# Influence of Process Parameters on Micro hardness of AA7075/MWCNT Surface Composites Fabricated through Friction Stir Processing

Syed Azeem Pasha[1], Ravinder Reddy P[2], Laxminarayana P[3], Buschaiah K[4]
[1]*Mech. Eng. Dept., Deccan College of Eng. & Tech., Hyderabad, Telangana, India*
[2]*Mech. Eng. Dept., C.B.I.T., Hyderabad, Telangana, India*
[3,4]*Mech. Eng. Dept., UCE, Osmania University, Hyderabad, Telangana, India*

***Abstract-*** **The Surface metal matrix composites (SMMC) exhibit a unified combination of high tribological properties at the surface and toughness of the interior bulk metal. In the present work an attempt is made to fabricate SMMCs via Friction Stir Processing (FSP) by embedding Multiwall Carbon Nanotubes (MWCNT) in the Aluminum Alloy 7075 surface layers. During FSP, Rotational Speed (RS), Traverse Speed (TS) and the No. of FSP Passes (NoP) are varied so as to obtained a variety of SMMC billets. The SMMCs are subjected to Vickers Hardness tests to evaluate their Micro hardness across the stir zone. Taguchi technique is adopted to carry out the set of FSP experiments. The test results revealed that there is a steep enhancement in the micro hardness at the stir zone. The RS and NoP have a significant effect on micro hardness while the TS has a diverse effect on the same. The Taguchi main effect plots are extracted to analyze and also to estimate the optimal process parameters accordingly.**

***Index Terms-*** **FSP, Micro hardness, Rotational Speed, SMMC, Traverse Speed.**

## I. INTRODUCTION

Surface metal matrix composites (SMMC) exhibit a unified combination of high tribological properties at the surface and toughness of the interior bulk metal when compared with both Metal Matrix Composites (MMC) and monolithic materials [1]. Mishra et al. [2] explored the potential of FSP technique in fabricating silicon carbide (SiC) reinforced surface composite layer on aluminum (Al) 5083 alloy. Since then, a variety of surface composites based on magnesium, copper, titanium and steel have been developed. However, comprehensive coverage of surface composites prepared by FSP is very limited. Classical techniques for fabricating SMMC involves liquid phase processing at high temperatures such as laser melt treatment and plasma spraying, which may lead to the deterioration of composite properties due to interfacial reaction between reinforcement and the metal matrix [3]. The unavoidable defects such as dendritic porosity, particulate oxide inclusions, Secondary Dendritic Arm Spacing, Iron phase inter-metallics etc are ought to arise during classical methods of fabricating SMMCs. Moreover, precise control of processing parameters is required to obtain desired microstructure in surface layer after solidification. FSP is the best alternative technique to overcome the above mentioned problems during the fabrication of SMMCs. During FSP, the non-consumable rotating tool pin is plunged into a single piece of material and the abutting shoulder of the tool provides frictional heating and softens the metal underneath. The mechanical stirring of the hot metal is carried out by the pin. The stirring action and frictional heat generated by the FSP tool can be used to distribute ceramic particles as reinforcement on the surface of light metals like aluminum and magnesium to produce SMMCs. The important process parameters of the FSP include, Tool rotation speed, Traverse speed, Tool tilt angle, Plunge depth, Tool shoulder profile, Pin profile, Axial load and groove geometry etc. The response variables from the FSP are Tensile strength (TS), Microhardness (MH), wear resistance (WR), grain size etc. There are mainly four zones after FSP namely, Stir Zone (SZ), Heat Affected Zone (HAZ), Thermo-mechanically

Affected Zone (TMAZ) and the Base Metal (BM). The Stir zone is where the SMMC is considered to be formed.

## II. MATERIALS AND METHODS

*A. Matrix Material (Base metal)*

Alluminium Alloy, AA7075 is used as matrix material. The main alloying elements and important properties of AA7075 are as follows:

Table 1 Chemical composition of AA7075 (in wt %)

| Si | Fe | Cu | Mn | Mg | Cr | Zn | Al |
|---|---|---|---|---|---|---|---|
| 0.4 | 0.5 | 1.2 to 2 | 0.3 | 2.1 to 2.9 | 0.18 to 0.28 | 5.1 to 6.1 | Balance |

As received AA7075 flats of 6.3 mm thick were cut to 100 mm x 60 mm size by power saw. The Microhardness of as received AA7075 is 67 Hv.

*B. Multiwall Carbon Nanotubes (MWCNT)*

The MWCNT consist of multiple layers of graphite superimposed and rolled in on them to form a tubular shape. Such cylindrical graphitic polymeric structures have novel properties that make them potentially useful in a wide variety of applications in the field of material science. The important properties of MWCNT that include are Outer Diameter, 5-20 nm, length 1 to 10 microns, bulk density 0.2 to 0.35 g/cc.

*C. FSP Machine and Tool*

The entire FSP work was carried out on Semi-Automatic type Vertical Milling Machine, 10 HP, H.M.T. make, whose maximum speed is 3000 rpm. The FSP tool in H13 steel is made with square pin of 4.24 mm side and 4.7 mm long with tool Shoulder diameter of 20 mm hardened to 570 Hv by heat treatment process.

## III. EXPERIMENTAL

The FSP input process parameters such as Rotational Speed, Traverse Speed and No. of FSP passes are varied in three different limits as shown in table 2. The other input parameters that were maintained constant during the process are axial load 5kN, Tool tilt angle 2° and the Volume% of MWCNT at 10%.

Table 2 FSP Parameters and their levels

| Factor | Level 1 | Level 2 | Level 3 |
|---|---|---|---|
| (A) Rotational Speed (rpm) | 900 | 1200 | 1500 |
| (B) Traverse Speed (mm/min) | 30 | 50 | 70 |
| (C) No. of FSP Passes | 1 | 2 | 3 |

To accommodate above mentioned MWCNT reinforcement particles, a rectangular slot of 1mm width and 2mm deep is cut all along the length and 1 mm offset to the centre line of the AA7075 billet. The Design of Experiments was framed by Taguchi technique. According to the factors and their levels, Taguchi L9 Orthogonal Array was found to be suitable for carrying out the experiments. The design matrix of L9 Orthogonal Array for FSP experiments is as follows:

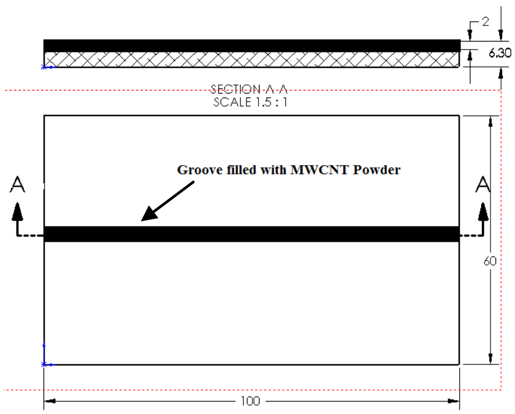
Table 3 Process parameters as per L9 OA Design Matrix

| Exp. No. | Rotational Speed (rpm) | Traverse Speed (mm/min) | No. of Passes |
|---|---|---|---|
| 1 | 900 | 30 | 1 |
| 2 | 900 | 50 | 2 |
| 3 | 900 | 70 | 3 |
| 4 | 1200 | 30 | 2 |
| 5 | 1200 | 50 | 3 |
| 6 | 1200 | 70 | 1 |
| 7 | 1500 | 30 | 3 |
| 8 | 1500 | 50 | 1 |
| 9 | 1500 | 70 | 2 |

Initially, the rectangular slot is cleaned thoroughly and filled with MWCNT powder. The capping (initial) pass was carried out by a pinless tool so as to prevent the possible spilling of MWCNT powder during the FSP passes. Subsequently, the FSP experiments were carried out as per the design matrix.

The Digital Display Micro Hardness Tester - LHV-1000B is used to carry out the tests. The measuring Range of the tester is 5-3000 HV with the Test Force ranging from 10 to 1000 gf. The test load considered is 200 gf and dwell time is 10 seconds.

The Vickers microhardness (HV) of the SMMC billet at all the zones (TMAZ, HAZ and SZ) of cut section is measured and analyzed. It is observed that the significant enhancement of microhardness is found at the stir zone of SMMC samples. Therefore, the microhardness is measured at the stir zone by the indentation made at 1.5 mm beneath the top surface of sample. The microhardness values are measured from the centre of the stir zone on either side (advancing and retreating) at an interval of 1 mm on both side at 7 difference points (3 points on either side and a centre point). The average Vickers Microhardness (HV) at the stir zone is recorded and tabulated in the design matrix.




(a)

Fig. 1 Schematic of the AA7075 billet for FSP Exp

## IV. RESULTS AND DISCUSSION

The S/N Ratios of the Microhardness values are extracted using the statistical software Minitab-17.

Table 4 Microhardness and S/N Ratios

| Exp. No. | RS (rpm) | TS (mm/min) | NoP | Micro-Hard-ness(Hv) | S/N Ratio (Db) |
|---|---|---|---|---|---|
| 1 | 900 | 30 | 1 | 92.67 | 39.39 |
| 2 | 900 | 50 | 2 | 101.35 | 40.12 |
| 3 | 900 | 70 | 3 | 107.94 | 40.66 |
| 4 | 1200 | 30 | 2 | 127.38 | 42.10 |
| 5 | 1200 | 50 | 3 | 139.52 | 42.89 |
| 6 | 1200 | 70 | 1 | 126.27 | 42.03 |
| 7 | 1500 | 30 | 3 | 147.59 | 43.38 |
| 8 | 1500 | 50 | 1 | 131.52 | 42.38 |
| 9 | 1500 | 70 | 2 | 136.45 | 42.69 |

An analysis of the tabulated results reveals that the S/N ratio for the $7^{th}$ FSP Experiment is found to be higher. Further, the analysis of these results is carried out in the subsequent results tables and plots.

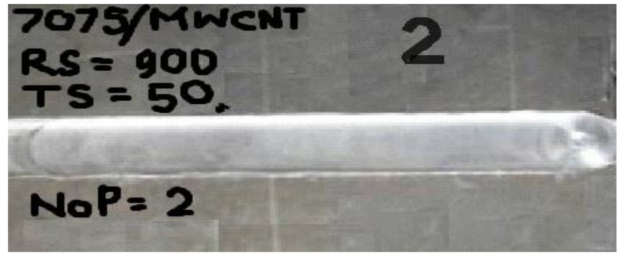



Fig. 2 AA7075/MWCNT SMMC billet from FSP Exp - 2

Taguchi Analysis: Microhardness (Hv) versus RS(rpm), TS(mm/min), NoP

Table 5. Response Table for Signal to Noise Ratios
Larger is better

| Level | RS(rpm) | TS(mm/min) | NoP |
|---|---|---|---|
| 1 | 40.04 | 41.61 | 41.25 |
| 2 | 42.34 | 41.80 | 41.64 |
| 3 | 42.82 | 41.80 | 42.31 |
| Delta | 2.78 | 0.19 | 1.06 |
| Rank | 1 | 3 | 2 |

Table 6. Response Table for Means

| Level | RS(rpm) | TS(mm/min) | NoP |
|---|---|---|---|
| 1 | 100.7 | 122.5 | 116.8 |
| 2 | 131.1 | 124.1 | 121.7 |
| 3 | 138.5 | 123.6 | 131.7 |
| Delta | 37.9 | 1.6 | 14.9 |
| Rank | 1 | 3 | 2 |

From the above response tables for S/N ratios and Means that is table 5 and table 6, it may be reported that, the influence of the Rotational Speed (RS) is highest on the microhardness of the SMMC samples fabricated through FSP. The No. of Passes of FSP stands second to influence the microhardness of the SMMCs. It is also learnt from the tables that, the effect of the Traverse Speed (TS) is diversified on the microhardness of SMMCs.

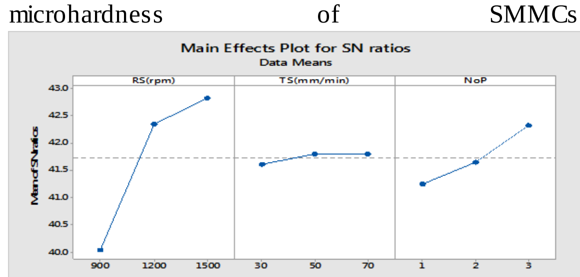



Fig. 3 Main Effect Plot for S/N ratios (Data Means)

From the Main Effect Plot for S/N ratios and Means of the Microhardness Vs the RS, TS and NoP, (Fig. 2 and 3) it is predicted that the optimal set of process parameter is A3B2C3, that is the RS at 1500 rpm, TS at 50 mm/min and No. of Passes (NoP) at 3 passes, from which the maximum (the best) value of Microhardness of the SMMC billets is expected.

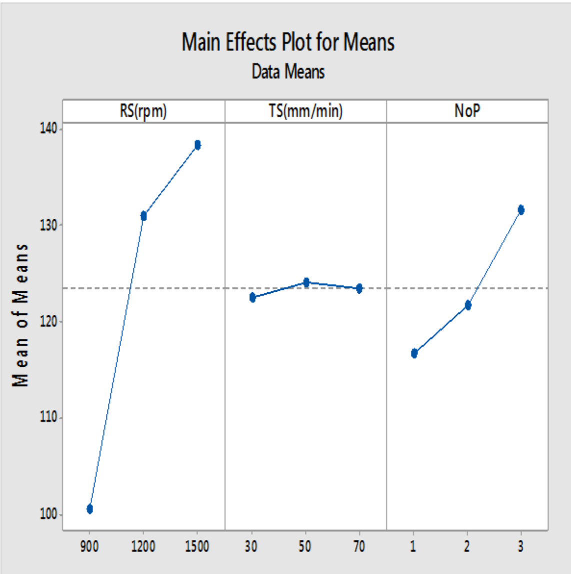



Fig. 4 Main Effect Plot for Means (Data Means)

General Linear Model: S/N Ratio versus RS(rpm), TS(mm/min), NoP
Factor coding (-1, 0, +1)
Factor Information

| Factor | Type | Levels | Values |
|---|---|---|---|
| RS(rpm) | Fixed | 3 | 900, 1200,1500 |
| TS(mm/min) | Fixed | 3 | 30, 50, 70 |
| NoP | Fixed | 3 | 1, 2, 3 |

Table 7 Analysis of Variance (ANOVA)

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| RS(rpm) | 2 | 13.2544 | 6.62720 | 220.82 | 0.005 |
| TS(mm/min) | 2 | 0.0715 | 0.03574 | 1.19 | 0.456 |
| NoP | 2 | 1.7389 | 0.86944 | 28.97 | 0.033 |
| Error | 2 | 0.0600 | 0.03001 | | |
| Total | 8 | 15.1248 | | | |

Model Summary

| S | R-sq | R-sq(adj) | R-sq(pred) |
|---|---|---|---|
| 0.173237 | 99.60% | 98.41% | 91.96% |

From the ANOVA table if P-value is observed, it can be revealed that, the P-values for RS and NoP provide a significant remark that furnishes a validity for the model, while the P-value for TS gives a not-significant remark, as the P-value is more than 0.05. From the Model summery the R-Square value is 99.60% which a very good variations in the responses can be observed by changing the factors.

Confirmation Test:

With the obtained optimal set of process parameter, A3B2C3, that is the RS at 1500 rpm, TS at 50 mm/min and No. of Passes (NoP) at 3 passes, the FSP confirmation tests were conducted and the average value for microhardness is obtained as 145.67 Hv. The difference of the microhardness values obtained by optimal set of process parameters and from the Taguchi Design Matrix is

147.59 – 145.67 = 1.92 (1.3%)

which can be a considerable range. Thus the Maximum Microhardness from the optimal set of the process parameters is obtained as 147.59 Hv for AA7075/MWCNT.

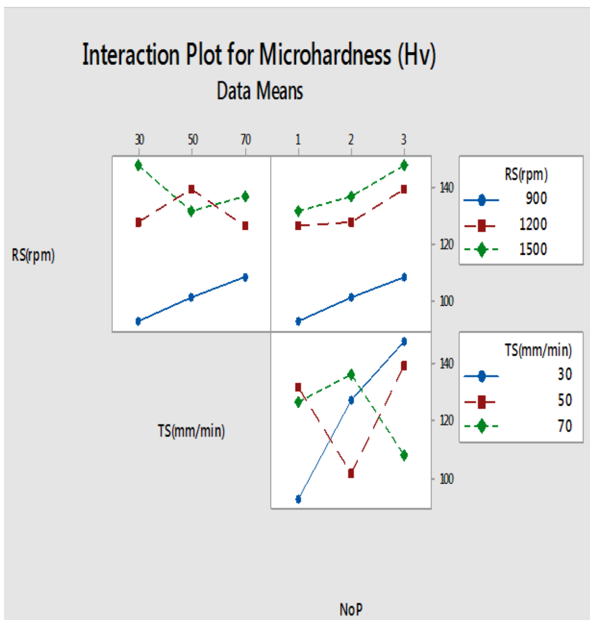



Fig. 5 Interaction Plot for Microhardness (Data Means)

From the interaction plots for Hardness, the factors RS and TS show dependency between 1200 rpm at 45 mm/min and also at 55 mm/min at 1500 rpm. While the NoP does not show any dependency on RS at all the three levels. It is also observed that there exist dependency of NoP on TS almost at three levels.

## V. CONCLUSIONS

Following are the conclusions drawn from the Friction Stir processing of the AA7075 with MWCNT to fabricate the Surface MMCs.

- AA7075/MWCNT Surface composites are fabricated through Friction Stir Processing
- Process parameters such as RS, TS and NoP are varied intentionally to variety of SMMCs.
- Taguchi DOE is adopted with L9 Orthogonal Array to carry out FSP experiments.
- Microhardness of the SMMC samples and the S/N ratios of the same is obtained using Minitab-17 software.
- Response table and Main Effect plots are obtained from Minitab to reveal the significant factors and their level.
- Optimal set of process parameters are extracted from the plots.
- Confirmation tests are conducted with optimal set of process parameters to obtain the average microhardness value.
- The value of Microhardness from the confirmation test found in the comfortable acceptance, hence confirmed.
- The ANOVA is conducted to find most significant factor and the relevant interactions plots are extracted to comment and conclude.

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