STM JOURNALS

Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 13, Special Issue 1, 2025
DOI (Journal): 10.37591/JoPC

https://journals.stmjournals.com/jopc

Research JoPC

Wear Attribute of Aluminium Metal Matrix Composite Reinforced With MWCNT, Produced By FSP, on A Vertical Milling Machine

Mohd Firasath Ali[1,*], Syed Azeem Pasha[2], Syed Mujahed Hussaini[3]

Abstract

The exceptional properties of Aluminium metal matrix composites (AMMCs) like good hardness, specific strength, enhanced wear rate made huge demand in the automobile and aerospace industries. The classical methods of manufacturing AMMCs leave problems at the interface of matrix and reinforcement segregation, like an agglomeration of reinforcements, wettability etc. To overcome this, an alternate, innovative method of fabricating aluminium matrix surface composites has been invented, which is termed friction stir processing. In this paper friction stir processing attempted to fabricate aluminium matrix surface composites by considering AA7075 as the matrix and multi wall carbon Nano tubes (MWCNT) as the reinforcement particles. The process parameters of FSP such as rotational speed, traverse speed and weight percentage of MWCNT have been varied at three levels and the resulting variables such as wear resistance, grain size and microstructure of the composite focused. Design of experiments planned according to the Taguchi technique for optimizing the response variable wear rate with respect to FSP parameters. It found that the wear resistance has been enhanced to 78.72 % when compared to base metal. The relevant plots obtained pertaining to the experimental data using Minitab -17 software to reiterate and analyse the results accordingly to conclude.

Keywords: Friction, Aluminium, Pin-on-Disc, Taguchi, wear

INTRODUCTION

Friction Stir Processing (FSP) is a solid-state joining technique developed by the Welding Institute [1]. (TWI) in 1991 to improve the mechanical properties of alloys that exhibit significant loss and non-weldability due to poor solidification and scarce fusion zone porosity. FSP uses a revolving tool to stir reinforcement and traverse along the joint line, enhancing specific properties through localized plastic deformation. The tool and sheet soften the material in solid-state, yielding a fine, equiaxed, and defect-free dynamically recrystallized grain structure see Figure 1. The precursor of FSP is Friction Stir Welding which welds several metal pieces in absence of heat affected zone. FSP creates "high-strain-rate super plasticity" [2]. FSW does not use filler metal, allowing for the joining of any aluminum alloy without concern for composition compatibility. Welding parameters, tool geometry, and joint design influenced the microstructure of FSP. There are Stir Zone (SZ), Nugget Zone, Thermomechanical affected Zone (TMAZ), Heat Affected Zone (HAZ), and Unaffected or Parental Material [3,4].

***Author for Correspondence**
Mohd Firasath Ali

[1]Assistant Professor, Mechanical Engineering Department, NSAKCET, Hyderabad, India
[2]Associate Professor, Mechanical and Production Engineering Department, DCET, Nampally, Hyderabad, Telangana, India
[3]Professor, Mechanical Engineering Department, NSAKCET, Hyderabad, India

Received Date: August 02, 2024
Accepted Date: August 30, 2024
Published Date: December 10, 2024

Citation: Mohd Firasath Ali, Syed Azeem Pasha, Syed Mujahed Hussaini. Wear Attribute of Aluminium Metal Matrix Composite Reinforced With MWCNT, Produced By FSP, On A Vertical Milling Machine. Journal of Polymer & Composites. 2025; 13(Special Issue 1): S525–S539p.

LITERATURE REVIEW

FSP and FSW are recent technologies that have been studied extensively since 1998. They have been used to fabricate superplastic 7075 aluminum alloys, improve fatigue properties, and make them corrosion-resistant [5]. FSP is a promising fabricating method of surface MMCs in solid state. Researchers investigated upon aluminum 6061 with alumina and carbon nanotubes reinforcement, finding grain refinement, improved fatigue properties, and wear resistance [6-13]. The addition of carbon nanotubes has been shown to enhance deformation resistance in carbon nanotube reinforced aluminum composites. FSP has been found to be effective in achieving more microstructural refinement, densification, and homogeneity in a short, one-step process, and at a lower cost, with microstructure and mechanical properties of the processed area being controlled through tool optimization. FSP/FSW has been found to be an effective high-strain superplastic commercial 7075 Al alloys producing technique in solid state joining techniques [14-18].

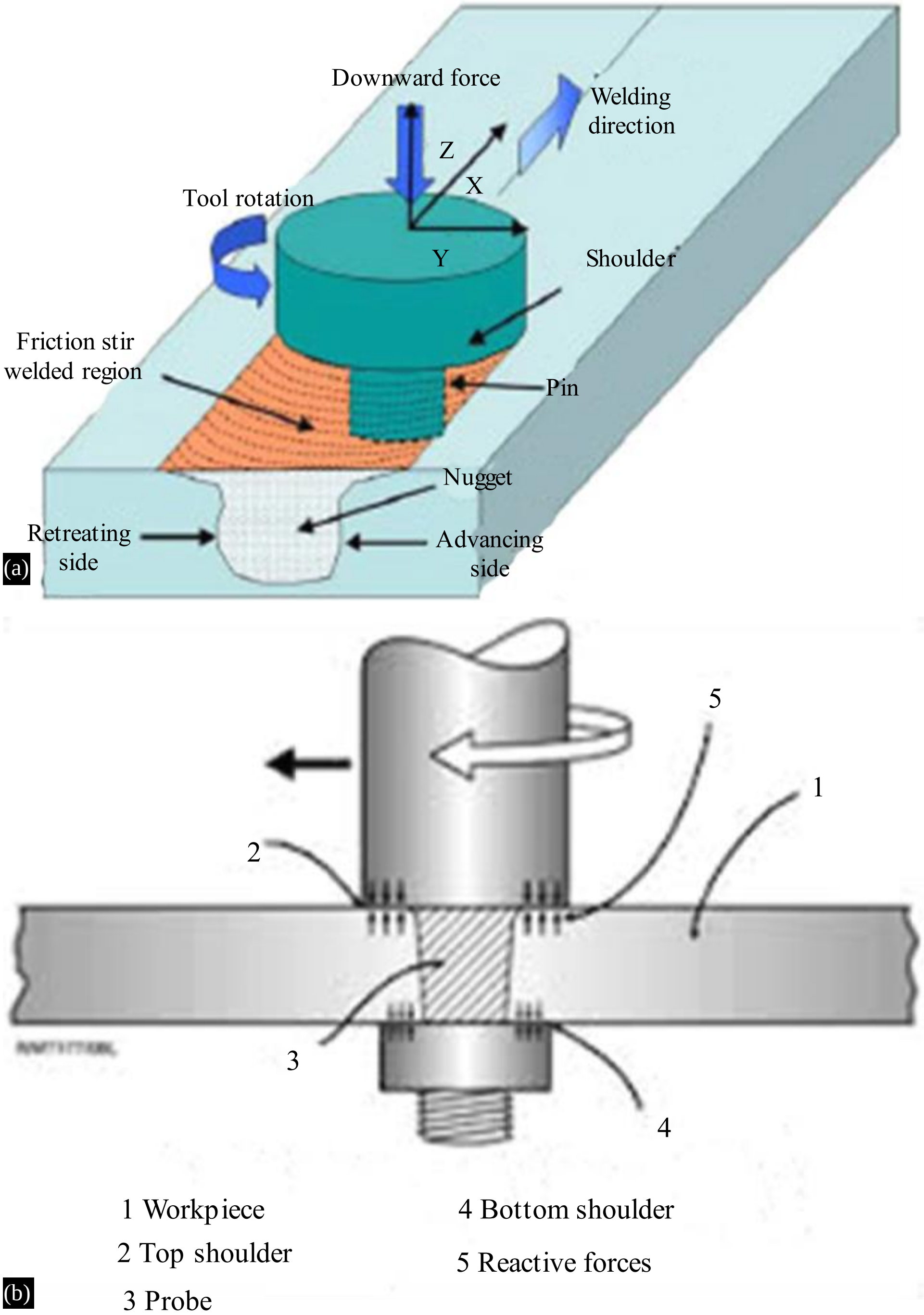


Figure 1. (a) FSP process (b)Tool geometry.

ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

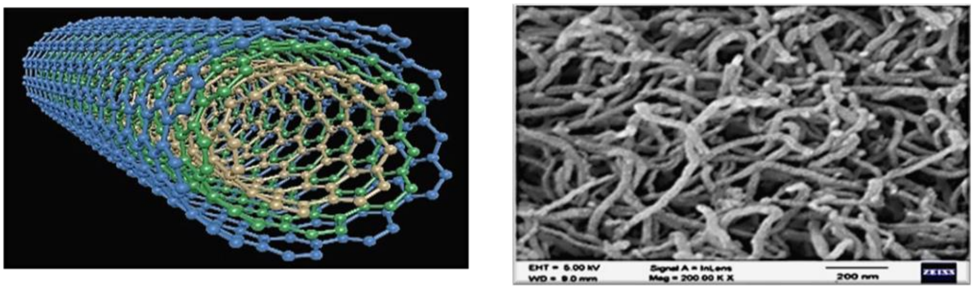
METHODOLOGY AND SET-UP

Aluminium Alloy 7075

It is a strong, corrosive-resistant alloy with zinc as its primary alloying element (see Table 1), boasts enhanced fatigue strength and median machinability in T6 and T651 tempers. Alluminium alloy (AA7075) of tensile strength of 125 MPa and a yield strength of 55 MPa at maximum. It has various applications, including aircraft structures, yacht construction, automotive parts, aluminum food cans, and SCUBA tanks. AA7075-T4 has an ultimate tensile strength of 207 MPa and a yield strength of 110 MPa, while AA7075-T6 has an ultimate tensile strength of 300 MPa and a yield strength of 241 MPa. It is also used in bicycle frames, aluminum docks, firearm sound suppressors, AR-15 rifle receivers, and remote-controlled model aircraft parts. Multi Walled Carbon Nano Tubes (MWCNTs) are a new technological nanomaterial with excellent mechanical and electrical properties, potentially useful in electronics, optics, and other materials science fields [19]. The microstructure of MWCNT made of a multilayer of graphene sheets rolled in a tube shape and separated by interlayers in the middle. (see Figure. 2).

Table 1. Aluminum Alloy AA7075 With Constituents.

METAL	Minimum	Maximum
Silicon	-	0.4%
Iron	-	0.5%
Copper	1.2%	2%
Manganese	-	0.3%
Magnesium	2.1%	2.9%
Chromium	0.18%	0.28%
Zinc	5.1%	6.1%
Aluminum	87.1%	91.4%



(a) (b)

Figure 2. Multi-walled carbon nanotubes showing microstructure.

The study [20]. discusses the potential hazards and risks associated with MWCNT, a material that can cause health issues and pose a threat to blood if in contact with blood. It emphasizes the need for enclosed, ventilated workbenches, defined cleaning procedures, and limited lab access. The experiment involved using AA7075 plates on Vertical Milling Machine (Figure 4 (a), with the FSP tool used for machining and reinforcing samples at different speeds and reinforcement conditions (Figure 3).

Design of Experiments (Table 2-4)

For DoE, three Process parameters viz., Tool rotational speed, Traversing speed and Reinforcement percentage are taken at levels shown in Table 2. It is framed by the design matrix L9 orthogonal array of TAGUCHI, as shown in Table 3. Taken processed parameters on L9 OA with three levels for this research is shown in Table 4.

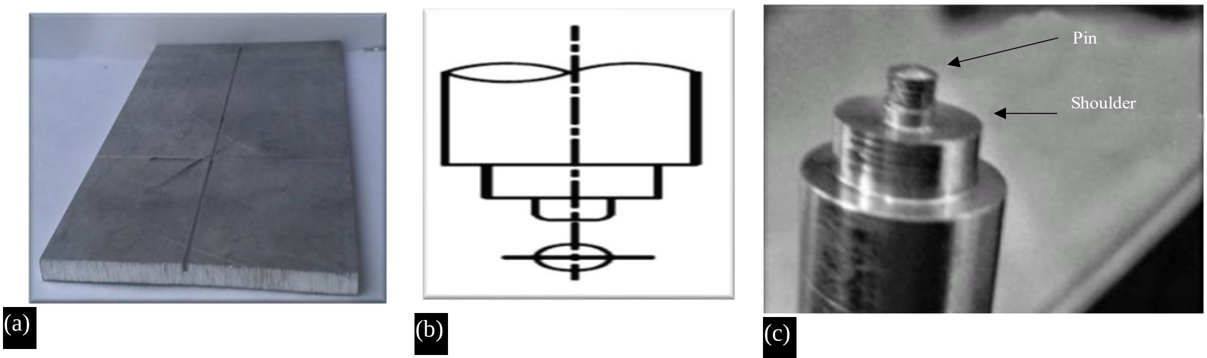


Figure 3. The Slot Cut in The Surface of AA7075 Billet Ready for FSP With Tool Made In H13 Tool Steel With Straight Cylindrical Pin And Its Orthographic Projection.

Table 2. Showing The FSP Process Parameters and Their Levels.

Process Parameters		**Levels**		
		1	***2***	***3***
Tool Rotational Speed (rpm)	A	710	900	1120
Traversing Speed (mm/min)	B	32	40	50
Reinforcement Particles (W)	C	5% MWCNT	10%MWCNT	15%MWCNT

Table 3. Design Matrix of L-9 Orthogonal Array, Orthogonal Array L9 Of TAGUCHI.

Exp. N.	**Process parameters**		
	A	***B***	***C***
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

Table 4. Processed Parameters on L9 Orthogonal Array.

S N.	**Rotational Speed (r.p.m.)**	**Traverse speed (mm/min)**	**Reinforcement (W%)**
1	710	32	MWCNT (5%)
2	710	40	MWCNT (10%)
3	710	50	MWCNT (15%)
4	900	32	MWCNT (10%)
5	900	40	MWCNT (15%)
6	900	50	MWCNT (5%)
7	1120	32	MWCNT (15%)
8	1120	40	MWCNT (5%)
9	1120	50	MWCNT (10%)

The procedure involves filling slots with reinforcement particle mixtures according to the design matrix, using a pin-less FSP tool to prevent powder scattering. The process involves rolling plates in a normal direction, resulting in defect-free Surface Metal Matrix Composites [21]. Vertical milling machine with a swiveling head used for FSP, drilling, borering, cutting gears, and producing slots as in Figure.4 (b and c).


(a) (b) (c)

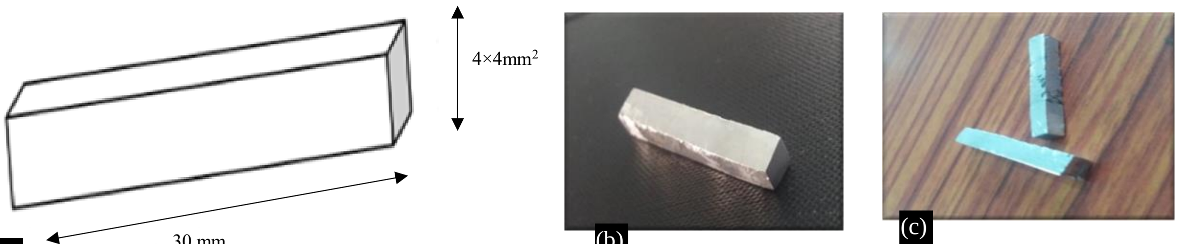
Figure 4. FSP On Milling Machine.
(A) HMT Make FN-2, 10HP, 3000 RPM Vertical Milling Machine (VMM)
(B) The FSP Performed AA7075 Nine Billets(C) AA7075 MMCs Fabricated Through FSP

Wear Test

The wear resistance of metal matrix composites (MMCs) in solid-state contact have to be measured. The wear mechanism in MMCs is enhanced by particulate reinforcement and plastic deformation, leading to a thin layer at the matrix material [22]. AA 7075 is poor wear resistant, limiting its application to automobile machine parts. The Pin-On-Disc machine (see Figure. 5) measuring loss of wear volume per unit sliding distance, called as wear test. The significance of wear tests lies in their ability to predict material combinations' importance, but pin-on-disk tests cannot accurately predict wear rates under various conditions. Test specimens were prepared to resist stresses without failure. Materials were detailed, including size, surface lustre, type, form, makeup, microstructure, processing methods, and indentation hardness [23]. Sample pieces were cut from nine billets of surface metal matrix composite as depicted in Figure 6, polished with emery paper, and dried sliding wear tests performed by pin-on-disc machine. All specimens were subjected to standard loads of 10 N and 7.5 m/s sliding speed.


(a) (b) (c)

Figure 5. Pin-On-Disc Machine:(A). Top View(B). Landscape View(C). Wear Test Rig.



(a) (b) (c)

Figure 6. Sample specimen.

The present work maintains constant load, speed, and distance parameters throughout all experiments, including the sliding wear test, as listed in the Table 5.

Table 5. Constant parameters during sliding wear test.

S. N.	Parameter	Value
1.	Pin material	AA7075 + MWCNT Composite
2.	Disc material	EN 31 steel
3.	Pin dimension (mm)	Rectangular with Length=30, Cross section area=4x4
4.	Sliding speed (m/s)	7.5
5.	Normal load (N)	10
6.	Speed of rotating disc (r.p.m)	700
7.	Sliding distance (m)	4241
8.	Time of each Test duration (min)	3

The Pin-On-Disc Test

It requires cleaning of pin and disc by ethanol-soaked cotton before start as per the ASTM standards designation [G 99 – 95a (Reapproved 2000)]. The pin surface is flat and ground using emery paper. Run-in-wear is conducted to prevent turbulence. Steady state wear occurs when material transfers from the pin onto the disc. [24,25]. The position of specimen is perpendicular to the resolution axis in the holding device and holder. Tests are carried out until the required number of revolutions is attained after the system lever is modified to increase force. Debris is removed, and characteristics like protrusions, displaced metal, discoloration, microcracking, or spots are observed. The pin is reweighted and dimensions remeasured. Two samples—a flat circular disc and one perpendicular to the other—are needed for the pin-on-disk wear test. The machine rotates the disc specimen, with wear results varying for different orientations and loading methods.

RESULTS AND DISCUSSIONS

Wear Measurement

It is a loss of volume in cubic millimeters report for pin and disc separately, using equations like Area = Cross sectional Area x Height loss and Wear rate = Volume loss / Sliding distance. Parameters include load, speed, temperature, roughness, and sliding distance. The study used a L9 OA with 9 rows and 3 columns to identify the critical components affecting the wear process. The experiments use the L-9 OA of the Taguchi Technique and a conceptual method to analyse the S/N ratio to relate the impacts of applied load, sliding speed, and sliding distance. [26].

Minitab

It is a statistical software for data visualization and analysis, ideal for six-sigma applications. Dr. Taguchi develops a technique that lowers variation in tests with ideal control parameters, based on "Orthogonal ARRAY" trials. His Signal-to-Noise ratios (S/N) are objective functions that are used in data analysis, forecasting, and optimisation; the highest S/N ratios are obtained with the highest levels of control variables. [27].

Microstructure Analysis

Optical microscopy

Microstructure, the small-scale organization of a material under a microscope, significantly impacts its physical characteristics like wear resistance, high/low temperature behavior, corrosion resistance, strength, toughness, ductility, and hardness, which control their industrial use.

Preparation of sample and procedure of Optical microscopy (Figure 7)

The samples underwent a conventional metallographic process for microstructure analysis, which involved grinding, polishing, and exposure to Keller's reagent. After that, the samples were inspected using a falling power objective lens in an optical microscope, adjusting the focus knob, and adjusting the condenser for maximum light output. The samples were then lowered and removed.

Precautions

Do not touch glass part and use only special lens paper to clean. Always carry a microscope with both hands.

Journal of Polymer & Composites
Volume 13, Special Issue 1
ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

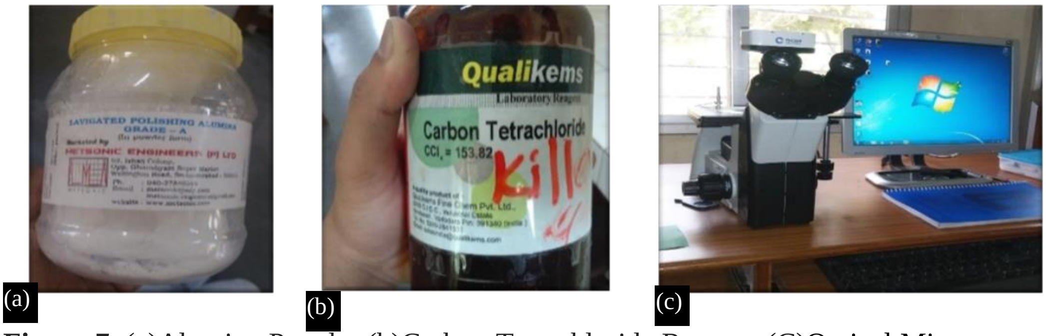


Figure 7. (a)Alumina Powder (b)Carbon Tetrachloride Reagent (C)Optical Microscope (Linked With PC).

Optical microscopy images (see Figure 8) show fine grain and uniform reinforcement particle distribution in matrix material, with appreciable properties, as shown in graphs of average wear in microns obtained by computer connected Pin-on-Disc machine.

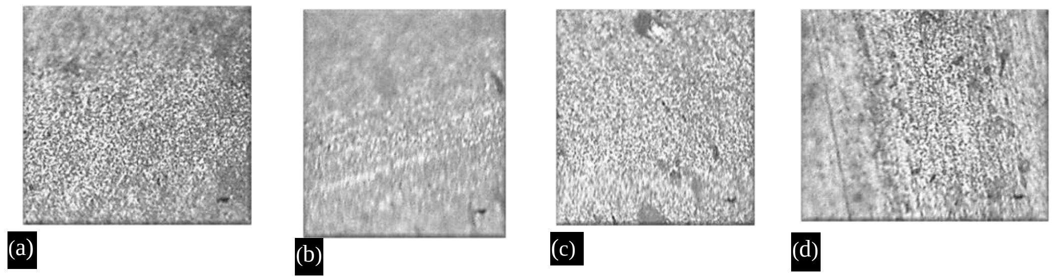


Figure 8. Typical Microstructure of AA7075/MWCNT surface composites after wear test.

Minitab S/N Ratio Analysis and Graphs

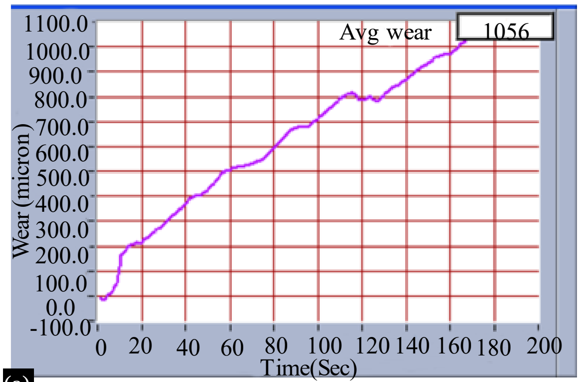
The study examines friction stir processing on nine AMMC billets, considering L9 Orthogonal Array process parameters (shown in Table 6), and produces various surface metal matrix composites. Results include wear in microns, grain size & microstructural images.

Table 6. Results Obtained After FSP: Wear Test, Grain Size of AA7075 + MWCNT SMMCs.

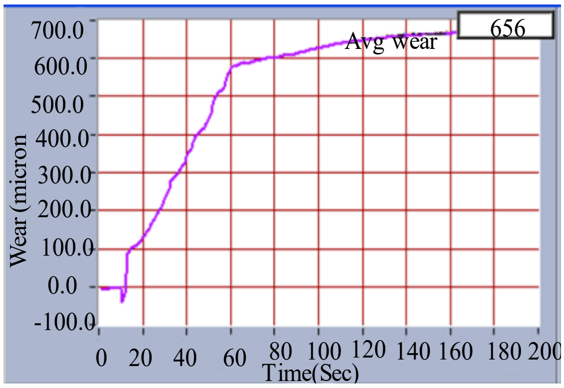
FSP Trail	Tool rotation (rpm)	Traverse speed (mm/min)	Reinforcement (MWCNT)	Wear (μm)	Grain size (mm)
FSP 1	710	32	5%	1056	6.318
FSP 2	710	40	10%	658	5.321
FSP 3	710	50	15%	1121	6.047
FSP 4	900	32	10%	771	6.978
FSP 5	900	40	15%	635	4.018
FSP 6	900	50	5%	379	5.814
FSP 7	1120	32	15%	667	3.962
FSP 8	1120	40	5%	769	3.713
FSP 9	1120	50	10%	905	4.001

Results of Statistical Analysis of Experiments

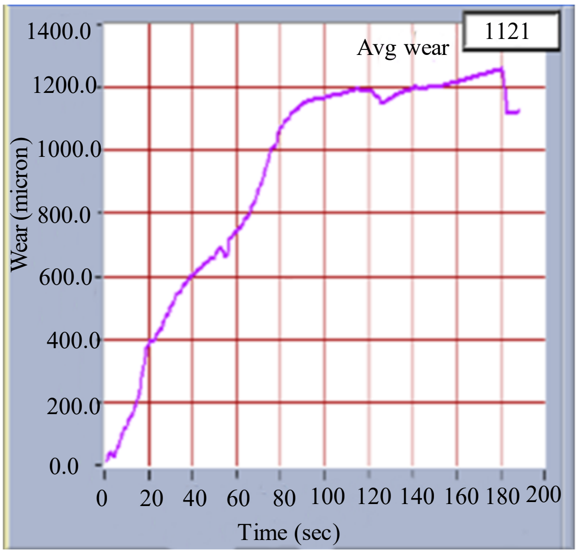
This study analyzes parameter combinations in MINITAB 17, a DOE software, to assess quality features and control parameters' impact on wear rate and COF. Wear Test graphs with time and Wear rate shown in Figure 9.


Avg wear
1056
Wear (micron)
Time(Sec)
1100.0
1000.0
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
-100.0
0 20 40 60 80 100 120 140 160 180 200

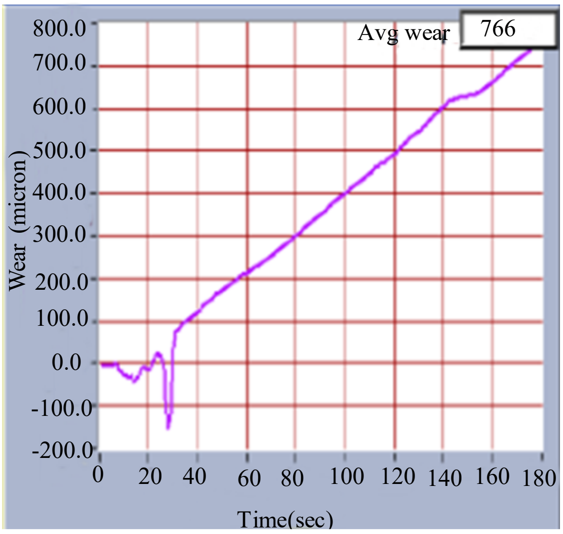
(a)


Avg wear
656
Wear (micron
Time(Sec)
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
-100.0
0 20 40 60 80 100 120 140 160 180 200

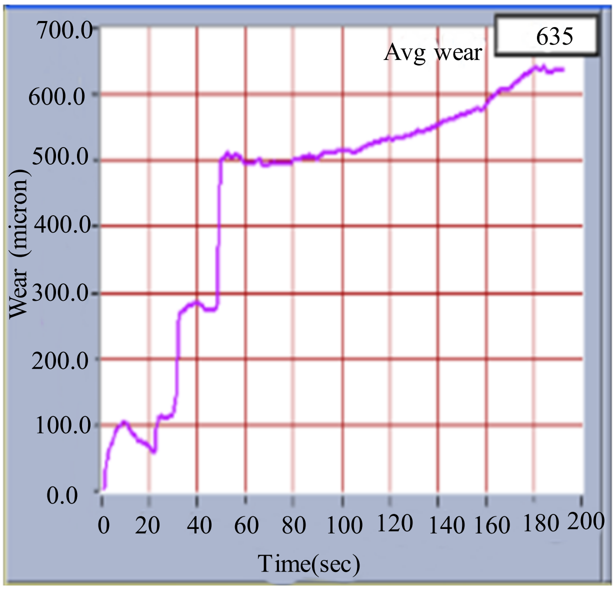
(b)


Avg wear
1121
Wear (micron)
Time (sec)
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
0 20 40 60 80 100 120 140 160 180 200

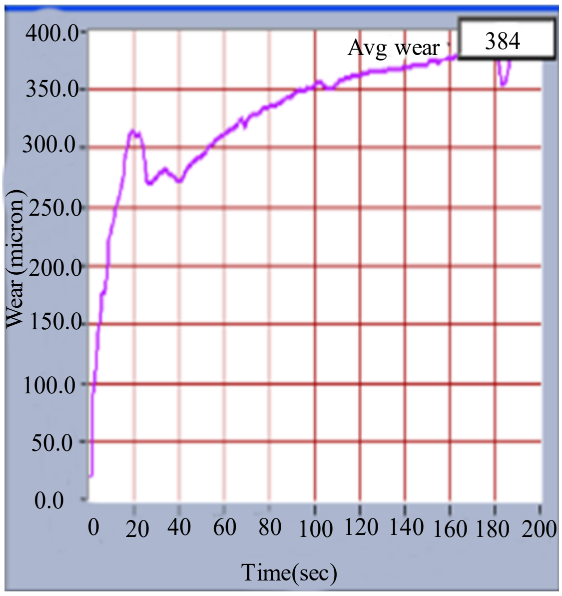
(c)


Avg wear
766
Wear (micron)
Time(sec)
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
-100.0
-200.0
0 20 40 60 80 100 120 140 160 180

(d)


Avg wear
635
Wear (micron)
Time(sec)
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
0 20 40 60 80 100 120 140 160 180 200

(e)


Avg wear
384
Wear (micron)
Time(sec)
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
0 20 40 60 80 100 120 140 160 180 200

(f)

Journal of Polymer & Composites
Volume 13, Special Issue 1
ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

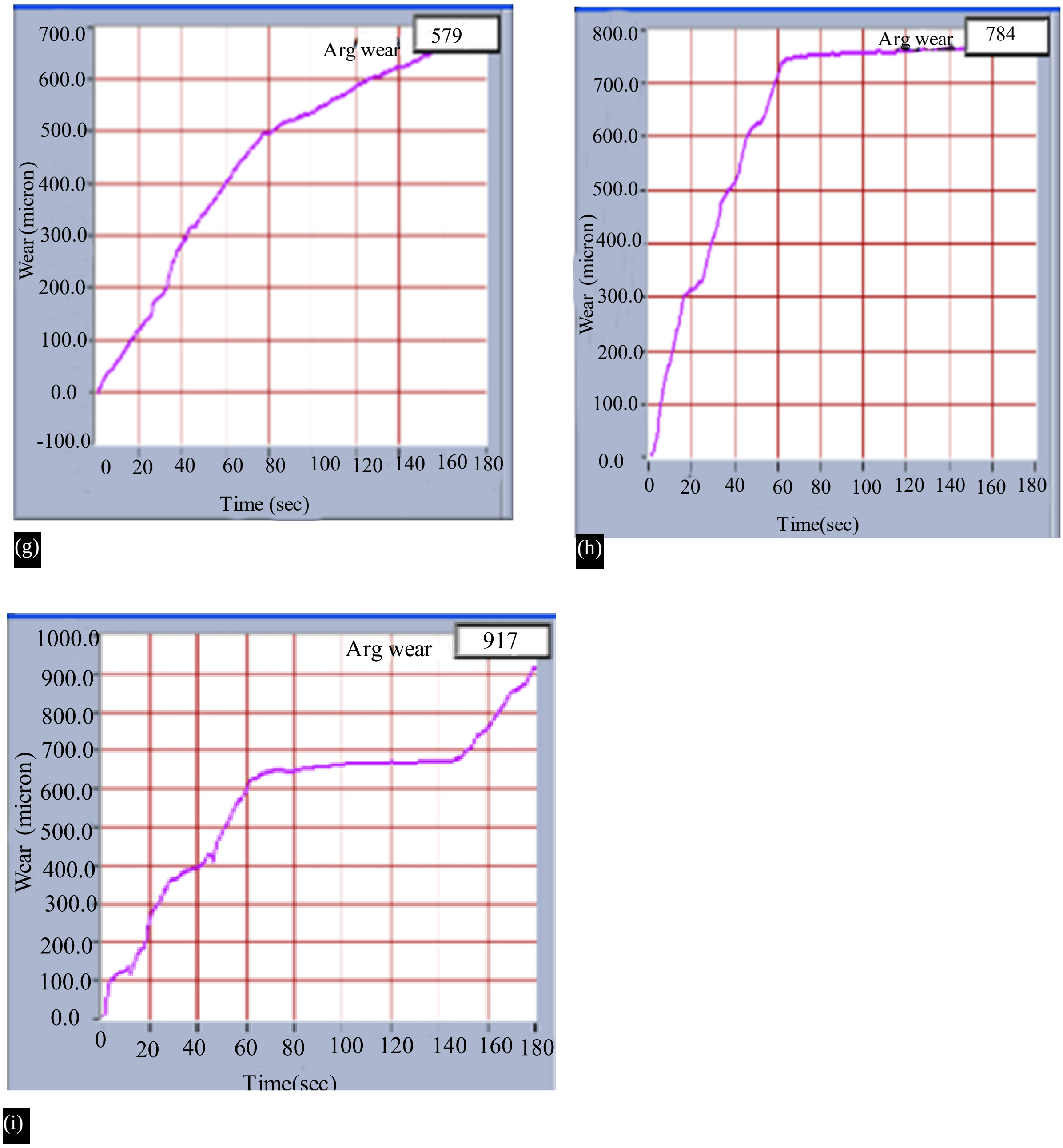


Figure 9. Wear test graphs; Time (Sec) On X-Axis Vs Wear (Microns) On Y-Axis Of L9 Nine Experiments.

Analysis by Signal-to-Noise ratios (S/N)

Signal-to-Noise ratios (S/N) are vital for statistical data analysis, determining control factor settings that reduce the influence of noise on response. The S/N ratio is determined using prior knowledge and process understanding. Larger, nominal, or smaller ratios maximize response, with larger ratios corresponding to better-quality characteristics. The highest S/N ratio level is the ideal process parameter level. [28].

Taguchi method - S/N ratio and Mean Results

The Minitab-17 program analyzes signal-to-noise ratios for rotational speed, traverse speed, and FSP passes (see table 7). A negative S/N ratio indicates noise power exceeds signal power, indicating that receiver performance can be improved in loud environments [14].

Table 7. Ratios of Signal To Noise (S/N) For The Response Variable Wear Rate.

S.N.	RS (rpm)	TS (mm/min)	MWCNT (W%)	Wear rate (cub mm/m) (X1000)	SNRA1	Mean
1	710	32	5	3.9751	-11.9870	3.9751
2	710	40	10	2.4771	-7.8789	2.4771
3	710	50	15	4.2202	-12.5067	4.2202
4	900	32	10	2.9021	-9.2542	2.9021
5	900	40	15	2.3905	-7.5698	2.3905
6	900	50	5	1.4268	-3.0873	1.4268
7	1120	32	15	2.5111	-7.9973	2.5111
8	1120	40	5	2.8951	-9.2333	2.8951
9	1120	50	10	3.4071	-10.6477	3.4071

The following is a description of the main impact graphic for the S/N ratio of Wear Rate vs the three FSP parameters:

Analysis of Process Parameter Ranking

The study ranks aluminium alloy 7075 and MWCNT wear rate and COF using signal-to-noise ratios, focusing on control parameters and sliding distance, load, and speed. Ideal parameters are identified using S/N ratios (see Figure 10).

Design by Taguchi

Taguchi orthogonal Array design

L9 (3∇3), Factors: 3, Runs: 9

Columns of L9 Array1 23

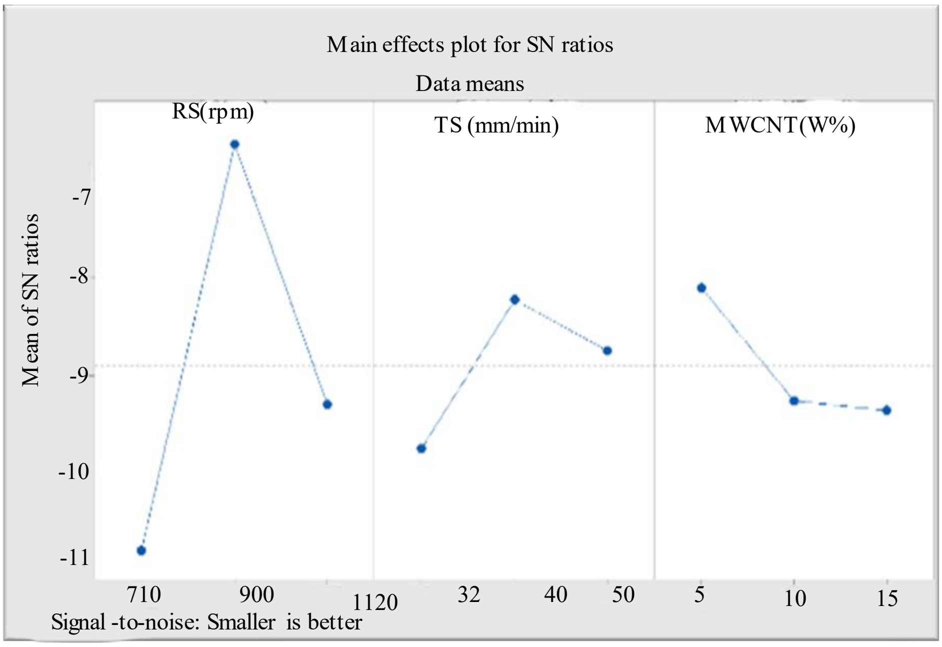


Figure 10. Main effects plot for S/N ratios.

Taguchi Analysis

Table 8 and 9 shows Wear Rate (mm^3/m) (X1000) verses RS (r.p.m.), TS (mm/min), MWCNT (W%) for S/N and Means effects respectively.

Table 8. Response Table for Signal to Noise Ratio for Wear Rate. (A Smaller Size Is Preferable).

Level	R.S. (r.p.m.)	T.S. (mm/min)	MWCNT (W%)
1	-10.791	-9.746	-8.102
2	-6.637	-8.227	-9.260
3	-9.293	-8.747	-9.358
Delta	4.154	1.519	1.255
Rank	1	2	3

Table 9. Response Table for Means for Wear Rate.

Level	RS (r.p.m.)	TS (mm/min)	MWCNT (W%)
1	3.557	3.129	2.766
2	2.240	2.588	2.929
3	2.938	3.018	3.041
Delta	1.318	0.542	0.275
Rank	1	2	3

Analysis of Means

The analysis of means for each experiment ensures better process parameter combination, with the mean response representing the average performance characteristics at various levels, and mean effect calculated using Minitab and drawn Main effects plot for means as in Figure 11.

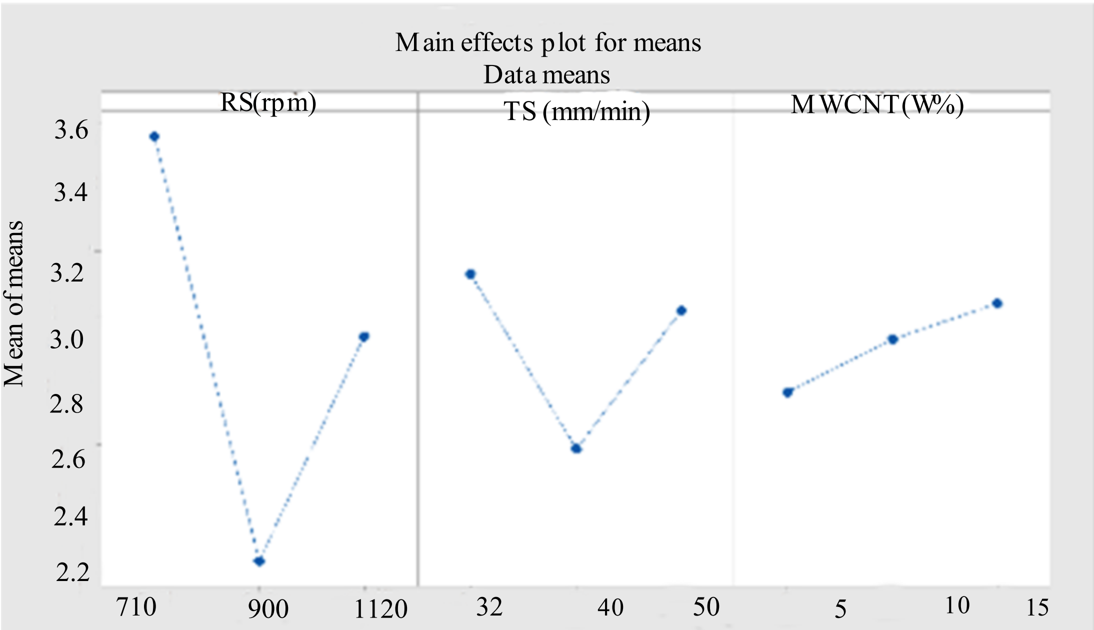


Figure 11. Main effects plot for means.

From the above results (for Means plot) the optimum set of values obtained by the Minitab Software as follows

A_2	B_2	C_1
Rotational Speed (r.p.m.)	Traverse Speed (mm/min)	MWCNT (W%)
900	40	5

On observing the L9 Orthogonal Array in Table 9, the optimal set of FSP parameters are not available. Hence the optimum performance wear characteristic of FSP calculated by Mathematical calculations described in the following estimations.

Estimation of the Optimum Performance Characteristics

The study focuses on predicting and optimizing response variables by identifying significant process parameters and their contribution. The optimum parameter combination can be either identical to the orthogonal array or not included in the array. If the optimal combination is not among the nine assessed combinations, the optimum values for a response variable can be calculated using a generalized empirical relation [29].

$$\omega = RS_i + TS_j + W_k - 2T_o$$

Where, ω = Mean Value of Response variable (Wear Rate)

- RS_i = Average value of Response variable at i^{th} level of Rotational Speed
- TS_j = Average value of Response variable at j^{th} level of Traverse Speed
- W_k = Average value of Response variable at k^{th} level of W% of MWCNT
- T_o = Overall Mean of the Response variable (reference (*horizontal)* line of main effects plot for means)

Confirmation tests used to evaluate whether the anticipated parameters for a certain response variable are valid.

Calculation of Mean

We know that,

$$\omega = RS_i + TS_j + W_k - 2T_o$$

Here i, j and k refer to 3 levels of RS, TS, and MWCNT % taken as A_2, B_2 and C_1 as referred in main effects plot of Means.
Therefore,

$$\omega = RS_2 + TS_2 + W_1 - 2T_o$$

The values of RS_2, TS_2, and W_1 factor levels for prediction which are optimum set of FSP parameters and given as
$RS_2 = 2.240,$
$TS_2 = 2.588,$
$Wt_1 = 2.766$ *and*
$T_0 = 2.912.$

By substituting above values, we get,

$$\omega = 2.240 + 2.588 + 2.766 - 2(2.912)$$

$\omega = 1.769$ mm^3/m.

These results predicted by Minitab Software and hence it gave the following results. The Scree grab of the Minitab software is shown in Fig. 12 that the results of optimum combination of parameters are taken from it.

Confirmation Tests

It involved conducting FSP confirmation experiments with optimal parameter values, recording average response values, and verifying results within confidence intervals see Table 10. The wear in microns of each sample was evaluated on a Pin-on-disc machine.

Main Effects Plot for Means

Main Effects Plot for SN ratios

Taguchi Analysis: Wear Rate (cub. mm/m) (X1000) versus RS(rpm), TS (mm/min), MWCNT(W%)
Predicted values

NOTE The response labeled "St Dev" contains all missing values. No predictions will be computed or stored for this response

S/N Ratio	Mean
-5.15312	1.76968

Factor levels for predictions

Ri (rpm) TS
900 (mm/min) MWCNT(S)
40 5

Figure 12. Prediction of optimized main Effective mean of L9 OA processed parameter of FSP.

Table 10. Obtained Optimal Combination of Process Parameters of FSP.

S. N.	**Process Parameters**			**Wear Rate (mm^3/m)**
	Rotational Speed(r.p.m.)	***Traverse Speed (mm/min)***	***MWCNT W%***	
1.	900	40	5	1.6121
2.	900	40	5	1.6425
3.	900	40	5	1.5995

Calculation of Average Mean

Average Wear rate $= \frac{(x1+x2+x3)}{3} = \frac{1.6121+1.6425+1.5995}{3}$ = 1.6180 mm^3/m.

The average Wear Rate of Confirmation Test was 1.618 mm3/m, validated using the Taguchi Method, ensuring less than 10% margin error in both statistical and conformational results.

Error calculated as follows: Percentage error = $\frac{x_1-x_2}{x_1} \times 100 = \frac{(1.7697-1.6180)}{1.7697}$ X 100 = 8.57 % $\cong$ 8.6 %

The study found that the optimal process parameters of FSP were within acceptable range, and the experiment was justified. Response tables for main effects plots, the mean, and the signal to noise ratio were produced by the Taguchi Method using Minitab 17. The enhanced wear rate of FSPed AA7075/MWCNT Surface Composite was calculated to be 1.6180 mm3/m, which is less than of the Aluminum base metal wear rate. (7.597 mm^3/m)

Percentage change = $\frac{x_1-x_2}{x_1} \times 100 = \frac{(7.597-1.6180)}{7.597}$ X 100 = 78.72 %

Hence, the wear resistance of MWCNT reinforced AMMC has enhanced by 78.72, compared to base metal AA7075.

CONCLUSION

1. AA7075 used as the matrix material in the fabrication of Hybrid Metal Matrix Composites (MMCs) with MWCNT powder as reinforcements. Friction Stir Processing (FSP) was employed using a Vertical Milling Machine with a H13 Tool steel FSP tool.
2. The process parameters—Tool rotational speed, Traverse speed, and Reinforcement % were optimized using Taguchi Design of Experiments with an L9 Orthogonal Array.

3. Wear rate values of the MMC billets were evaluated using a Pin-on-Disc apparatus. Optical micrography revealed a significant reduction in grain size at the stir zone, with enhancing the wear properties of the MMC billets.
4. Taguchi Method & Minitab Software utilized to optimize the wear rate values of MMCs. Graphical representations of wear test results, Signal to Noise ratios and Mean effect plots generated to analyze and conclude the findings.

REFERENCES

1. Thomas WM, Nicholas ED, Needham JC, Church MG, Templesmith P, Dawes CJ (1991) The Welding Institute, TWI, International Patent Application No. PCT/GB92/02203 and GB Patent Application No. 9125978.8.
2. MorisadaY *et. al* (2006) MWCNTs/AZ31 surface composites fabricated by FSP. Mater SciEng,A 419:344–338.
3. Mishra RS, Mahoney MW, McFadden SX, Mara NA, Mukherjee AK. High strain rate superplasticity in a friction stir processed 7075 Al alloy. Scripta materialia. 1999 Dec 31;42(2):163-8.
4. Thostenson ET, Ren Z, Chou TW. Advances in the science and technology of carbon nanotubes and their composites: a review. Composites science and technology. 2001 Oct 1;61(13):1899-912.
5. CJ DAWES, W.M. Thomas: Annual North American Welding Research on ference 1995, p.301.
6. Johannes LB, Mishra RS. Multiple passes of friction stir processing for the creation of superplastic 7075 aluminum. Materials Science and Engineering: A. 2007 Aug 25;464(1-2):255-60.
7. Stewart MB, Adams GP, Nunes AC. A combined experimental and analytical modeling approach to understanding friction stir welding. Developments in theoretical and applied mechanics.. 1998;19:472-84.
8. Pasha SA, Reddy R, Laxmi Narayana P. Wear behavior and microstructural characterization of AA7075/MWCNT surface composites fabricated through friction stir processing. IOSR J Mech Civ Eng. 2017;14:140-6.
9. Lim DK, Shibayanagi T, Gerlich AP. Synthesis of multi-walled CNT reinforced aluminium alloy composite via friction stir processing. Materials Science and Engineering: A. 2009 May 15;507(1-2):194-9.
10. K.V. Jata, et al. eds., Indianapolis, IN, pp. 83-91.
11. Kumar K, Gulati P, Gupta A, Shukla DK. A review of friction stir processing of aluminium alloys using different types of reinforcements. Int. J. Mech. Eng. Technol. 2017 Jul 8;8(7):1638-51.
12. Du Z, Tan MJ, Guo JF, Bi G, Wei J. Fabrication of a new Al-Al2O3-CNTs composite using friction stir processing (FSP). Materials Science and Engineering: A. 2016 Jun 14;667:125-31.
13. D.S. ChandraMouli, R. Uma MaheswaraRao and A. Sarath Kumar, A Review on Aluminum Based Metal Matrix Composites by Friction Stir Processing, International Journal of Engineering and Manufacturing Science. ISSN 2249-3115 Volume 7, Number 2 (2017), pp. 203-224.
14. Pasha SA, Ravinder Reddy P, Laxminaraya P. Electric discharge machining characteristics of AA7075/MWCNT surface MMCs fabricated through Friction Stir Processing. 6th International AIMTDR-2016. 2016 Dec 16:16-8.
15. Mahmoud ER, Takahashi M, Shibayanagi T, Ikeuchi K. Wear characteristics of surface-hybrid-MMCs layer fabricated on aluminum plate by friction stir processing. Wear. 2010 Mar 25;268(9-10):1111-21.
16. Yildirim M, Özyürek D, Gürü M. Investigation of microstructure and wear behaviors of al matrix composites reinforced by carbon nanotube. Fullerenes, Nanotubes and Carbon Nanostructures. 2016 Jul 2;24(7):467-73.
17. Mokdad F, Chen DL, Liu ZY, Xiao BL, Ni DR, Ma ZY. Deformation and strengthening mechanisms of a carbon nanotube reinforced aluminum composite. Carbon. 2016 Aug 1;104:64-77.
18. Su JQ, Nelson TW, Sterling CJ. Friction stir processing of large-area bulk UFG aluminum alloys. Scripta materialia. 2005 Jan 1;52(2):135-40.

ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

19. Eatemadi A, Daraee H, Karimkhanloo H, Kouhi M, Zarghami N, Akbarzadeh A, Abasi M, Hanifehpour Y, Joo SW. Carbon nanotubes: properties, synthesis, purification, and medical applications. Nanoscale research letters. 2014 Dec;9:1-3.
20. Donaldson K, Aitken R, Tran L, Stone V, Duffin R, Forrest G, Alexander A. Carbon nanotubes: a review of their properties in relation to pulmonary toxicology and workplace safety. Toxicological sciences. 2006 Jul 1;92(1):5-22.
21. Schumacher C, Oeffling B, Möhlmann C, Monte C, Plitzko S. Risk assessment of handling rigid carbon nanotube at technical centre in Berlin. GEFAHRSTOFFE REINHALTUNG DER LUFT. 2017 Oct 1;77(10):416-20.
22. Eyre TS. Source book on wear control technology. ASM, Metals Park. 1978:1-0.
23. K. J. Bhansali, in “Wear of Materials” Proceedings of the Conference on Wear of Materials (American Society of Mechanical Engineers, 1979) p. 146.
24. Basavarajappa S, Chandramohan G, Davim JP. Application of Taguchi techniques to study dry sliding wear behaviour of metal matrix composites. Materials & design. 2007 Jan 1;28(4):1393-8.
25. ASTM standards Designation: G 99 – 95a (Reapproved 2000) “Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus”.
26. Roy RK. Design of experiments using the Taguchi approach: 16 steps to product and process improvement. John Wiley & Sons; 2001 Feb 13.
27. Divakar R. Wear testing of advanced materials. ASTM International; 1992.
28. Joseph VR, Wu CJ. Performance measures in dynamic parameter design. Journal of Japanese Quality Engineering Society. 2002;10:82-6.
29. Nourani M, Milani AS, Yannacopoulos S. Taguchi optimization of process parameters in friction stir welding of 6061 aluminum alloy: A review and case study. Engineering. 2011 Feb 28;3(2):144-55.

