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Improvement of Tensile Strength of Friction Stir Processed AA6086/Tic Surface Composite

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***Abstract*:** Friction stir processing (FSP) is a new solid state processing technique that can eliminate casting defects and refine micro structures, enhances mechanical properties of metallic materials. FSP can also produce fine grained structure and can able to fabricate the surface composite. The Aluminum alloy (Al–Mg–Si alloy) has gathered wide acceptance in the fabrication of light weight structures requiring a high strength-to-weight ratio and good corrosion resistance especially in aerospace and automotive industry.

In this work , The concept of friction stir processing was utilized to successfully disperse the titanium carbide particles of 5 µm on to the surface of AA6086.The Taguchi Design Of Experiments (DOE) was applied to determine the most important factors which influences the ultimate tensile strength of AA6086/TiC surface composites produced by friction stir processing. An L_9 orthogonal array, Signal to Noise ratio, Analysis of Variance (ANOVA) were applied to study the performance characteristics. The high value of S/N ratio indicated that the speed is the most influential parameter and the ANOVA results showed that rotational speed is the most influential parameter. Based on experimentation and statistical analysis, it is found that the UTS is higher with higher rotational speeds and is better with lower transverse feeds.

Keywords: *FSP, ANOVA, Regression Analysis, Tib_2, UTS, AA6086, Orthogonal array, Taguchi DOE, Particle size.*

1. Introduction

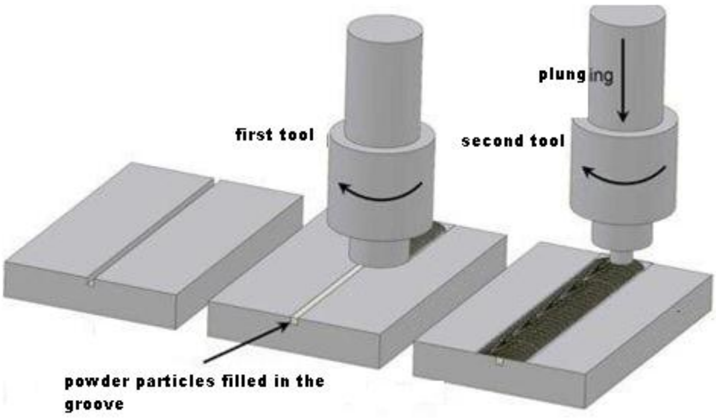
Aluminum alloys are widely used in automotive, aerospace and ship building industries due to good strength to weight ratio, high thermal conductivity and corrosion resistance but their triobological applications have been limited by poor wear resistance and fatigue resistance. Metal matrix composite (MMC) exhibited high strength and improved resistance to fatigue and wear (1, 2).How ever, the MMC ‘s are limited the wide applications with respect to low ductility and toughness due to presence of hard ceramic reinforcements (3,4).So it is necessary that only surface layer of composite was reinforced with ceramic particles while bulk of component retained the original properties and structure with the high toughness.

Surface composites can be produced by several techniques such as stir casting, plasma spraying ,laser beam , cast sintering , electron beam irradiation and pressure less infiltration have been developed over the years to fabricate surface metal matrix composite (5,6,7,8,9). These techniques are based on liquid phase processing at high temperature. The detrimental phases are formed due to interfacial reactions of reinforcement with metal matrix. The process plays a crucial role to obtain microstructure and number of defects also be produced. So these problems and defects can be minimized with Friction stir processing.

Friction stir processing (FSP) is a emerging novel technique to fabricate surface composite of metals and alloys is based friction stir welding (10).Though the FSP is a grain refinement and mechanical properties improvement technique , it is a very attractive method for incorporation of particles into metal matrix which results in fabrication of surface composite .The surface composite produced by FSP has special advantages like less distortion, no hydrogen porosity that frequently occurred in aluminum alloys in case of other traditional liquid phase techniques .The grains are refined due to dynamic recrystalization in the stir zone and improves its strength, corrosion, wear and fatigue ,formability (11) The process is environmentally clean technology as it does not produce any fumes , harmful gases and produce no noise like in other conventional surface fabrication techniques . The material to be welded or processed does not go distortion as process can be done in the solid state itself.(9,10)

The FSP process parameters such as rotational speed , transverse feed and axial load or tool penetration depth are major importance in the research area (12,13,14). The mechanical properties of metal matrix composites (MMCs) can be further enhanced by decreasing the sizes of ceramic particulates and/or matrix grains from micrometer to nanometer level . MA Z Y et al (15) showed that the tensile strength of the 1% vol. of 15 nm Si3N4 /Al composite is comparable to that of the 15% 3.5 μm SiCp /Al composite, and that yield strength of the former is much higher than that of the latter. Also, M.Sharifitabar et. al (16) showed that after the addition of 7 nm Al_2O_3 particles in the matrix showed that grain size of stir zone decreased and uniform distribution of particles. It indicated that tensile strength and yield strength were higher.

In FSP, a cylindrical rotating tool with a pin and shoulder travels along the surface of metal plates and the heat is produced locally due to friction between the rotating tool shoulder and the work piece and raise the temperature material above the recrystallization but below the melting point of materials .(10 ,11).The FSP samples consists of various zones like Stir zone(SZ), thermo mechanically effected zone (TMAZ),and heat effected zone (HAZ).



Fib .1 Basic Friction stir processing

The application of FSP technology was first developed by (1) to fabricate the AA 5083/Sic composite.The Sic particles were incorporated on the surface and well bonded with the matrix .Many different ceramic particles like oxides , carbides and borides such as sic, B4C, Al_20_3, Tic, TiB_2 etc have been added to aluminum and magnesium alloys.(13,14). Among these titanium carbide is an outstanding reinforcement with low cost, stiff, hard and it does not react with aluminum to form any inter phase at the interface between the reinforcement and the matrix (14) and is an electrical conductive (16).

Now a days the use of micro and nano particles to reinforce metallic materials has increased considerable interest in recent years because of the potential development of surface composites with unique mechanical and physical properties. In the present investigation , an attempt is made to investigate the fabrication of metal matrix composites called surface composite.The titanium carbide micro powder particles of 8 % by volume are incorporated on to a surface of 6 mm thick aluminum plate using FSP technique with various process parameters like rotational speed , transverse feed to and the process parameters for tensile strength are optimized by Taguchi design of experiments and ANOVA is used to identify the most important influencing parameter.

Taguchi method

The Taguchi method is very effective, because it is simple to carry out the experimental design and its approach is very systematic to provide good quality and low cost in manufacturing. The major objective of the Taguchi method is to analyze the statistical data of input and to produce an optimum result. The effect of the combination of the input parameters as a result is produced by the S/N ratio and mean response (17).

Experimental procedure

The material used in this work are AA6086 alloy (Al- Mg- Si) 6 mm rolled plate as matrix material and Tib_2 powder with an average particle size of 2 µm as an reinforcement .The nominal composition of AA6086 is given in the table 1.

Table 1: chemical composition of AA 6061 alloy

Element	**Mg**	**Si**	**Fe**	**Mn**	**Cu**	**Zn**	**Cr**	**Ti**	**Al**
Wt %	1.02	1.8	0.19	0.71	0.152	o.17	0.18	0.083	Remaining

Table 2: Mechanical properties of AA 6061 alloy.

Yield point strength (Y.S.)	**Ultimate tensile strength (MPa)**	**Percentage Elongation (%)**	**Hardness (Hv)**
248	286	16	104

Table 3: Process parameters with range

Process parameter	**Range**	**Level 1**	**Level 2**	**Level 3**
Rotational speed	650 rpm -1350 rpm	650	1000	1350
Transverse feed	20 mm/min – 45 mm/min	20	30	45
Tool penetration depth	0.1 mm -0.20 mm	0.10	0.15	0.20

The three process parameters with three levels (speed, feed and tool penetration depth) were taken . An L9 orthogonal array was generated by the Mini tab software .The number of runs can be eliminated with an array as a result time and cost can be saved drastically when compared to full factorial experimental design . The total of 9 runs were conducted using the different combination of levels for each of process parameter as per L9 array. The array was shown in the table

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Table 4: L9 orthogonal array

Run/ Experiment	Rotational Speed(rpm)	Transverse feed(mm/min)	Tool penetration depth(mm)
1	650	20	0.10
2	650	30	0.15
3	650	45	0.20
4	1000	20	0.15
5	1000	30	0.20
6	1000	45	0.10
7	1350	20	0.20
8	1350	30	0.10
9	1350	45	0.15

The work pieces are cut to size of 100 mm × 100mm × 6 mm .A groove of 1 mm in width and 1.3 mm in depth was made by CNC milling machine on the centre of plate. The surface of plate is cleaned with ethanol before processing. The powder is filled in to the groove after placing the plate on to the vice of machine. A hardened HSS tool was used that consists of shoulder with a diameter of 18 mm and square pin has of 5.5 mm in length and 6 mm excircle diameter .

The FSP was carried out on CNC Vertical Milling Machine (AGNI BMV 45) with Fanuc controller and has capacity of 30 HP and 3000 rpm. The FSP process parameters are given in the table. At first, the tool without pin is traversed along the groove to compact the powder in to the groove for not to disperse from the groove . The down ward force is applied by means of Tool penetration depth (TPD). While processing the tool shoulder's head face is penetrated on to the upper surface of aluminum plate by an given value (called TPD) . The equipment and devices were shown in the figures 2 (a) and 2 (b). The different runs were fabricated with various process parameters as per array and shown in the figure 3.

Fig 2(a) : CNC machine **Fig 2(b) : 3 –D view of tool**

The specimens were cut perpendicular to the FSP direction to carryout the tensile tests. The pieces were cut as per ASTM – E 8 Standards to evaluate the tensile properties like yield strength , Elongation and ultimate tensile strength.

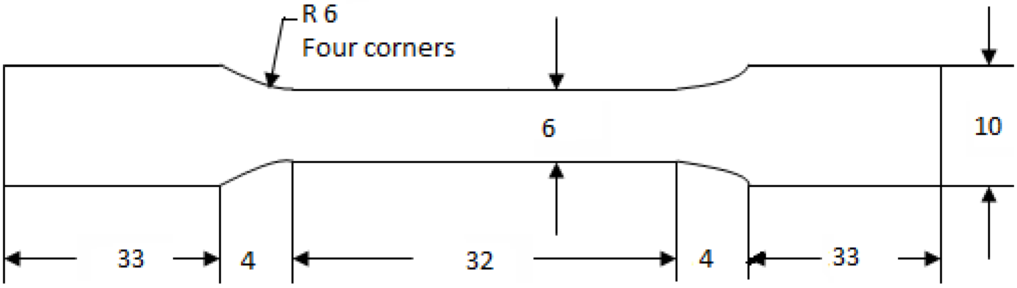

Fig.4 Tensile test specimen as per ASTM-E8 standards

2. Results And Discussions

Statistical analysis

The ultimate tensile strength (UTS) was analyzed in order to optimize the friction stir processing parameters .The influence of each parameters on response , means and S/N ratio for each factor can be calculated . The term Signal indicates the desirable value for output characteristic and noise represents the undesirable value for the output. The S/N ratio is selected using the criterion larger the better in order to calculate the maximum response.

$$\text{S/N ratio} = -10 \log (1/n . \sum 1/y2)$$

Where y is the observed data and n is the no. of observations. The mean

The tensile strength of the FSW weld is taken as the output characteristic. The response table for the S/N ratio shows that the rotational speed is the first rank in the contribution of good joint strength, while the traverse speed and tool penetration ranked the second and third. The similar trend has observed in the response table of the mean which is presented in Tables 5 and 6 respectively. The response plot for the S/N ratio and Mean are shown in Fig 6. The tensile strength is estimated to be the maximum at 1350 rpm rotation speed, 20mm/min travel feed and 0.20 mm tool penetration depth which is optimal from the plots obtained.

The obtained tensile strengths were converted into S/N ratio. The S/N ratio of tensile strength for each parameter for all levels are listed in Table 5.

Table.5 Experimental results and S/N ratio.

Experiment	Ultimate Tensile strength (Response) (Y)MPa	S/N ratio dB
1	165.0	44.3497
2	156.0	43.8625
3	125.7	41.9867
4	182.5	45.2253
5	160.0	44.0824
6	168.0	44.5062
7	208.5	46.3821
8	173.8	44.8010

9	164.3	44.3128

Table 6. Mean Response table for Signal to Noise ratio and experimental data for means

Levels	S/N ratio			Experimental data for mean		
	Rotational Speed(rpm)	Feed (mm/min)	TPD (mm)	Rotational Speed(rpm)	Feed (mm/min)	TPD (mm)
1	43.40	45.32	44.55	148.9	185.3	168.9
2	44.60	44.25	44.47	170.2	163.3	167.6
3	45.17	43.60	44.15	182.2	152.7	164.7
Max-Min(Delta)	1.77	1.72	0.44	33.3	32.7	4.2
Rank	1	2	3	1	2	3

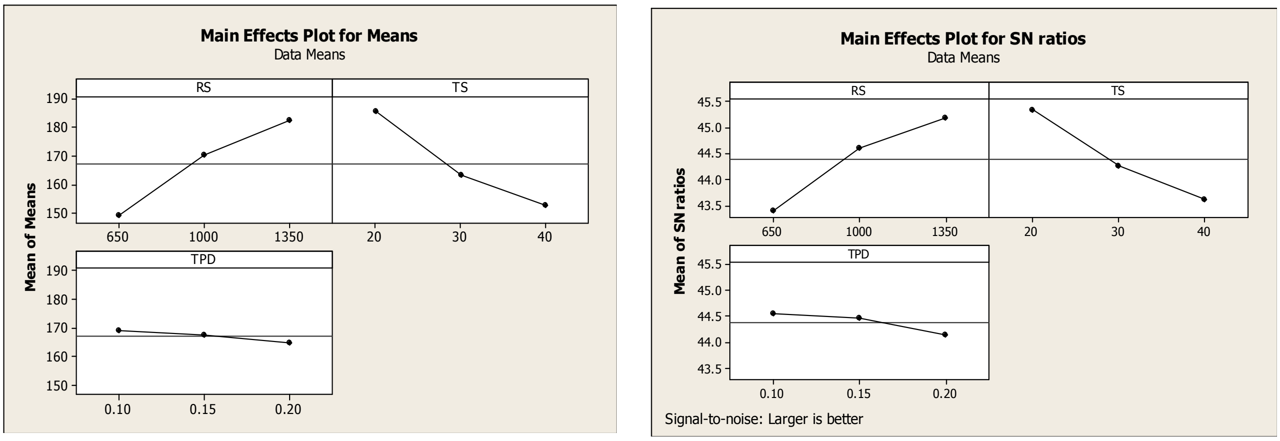

Fig. 6 Response plot comparison of S/N ratio and mean for tensile strength

Fig 6 shows graphs for mean and S/N ratio for rotation speed , transverse feed and tool penetration depth and corresponding values are tabulated in table 6.The optimum process parameters for tensile strength is based on the highest value of S/N ratio and mean values and first ranked the rotation speed and second as a transverse feed .

Analysis of variance (ANOVA)

The taguchy method cannot judge the process parameters and their effect on the entire process. The aim of ANOVA is to investigate the significance of the process parameters which affect the tensile strength of composite and their percentage contribution of individual process parameters. The Results of ANOVA can determine very clearly the impact of each factor on output parameter..

In addition, the frequency test (F- test) was used in statistics to determine which process parameters that have a significant effect the tensile strength. The Larger the F value indicates that variation of the process parameter makes a considerable change on the quality characteristics.

Table 6. ANOVA of S/N for tensile strength

Factor	Process parameter	Degrees of freedom	Sum of squares	Mean of square	F- test	Contribution (%)
A	Rotational speed	2	4.88	2.44	2.39	60.30
B	Transverse feed	2	2.51	1.25	2.09	30.13
C	TPD	2	0.31	0-14	0-08	3.91
Error		2	0.46	0.23	0.08	5.66
Total		8	8.12			100

Table 7.ANOVA of ultimate tensile strength

Factor	Process parameter	Degrees of freedom	Sum of squares	Mean of square	F- test	Contribution (%)
A	Rotational speed	2	1706	853	2.34	50.22
B	Transverse feed	2	1666	833	2.24	48.78
C	TPD	2	28	14	0.02	0.87
Error		8	14	7		0.33
Total			3444			100

The ANOVA was carried out for a level of significance of 5 % i.e 95 % confidence level. . The table 6 & 7 respectively shows the ANOVA results for tensile strength. The percentage contribution is the ratio of function of the sum of squares for each significant item and can calculated as. (17.) The results of ANOVA indicated that the rotational speed with 60 % has the highest effect on the tensile strength of composite followed by the transverse speed with 30.1 % , and tool penetration depth with 3.91 % .M. salehi et.al (18) studied the formation of sic particle reinforced composite on AA 6061 alluminum surface by FSP and they found that rotational speed was the main important parameter that effecting the distribution of sic particles.

Predicting the optimum tensile strength

The optimum tensile strength can be predicted after determination of optimum process parameters using the following equation (17)

$\bar{Y}_{predicated} = \bar{Y}_{RS} + \bar{Y}_{TF} + \bar{Y}_{TPD} - 2 \times \bar{Y}exp$ where

$\bar{Y}exp$ = Total average response of the experiments in the array (ΣY), $\bar{Y}_{RS}$ = Average responses for a RS $_{L3}$, $\bar{Y}_{TF}$ = Average responses for a TF $_{L1}$, $\bar{Y}_{TPD}$ = Average responses for a TPD $_{L1}$, The predicted tensile strength is 192.48 MPa. Three confirmation experiments were conducted to validate the model at the optimum setting of process parameters namely RS $_{L3}$ (i.e 1350 rpm), TF $_{L1}$ (i.e 20 mm/min) and TPD $_{L1}$ (i.e 0.1mm) and the experimental average value of the three tensile test to be 297 MPa, The confirmation test also conducted by setting after the experimentation to validate the model and was found good agreement with the predicted value. .

3. Conclusion

The surface composites was successfully fabricated by friction stir processing technique It is an alternate method for fabrication of composites. The three process parameters and three level were selected with L9 array. The optimum process parameters for ultimate tensile strength are rotational speed of 1350 rpm , transverse feed of 20 m/ min and tool penetration depth of 0.20 mm. The percentage contribution of process parameters found with ANOVA. It is found that rotational speed contributes 60 % is the dominant parameter, transverse feed contributes 30.1 % and tool penetration depth contributed with 3.91% on ultimate tensile strength of composite fabricated. The confirmation test was conducted by experimentation and found that predicted tensile strength are within the confidence levels.

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