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INVESTIGATION OF CUTTING FORCE IN END MILLING OF Al/n-Tic/MoS_2 SINTERED NANO COMPOSITE

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In industries, metal matrix nano-composites have implied its position by the mechanical properties. But, studies have given importance to micro/macrosize particles. The main aim of the research analysis is to understand the influence of machining parameters for the cutting force (Fc) and surface roughness (Ra) in end milling of hybrid nano-composites Al + 10 % n-Tic + 7,5 % MoS_2. Powder metallurgy process is adopted to prepare nano-composite samples. Microstructural analysis of nano-composite material done by Field Emission Scanning Electron Microscope (FESEM) confirms the uniform distribution of the reinforced particle. Experimentation was conducted by Central Composite Design (CCD), and the evaluation of surface roughness and cutting force was carried out using Response Surface Methodology (RSM) and Genetic Algorithm (GA).

Keywords: Al / n-Tic / MoS_2, machining, cutting force, scanning electron microscope (SEM), roughness

INTRODUCTION

Metal matrix composites (MMCs) are the attention of strong research and development wide-reaching for many industrial branches, where decrease in weight of elements along with the enhancement in strength, specific modulus, wear resistance, thermal stability are essential [1–2]. The reinforcement of nanoparticles on aluminium matrix composites (AMCs) has a unique value in the field of nanostructured materials. The ceramic nanoparticles are used for reinforcements to increase the mechanical properties. SiC, TiC, B4C and MgO, Al_2O_3 are added as a nanoparticle to the AMCs. Among these ceramic nanoparticles, TiC have been considered very popular for its low density, good wear resistance, weldability, for increasing the specific strength and modulus with liquefied aluminium [3]. Cutting force is focused by several researchers in understanding the effect of machining the aluminium matrix composites (AMCs) [4-5]. The surface quality and life of the tool end mill are affected by the inappropriate selection of machining parameters with huge economical loss [6]. Hence during the manufacturing process the significance of the parameters and the machined tool was examined [7]. During the milling process, mechanical loading can be reduced by minimizing the cutting force and power consumption [8].

The present work is focused on conducting the experiment on an aluminium metal matrix Al + 10 %n-Tic + 7,5 % MoS_2 as work piece material. For the two main responses, the parameters like spindle speed (N), Feed rate (F) and depth of cut (Da) are considered at a variation of three different levels. Three axis tool dynamometer- syscon instrument is used for measuring the cutting force in terms of infeed force (Fx), crossfeed force (Fy), thrust force (Fz) [9], and surface tester is adopted in measuring the surface roughness of work piece. During the slot milling, the RSM is employed for conducting the experimental design. Optimal value of the cutting force (Fc) and surface roughness (Ra) are predicted by MOGA.

MATERIALS AND METHODS

Powdered metallurgy process is adopted for the reinforcement of aluminium powder with n-TiC and MoS_2 for preparing samples. 99,8 % pure Al powder and 200 mesh average particle size is reinforced with TiC powder average particle size about 99,5 % pure < 200 nm and MoS_2 powder average particle size about 99,5 % pure and < 2 μm for preparing reinforced material. The sintering process was carried out at a temperature 575°C for a dwell period of 1 hour in tightened furnace and left in the furnace to achieve the room temperature [1]. Comparing the base material the mechanical properties of the nano hybrid composite material was improved. Based on ASTM, the testing was done on mechanical properties of nano-composite material and presented in the Table 1.

Table 1 Hybrid nano-composite mechanical properties

Density / g/cm³	3,7
Micro-Hardness / HV	125,7

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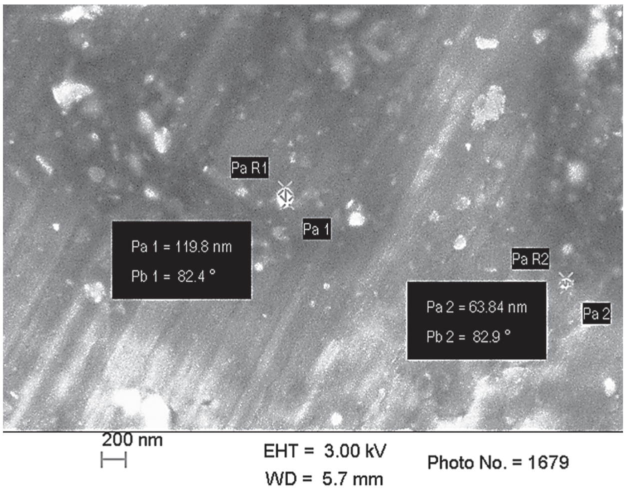

Figure 1 FESM of Al +10 % n-Tic + 7,5 % MoS_2

Analysis of the microstructure using the Field Emission Scanning Electron Microscope (FESEM) shows the uniform distribution of the particle Al + 10 %n-Tic + 7,5 % MoS_2. The interpretations revealed that presence of porosity in the composites material were minimum. Figure 1 depicts analysis of FESEM which indicates the presence of sintered composite samples aluminium composites with ≤ 200 nm TiC and ≤ 2 µm particles. The presence of sample particle n-TiC and MoS_2 in the Al matrix is confirmed from the peaks of Ti, C, Mo and S from the EDS spectrum shown in Figure 2.

EXPERIMENTAL DETAILS AND PLAN

Experimentation was carried out using HAAS CNC vertical machining center with High Speed Steel (HSS) mill cutter. The work piece material (Al+10%n-Tic + 7,5 % MoS_2) employed in the study has a wide range of application in the manufacturing of components in aerospace components for its properties like toughness, strength corrosion resistance, stiffness, and hardness. Three axis milling tool dynamometers were used for measuring the cutting forces: infeed force, cross feed force and thrust force. The average surface roughness value was determined by measuring the values at three different locations by adopting the Mitutoyo Surftest SJ201. Table 2 shows the lower (-1) and upper (1) levels of three process variables. The experimentation is repeated thrice for each of the 32 runs and the further analysis was carried out from the average response values. Table 3 depicts the recorded experimental values developed from the design matrix.

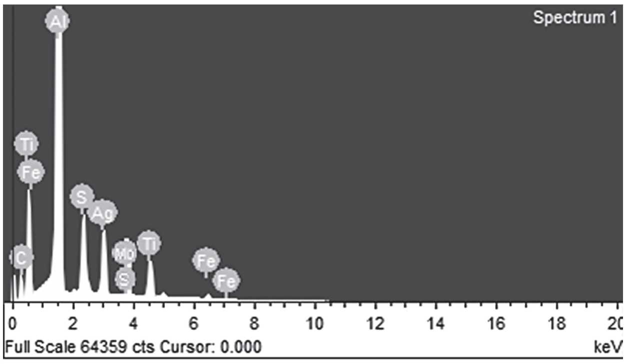

Figure 2 Energy Dispersive Spectroscopy (EDS) Spectrum of Al + 10 % n-Tic + 7,5 % MoS_2

Table 2 **Machining parameters**

Machining parameters	Units	Levels		
		-1	0	1
A	rpm	1 400	2 500	3 600
B	rev/min	0,04	0,08	0,12
C	mm	0,4	0,7	1

STATISTICAL ANALYSIS

The F statistical value for the developed model was found to be 7,75 from the variance of analysis and show the cutting force is significant. The comparison of pure error with lack of fit (LOF) shows that LOF is non-significant as the value is 1,37. The effect of milling parameters shows that the F statistical value for each responses are (2,52E-05) for spindle speed, (7,3E-05) for feed rate and (0.784356) for depth of cut. When compared to all the parameters the F-statistical value of depth of cut influenced more on the cutting force.

The F statistical value for the developed model was found to be 2,44 from the variance of analysis and show the surface roughness is significant. The lack of fit is non-significant when compared to the pure error as the value is 0,81. The effect of milling parameters shows that the F statistical value for each responses are (0,01345) for spindle speed, (0,264826) for feed rate and (0,813182) for depth of cut.

The R^2 value 93,1 point out the coefficient of cutting force has less variation in the developed model and fitted in the regression line. The R^2 value 96,5 point out the coefficient of surface roughness has less variation in the developed model and fitted in the regression line. The surface roughness and the cutting force can be predicted from the developed regression model equations 1 and 2.

$$\text{Cutting force} = +459{,}42815-0{,}096072*A+1005{,}04029*B-180{,}74198*C-4{,}89378*D -0{,}10653*A*B-0{,}00549242*A*C-0{,}0000284091*A*D+338{,}54167*B*C+3{,}90625*B*D+0{,}59028*C*D+0{,}0000251134*A*A+-9132{,}96569*B*B+109{,}85839*C*C+0{,}13576*D*D \quad (1)$$

$$\text{Surface roughness} = +3{,}24629-0{,}000605177*A-14{,}31771*B-2{,}67963*C+0{,}026782*D+0{,}00234375*A*+0{,}0009375*A*C-0{,}000028125*A*D-1{,}19792*B*C+0{,}69010*B*D+0{,}028819*C*D \quad (2)$$

RESULTS AND DISCUSSION

Complex problems are solved effectively by adopting the multi objective genetic algorithms. By adopting

Table 3 **CCD with responses**

A / rpm	B / rev/min	C / mm	Fc / N	Ra / µm
2 500	0,08	0,7	264	0,51
1 400	0,12	1	286	0,58
3 600	0,04	1	348	0,46
2 500	0,08	0,7	255	0,45
3 600	0,04	0,4	352	0,51
3 600	0,04	0,4	356	0,43
3 600	0,12	0,4	307	0,71
2 500	0,08	1	305	1,76
2 500	0,08	0,7	280	1,24
2 500	0,08	0,4	298	0,82
1 400	0,12	1	290	1,89
1 400	0,04	1	298	0,58
1 400	0,04	0,4	308	1,87
1 400	0,12	0,4	270	1,75
3 600	0,12	0,4	308	1,26
2 500	0,08	0,7	266	1,24
2 500	0,08	0,7	278	1,23
3 600	0,08	0,7	350	0,91
2 500	0,08	0,7	310	1,97
1 400	0,12	0,4	278	2,1
1 400	0,08	0,7	294	1,86
1 400	0,04	1	301	1,8
2 500	0,04	0,7	290	1,84
2 500	0,08	0,7	267	1,67
1 400	0,04	0,4	316	1,84
3 600	0,12	1	296	1,26
3 600	0,04	1	341	1,69
3 600	0,12	1	312	1,74
2 500	0,08	0,7	283	1,26
2 500	0,08	0,7	286	1,47
2 500	0,08	0,7	291	1,81
2 500	0,12	0,7	264	1,98

traditional optimization techniques, the conflict occurs between the one objective solution and the other which result in undesirable result. Hence multi objective genetic algorithm is adopted by many researchers in doing the research work for obtaining a satisfactory result for a set of solution without dominating the other solution. The equation 1 and 2 regression models were utilized for solving multi objective optimization problems.

The two main objective of the present study involves in

i. Minimizing the cutting force

ii. Minimizing the surface roughness

Subjected to constraints: $F_C \leq F_C$ limit

Ra ≤ Ra limit

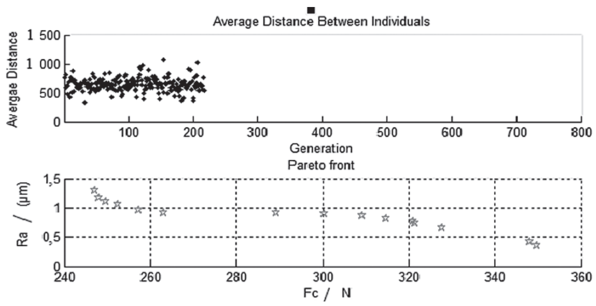

Figure 3 Pareto front

Table 3 **Pareto predicted solutions**

A / rpm	B / rev/min	C / mm	Fc / N	Ra / µm
3479,75	0,04	0,40	349,72	0,36
2266,95	0,12	0,66	247,02	1,30
3400,15	0,10	0,41	309,20	0,88
3467,39	0,04	0,40	348,00	0,43
1985,10	0,12	1,00	263,12	0,92
3394,38	0,11	0,41	300,27	0,91
3379,31	0,12	0,43	289,21	0,92
2265,28	0,12	0,72	248,01	1,17
3276,64	0,04	0,42	331,48	0,62
3280,99	0,04	0,51	325,51	0,69
3236,41	0,04	0,52	320,95	0,77
2215,63	0,12	0,85	252,36	1,06
3224,17	0,04	0,51	321,36	0,73
3310,56	0,04	0,51	327,59	0,67
2266,76	0,12	0,66	247,03	1,30

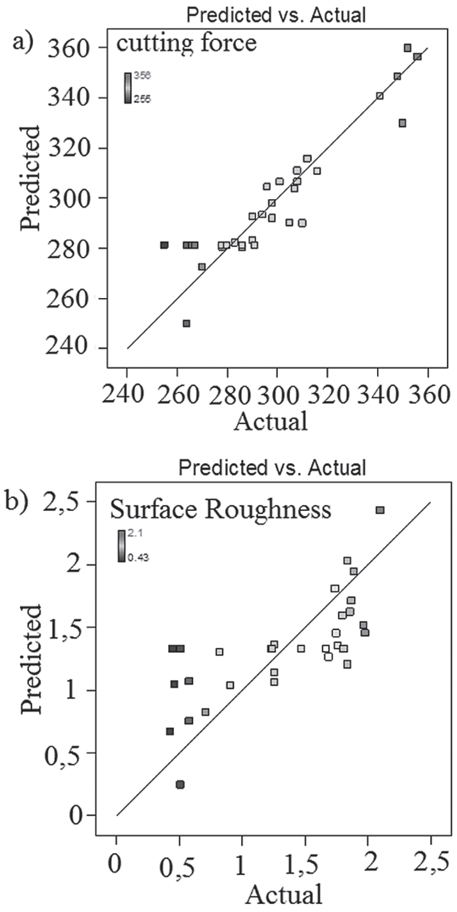

Figure 4a-b Scattered plot Predicted Vs. Actual

Where Fc, Ra limit indicate the lower and upper limits of the responses

Figure 3 depicts the Pareto optimal frontier spread points of the two responses. Between the range of 247,02 to 349,72 and 0,36 to 1 µm the cutting force and surface roughness was spread. The Figure 4a-b shows that actual and experimental values are scattered in closer so the developed models were reliable with minimum and acceptable range of errors. The Table 3 represents the 15 parametric combinations of the non-dominated Pareto optimal solutions. The values are verified for validation and the all the generated values were reliable and good.

CONCLUSION

In this investigational study, the three levels of central composite design were used in developing the regression models for the end milling process. Genetic algorithm was adopted for solving the Multi objective optimization.

- In the end milling process, The relationship between the machining parameters and responses shows a quadratic and linear relationship.
- The predicted Pareto front presents 15 number of non-dominated solutions in the parameters space.
- The validation of the predicted results shows a good agreement with experimentation.
- The experimental versus the predicted scatter plots were very close and has less possibilities in error.

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Note: The responsible translator for English language is Dr.B.R.Senthil Kumar, India