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Optimization of Turning Process Parameters of Al 6061/Si_3N_4 MMC using GA

G.Sreekanth Reddy[1,*], Bezawada Sreenivasulu[2] and K.V.P.Chakradhar[2]

[1]MITS, Madanapalli-517325, India.

[2]Department of Mechanical Engineering, MITS, Madanapalli-517325, India.

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ABSTRACT

This paper investigates the development of Al6061/Si_3N_4 metal matrix composites using stir casting technique and optimize the process parameters in turning based on Genetic Algorithm. In this metal matrix composites Al 6061 alloy reinforced with 3% and 5% weight by volume of Si_3N_4 particles of mean diameter 75µm was used. Experiments were performed in the CNC lathe by using CNMG inserts at various cutting conditions and parameters such as cutting speed, feed and depth of cut and surface roughness was found at different levels. The optimization of machining parameters was done by using Genetic Algorithm.

Introduction

In this investigation, Al 6061 alloy was matrix material. It has a medium to high strength, good surface finish, and excellent corrosion resistance. This alloy was used in many industrial applications such as aircraft and aerospace components, marine fittings, bicycle frames, camera lenses etc…Silicon Nitride (Si_3N_4) as a reinforcement material. It has high strength over a wide range of temperature, outstanding wear resistance etc…

In a Stir casting technique using mechanical stirring the particulate reinforcement was distributed uniformly in all directions into the aluminum melt. Composites with up to 30% volume fractions can be suitably manufactured using this method Himanshu Kala et al. [1]. For good wetability we need to keep operating temperature at semisolid stage i.e. 630 for Al (6061) Rajeshkumar et al. [2]. An issue occurred with the stir casting technique was the segregation of reinforcing particles due to settling of particles during solidus. A development in stir casting technique was double-step mixing process for achieving good mechanical properties Zhou and Xu et al. [3]. In this process, first step the matrix material was heated up to its liquidus temperature. The melt was then cooled down to a temperature between the liquidus and solidus points to a semi-solid state. In second step the preheated reinforcement particles were added and mixed. Again the slurry was heated to a fully liquid state and mixed thoroughly.

The machining processes were classified in various heads. Which are used in produce various design of parts. Slandered and common processes are turning, facing, taper turning, knurling, threading, boring, drilling, chamfering, forming etc... S.V. Bhaskar Reddy et al. [4], Nafis Ahmad et al. [5], R. Saravanan et. al. [6], R. QuizaSardinas et al. [7], T. Srikanth et al. [8], Doriana M. D' Addona, et al. [9] were worked with Genetic Algorithm for parameters of turning operation they determine the optimal machining parameters that minimize the surface roughness, production time, production cost without violating any imposed cutting constraints based on Genetic Algorithm approach

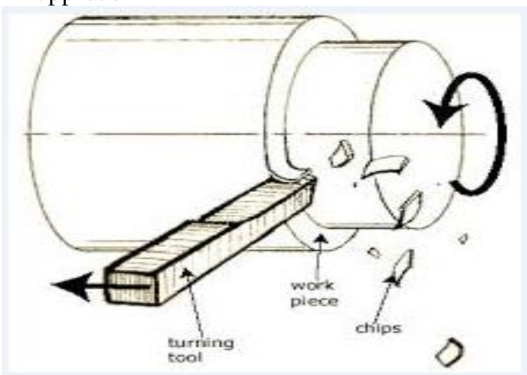

Figure 1. Schematic diagram of plane turning process

Genetic Algorithms (GA) were first developed by John Holland & Goldberg are one of the most evolutionary computing methods provides to an optimization of problems. A Genetic Algorithms was an evolutionary algorithm applies the principle of finding an optimal solution to a problem solver. In a Genetic Algorithm, the problem was encoded in a series of bit strings that were manipulated by the algorithm Shashi Prakash Dwivedi et al. [10]. In Genetic Algorithms we can use a population of solutions in each iteration, instead of single solution. The most influencing the optimal result was the number of the initial population, the type of the selection function, the cross over rate, and the mutation rate.

Materials and Methods

Work piece material

Al 6061/Si_3N_4 Metal Matrix Composite as a work piece material used for CNC Turning. The chemical composition of Al 6061 alloy shown in Table 1.

Si_3N_4 used as a reinforcement material of particle size 75µm. Si_3N_4 reinforcement help us to improve the wear resistance of Metal Matrix Composites (MMC).

Tele:
E-mail addresses: coolsree3400@gmail.com

Composite preparation

In this process Al 6061 was used as matrix material and reinforced with three different 0%, 3% and 5% weight by volume of Si_3N_4 particles of mean diameter 75µm. Stir casting setup was shown in Figure 2. In which Aluminium 6061 was melt in a conical shaped Graphite crucible by heating it in the muffle furnace up to 800^0c temperature. The reinforcement Silicon Nitride (Si_3N_4) particles preheated at 300^0c temperature for 1 hour Bharath et al. [11] to remove moisture content from the particles.

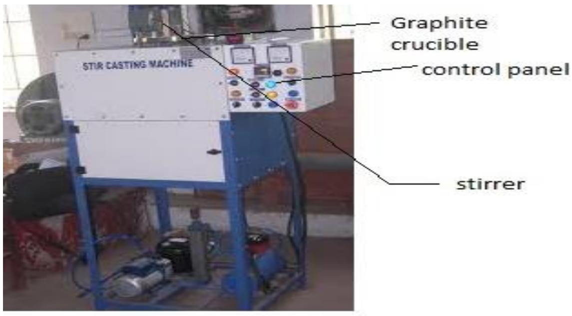

Figure 2. Stir casting setup

Figure 3. Round rod along with Die

For the purpose of complete melt of Al 6061 temperature raised above the liquidus temperature of 650^0c. After some time period the temperature of Al 6061 slurry cooled down from liquidus to semi solid state. The die placed upon the furnace for preheating purpose. Now the molten Al 6061 was stirred for 5 min for the homogenous melt form at stirring rate of 200rpm. Preheated Si_3N_4 particles were embedded in the molten by three steps mixing of melt Bharath et al. [11]. In every step before and after addition of reinforcement particles, mechanical stirring is carried out for a period of 5 min. The stirrer position was such that $1/3^{rd}$ of material should be below the stirrer and $2/3^{rd}$ of material should be above the stirrer Singla et al. [12]. After the complete addition of particles, the melt was stirred for a defined time. The melt was poured in the preheated mould to get a desired shape of composite. The casted part is shown in FIG.3.

CNC Turning

CNC Turning will be performing based on Taguchi's method and as per L_9 orthogonal array with considering three machining parameters (i.e. speed, feed, depth of cut). The experimental setup of CNC Turning as shown in FIG.4. The CNC Turning with larger shaft power up to 3700W, maximum spindle speed 4000 rpm, feed rate up to 5000mm/min. The specifications of CNC Turning as shown in Table 2.

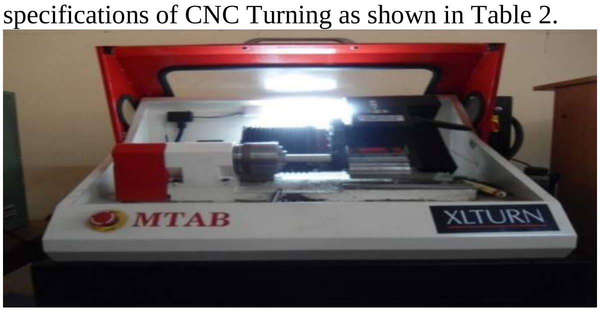

Figure 4. CNC turning setup

Design of Experiment

Experiments have been carried out by using Taguchi's method and as per L_9 orthogonal array with considering three machining parameters i.e. speed, feed, Depth of cut. Each factor has three levels. The cutting parameters and their levels are detailed in Table 3. The experimental inputs are mentioned in the Table 4.

Measuring Equipment

Surface roughness measured using Talysurf (Mitutoyo SJ-210) shown in Figure 5. Surface roughness of the waviness measured in terms of the aggregate roughness R_a, using a Talysurf tester.

Figure 5. Tallysurf SJ-210 equipment

Results and Discussions

The main objective of this investigation was to find the optimal cutting parameters to minimize the surface roughness value by using optimization technique. In which Genetic Algorithm used as an optimization technique to identify the best combination of cutting parameters.

Output responses of 0% wt. by volume of Si_3N_4

The output responses of 0% addition of Si_3N_4 are shown in Table 5.

Fitness function equation of surface roughness (R_a) will be created by using regression analysis with MINITAB 16. Fitness function equation of R_a of 0% wt. by volume of Si_3N_4 as follows.

R_a = 3.70 – 0.00275 speed + 48.3 feed + 1.84 doc

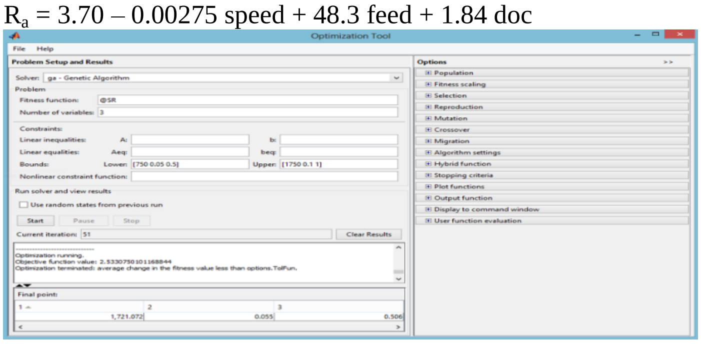

Figure 6. Result snap from MATLAB for R_a of 0% wt. by volume of Si_3N_4

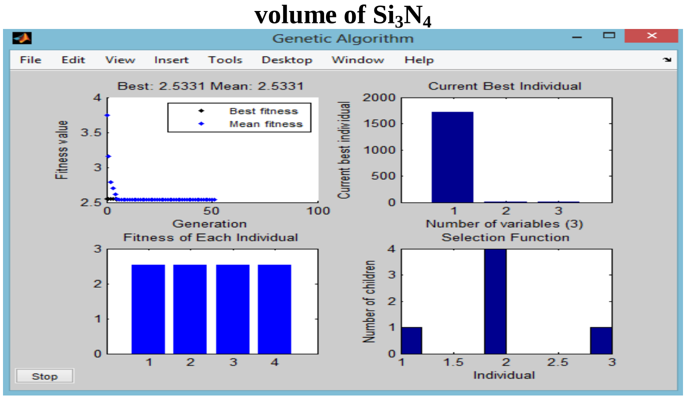

Figure 7. Graph for surface roughness R_a

Considering population 4, current generation 51, the optimization values for cutting parameters are spindle speed-1721.072 rpm, feed-0.055 mm/rev, depth of cut-0.506 mm. Best fitness for minimization of surface roughness is 2.5331µm.

Table 1. Chemical composition (w. %) of Al 6061 alloy

Component	Amount (wt. %)
Cr	0.04-0.35
Ti	0.15 Max.
Mn	0.15
Cu	0.15-0.40
Zn	0.25 Max.
Fe	0.7 Max.
Si	0.40-0.80
Mg	0.8-1.2
Others	0.05 Max.
Al	Balance

Table 2. Specifications of CNC Turning

Range of Spindle speed	150-4000 rpm
Extreme shaft power	3.7 KW
Range of feed rate	5000 mm/min
Bed type	45^0 slant bed
Max. swinging range of Dia. on chuck	80 mm
Chuck size	100 mm

Table 3. Cutting parameters & their levels

Cutting parameters	Levels		
	1	2	3
Speed (rpm)	750	1250	1750
Feed (mm/rev)	0.05	0.075	0.1
Depth of cut (mm)	0.5	0.75	1

Table 4. Experimental design

S.No	Speed (rpm)	Feed (mm/rev)	Depth of cut (mm)
1	750	0.05	0.50
2	750	0.075	0.75
3	750	0.1	1.00
4	1250	0.05	0.75
5	1250	0.075	1.00
6	1250	0.1	0.50
7	1750	0.05	1.00
8	1750	0.075	0.50
9	1750	0.1	0.75

Table 5. Output responses of 0% wt. by volume of Si_3N_4

S.No.	Input responses			Output responses
	Speed (rpm)	Feed (mm/rev)	Depth of cut (mm)	Surface Roughness- R_a (μm)
1	750	0.05	0.5	4.143
2	750	0.075	0.75	7.629
3	750	0.1	1.00	7.941
4	1250	0.05	0.75	3.964
5	1250	0.075	1.00	6.522
6	1250	0.1	0.50	5.729
7	1750	0.05	1.00	2.644
8	1750	0.075	0.50	4.480
9	1750	0.1	0.75	4.331

Table 6. Output responses of 3% wt. by volume of Si_3N_4

S.No.	Input responses			Output responses
	Speed (rpm)	Feed (mm/rev)	Depth of cut (mm)	Surface Roughness- R_a (μm)
1	750	0.05	0.5	3.317
2	750	0.075	0.75	6.435
3	750	0.1	1.00	8.982
4	1250	0.05	0.75	3.394
5	1250	0.075	1.00	3.955
6	1250	0.1	0.50	4.809
7	1750	0.05	1.00	2.366
8	1750	0.075	0.50	4.171
9	1750	0.1	0.75	2.544

Table 7. Output responses of 5% wt. by volume of Si_3N_4

S.No.	Input responses			Output responses
	Speed (rpm)	Feed (mm/rev)	Depth of cut (mm)	Surface Roughness- R_a (μm)
1	750	0.05	0.5	3.881
2	750	0.075	0.75	6.983
3	750	0.1	1.00	7.264
4	1250	0.05	0.75	4.397
5	1250	0.075	1.00	4.839
6	1250	0.1	0.50	5.734
7	1750	0.05	1.00	2.105
8	1750	0.075	0.50	3.022
9	1750	0.1	0.75	3.920

Table 8. Confirmatory test R_a

S.No.	% wt. by vol. of Si_3N_4	Predicted-R_a (μm) value from GA(P)	Experimental –R_a(μm) (E)	Error % ((E-P)/E) *100
1	0	2.533	2.727	7.11
2	3	2.232	2.214	0.83
3	5	1.9795	2.1534	8.05

Output responses of 3% wt. by volume of Si_3N_4

The output responses of 3% addition of Si_3N_4 as shown in Table 6.Fitness function equation of 3% wt. by volume of Si_3N_4 as follows

R_a = 3.33 – 0.00322 speed + 48.4 feed + 2.00 doc

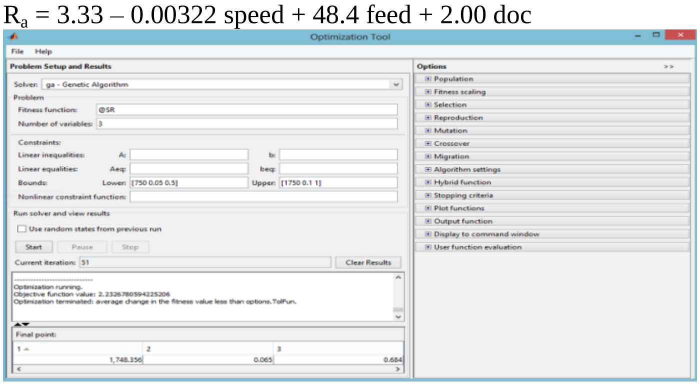

Figure 8. Result snap from MATLAB for R_a of 3% wt. by volume of Si_3N_4

Considering population 4, current generation 51, the optimization values for cutting parameters are spindle speed-1748.356 rpm, feed-0.065 mm/rev, depth of cut-0.684 mm. Best fitness for minimization of surface roughness is 2.2327μm.

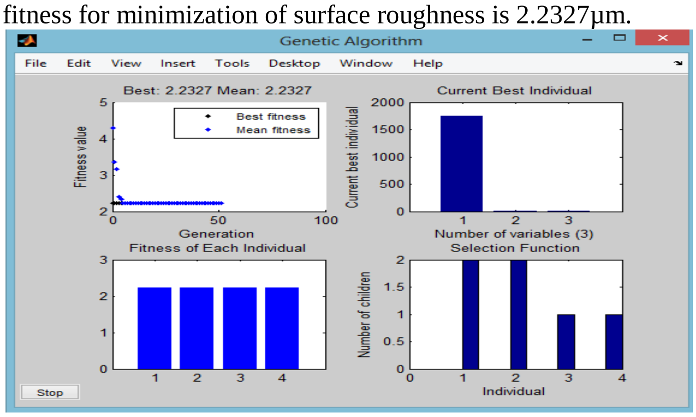

Figure 9. Graph for surface roughness R_a

Output responses of 5% wt. by volume of Si_3N_4

The output responses of 5% addition of Si_3N_4 as shown in Table 7.

Fitness function equation of 5% wt. by volume of Si_3N_4 as follows

R_a = 4.32 – 0.00292 speed + 43.8 feed + 0.57 doc

Considering population 4, current generation 51, the optimization values for cutting parameters are spindle speed-1638.952 rpm, feed-0.05 mm/rev, depth of cut-0.753 mm. Best fitness for minimization of surface roughness is 1.9794μm.

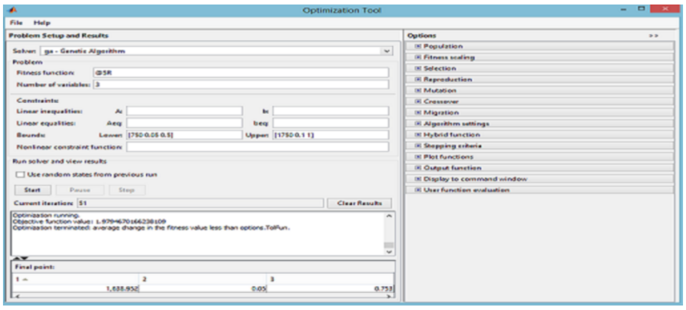

Figure 10. Result snap from MATLAB for R_a of 5% wt. by volume of Si_3N_4

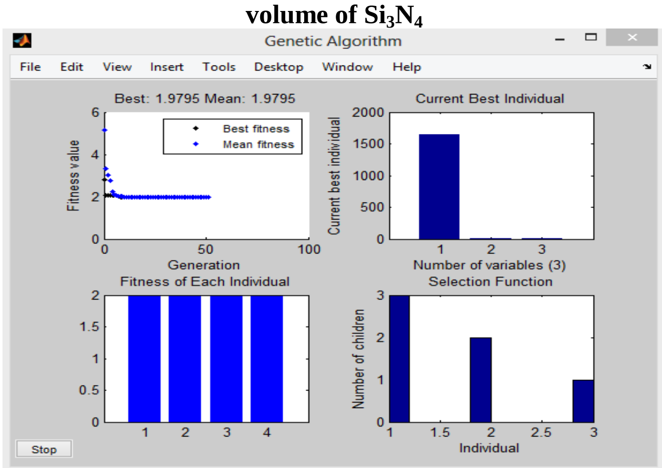

Figure 11. Graph for surface roughness R_a

Confirmatory test

Confirmatory test was conducted to find the percentage of error between Experimental values (E) and Predicted values (P). The confirmatory test as shown in below Table 8.

Conclusions

The Al 6061 reinforced with different % wt. by volume of Si3N4 was successfully produced by stir casting method and different cutting parameters & their levels was considered for CNC Turning. The below conclusions to be made based on investigation carried out.

1. The metal matrix composites having Al 6061 with 0, 3 and 5% wt. by volume of Si3N4 were successfully reinforced using stir casting technique.

2. The minimum surface roughness occurred at reinforcement of 5% wt. by volume of Si3N4.

3. The minimum surface roughness value 1.9795μm obtained at optimized cutting parameters i.e. spindle speed-1638.952 rpm, feed-0.05 mm/rev, depth of cut-0.753 mm.

4. The confirmatory test was conducted and determined that the percentage of error within 8.05%.

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