoulder diameter. The micro hardness of the base material was 50 Hv and as compared with the base metal the micro hardness of the welded samples varied from 47 Hv to 67.25 Hv in the stir zone. Micro hardness increased with increase in weld pitch from 0.0020 mm/ rev to 0.050 mm/rev, due to reduction in grain size with increase in weld pitch. The grain boundaries become the main obstacle to the slip of dislocations and the material with smaller grain size would have higher micro hardness as it would impose restriction to the dislocation movement [10]. It is also observed from Figure 12, that micro hardness increases with increase of tool shoulder diameter from 18 mm to 20 mm. The tool shoulder diameter is having directly proportional relation with heat generation due to friction. Thus with 20 mm tool shoulder diameter, the heat generation was higher due to large contact area and results in fine grains and high values of micro hardness as compared with tool shoulder diameter of 18 mm. The smaller tool shoulder diameter (18 mm) led to narrow contact area and resulted in less frictional heat generation, which decreased the micro hardness values [14].

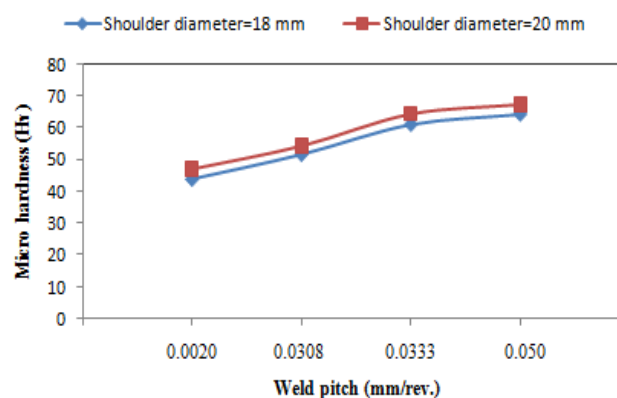


Figure 12 Micro hardness and Weld pitch relationship

#### 4. Conclusions

A brief investigation was carried out on Friction stir welding of AZ31B-O Mg alloy. The mechanical properties and the resultant microstructure for friction stir welded AZ31B-O Mg alloy were investigated.

1. A significantly high tensile strength of  $187.8 \text{ N/mm}^2$ , which is 91 % of that of the base material, was achieved at high weld pitch of 0.050 mm/rev with tool shoulder diameter of 20 mm due to sufficient heat generation, proper grain refinement and ductility. Hence tensile strength increases with increase in the value of weld pitch.
2. Most of the tensile test specimens fractured in the area between SZ and TMAZ towards advancing side because of softening point at this region. A  $45^\circ$  fracture angle was observed in the majority of joints.
3. Impact toughness of all the joints improved than that of the base material.
4. From microstructural analysis fine and equiaxed grain structure was observed in SZ due to dynamic recrystallization. Grain size decreased with increase in weld pitch. Thus average grain diameter of  $9.2 \mu\text{m}$  was observed at weld pitch of 0.050 mm/rev. with tool shoulder diameter of 20 mm.
5. Maximum value of hardness at the rate of 67.25 Hv was observed at weld pitch of 0.050 mm/rev. with 20 mm tool shoulder diameter.

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