OPTIMIZATION OF MACHINING PARAMETERS IN HIGH SPEED END MILLING OF AL-SiC USING GRAVIATIONAL SEARCH ALGORITHM

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ABSTRACT

Surface roughness is very important criteria for evaluation in end milling operation. It is very important to predict surface roughness to maintain or improve quality of the components and soft computing techniques help in optimizing the machining parameters required to predict surface roughness. Many researchers developed models in order to achieve minimum surface roughness in metal cutting operations at low cost. However, very few researchers worked in the area of high speed machining for minimizing surface roughness using gravitational search algorithm (GSA). In this paper, GSA which is inspired by Law of gravity, is used for optimization of surface roughness. Speed, feed, depth of cut and step over ratio are taken as the input parameters and Aluminum silicon carbide composite material is used as work material. Experiments are conducted by varying the input parameters at two levels each except for speed at three levels. These experiments are conducted on high speed CNC vertical machine and portable Taylor Hubson surface roughness tester is used for measuring surface roughness. A Non linear regression equation is used to establish relationship between surface roughness and the input parameters. MATLAB software has been used for writing code for GSA and results indicate that GSA proves to be effective in this optimization problem.

KEYWORDS

GSA, Surface Roughness, Composite Material, Non Linear Regression Equation, MATLAB Code.

1. INTRODUCTION

Metal matrix composite is world class engineering material with improved mechanical and thermal properties having application in automotive, aircraft and related industries. Now a days, aluminum silicon carbide composite (Al-SiC) is predominantly used in various applications in industries. The material retains machinability characteristics of aluminum and at the same time increases hardness of the material. In real life optimization problems with a high-dimensional search space, the conventional optimization algorithms do not give a feasible solution because of the continuously increasing search space with the problem size. Over the last decades, there has been a strong inclination in using algorithms inspired by the behaviors of natural phenomena. Various heuristic approaches have been applied by researches, such as, Genetic Algorithm (GA), Simulated Annealing (SA), Artificial Bee colony Algorithm (ABC), Particle Swarm Optimization (PSO) etc. These algorithms can be used to solve different optimization problems. However, there is no specific algorithm to solve all optimization problems. Some algorithms provide a better solution in particular case in comparison to other algorithms and thus they are very much problem specific. In this study, a new optimization algorithm inspired by the law of gravity, namely Gravitational Search Algorithm (GSA) is applied. This algorithm is influenced on Newtonian gravity: ‘‘Every particle in the universe attracts every other particle with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them". Heuristic algorithm are based upon either physical or biological processes.

1.1 Gravitational Search Algorithm (GSA)

In this algorithm, agents are correlated with the objects and their output is measured by their masses. Due to gravity, all these objects attract each other and it also produces a global movement of all objects towards the objects with heavier masses. Hence, gravitational force is medium of communication between masses. The big and heavy masses represents good solutions and it move significantly slower than lighter ones. This ensures the exploitation step of the algorithm. In GSA, each mass holds four stages, namely position, inertial mass, active and passive gravitational mass. The positions of the mass identify a solution of the problem and it is solved by using a fitness function. The algorithm is governed and directed by properly adjusting the gravitational and inertia masses. In due course of time, other small masses are attracted by the heaviest masses. This mass will present an optimum and feasible solution in the search space. The GSA virtually acknowledges it as an isolated system of masses in which masses are governed by the Newtonian laws of gravitation and motion. These laws are: law of gravity: each particle attracts every other particle and the gravitational force between two particles is directly proportional to the product of their masses and inversely proportional to the distance between them. Law of motion: the current velocity of any mass is equal to the sum of the fraction of its previous velocity and the variation in the velocity. Variation in the velocity or acceleration of any mass is equal to the force acted on the system divided by mass of inertia. The inertia mass causes obstacles in the motion and causes the mass movement to be slow. Therefore, agents with heavy inertia mass move slowly and it searches the space more effectively. GSA is a memory-less algorithm but as good as other algorithms with memory.

In this paper, in addition to introduction in this section, the literature review is given in section-2. The experimental work is explained in section-3. The data obtained from experiments and results and discussions are explained in section-4. The conclusions drawn about the work are explained in section-5.

2. LITERATURE REVIEW

The literature review on this topic reveals that very few researchers worked in parameter optimization of metal cutting process under high speed machining conditions for composite materials. The researchers mostly applied a few conventional optimization techniques, such as, goal programming, feasible direction method, etc. to solve the problems of optimization but subsequently, researchers could not achieve optimum values for the output variables by these conventional techniques. These techniques are very cumbersome and often not result oriented. To overcome the limitation of conventional optimization techniques, researchers attempted the advanced optimization techniques, such as, GA and its versions, SA, PSO and ABC algorithms. In the category of new optimization techniques, gravitational search algorithm (GSA) is a recent one and very result oriented for optimization problems.

Zubaidi et al (2013) deployed the gravitational search algorithm for the optimization of cutting conditions for end milling of Ti6Al4V Alloy and compared the results with the results obtained by applying genetic algorithm and particle search algorithm. They proved that GSA is more effective as compared to GA and PSO techniques. R.Arokiadass et al., (2012) studied the machining properties of LM25 Al/SiCp composite under high speed end milling conditions. They deployed the RSM and developed a mathematical model to estimate the high speed end milling process parameter.

Esmat rashadi et al., (2009) introduced a new optimization algorithm viz., gravitational search algorithm which is based on the law of gravity and mass interactions. This algorithm has been compared with some well-established heuristic search methods and best result is achieved as compared to other techniques for their case. Yusup et al (2012) have given the overall view and compared various evolutionary optimization techniques which are applied in optimization of cutting conditions for machining processes. They applied five techniques for comparison namely: genetic algorithm (GA), simulated annealing (SA), particle swarm optimization (PSO), ant colony optimization (ACO) and artificial bee colony (ABC) algorithm. The authors concluded that, in comparison to other machining processes, the most prominently used algorithm is genetic algorithm which was deployed mostly for multi pass turning operation. The performances of these techniques have been used widely in minimization of surface roughness.

Mahyar Khorasani et al.(2012) studied the parameters that influence the surface roughness in metal cutting processes in a significant way. They categorized the different machining parameters into six groups namely: tool properties, machine tool , cutting conditions, thermal and dynamic properties and work material. Ozcelik and Bayramoglu (2006) deployed a statistical model for surface roughness prediction in a high-speed flat end milling process considering wet cutting conditions, by applying machining variables, namely, spindle speed, feed rate, depth of cut, and step over ratio.

3. EXPERIMENTAL WORK

The experimental study was carried out in dry cutting conditions on a high-speed CNC vertical milling machine (Model-Agni-BMV-45-T-20-Year 2008) with a maximum spindle speed of 10,000 rpm, clamping area of 450 x 900 mm^2 , feed rate of (1-10000) mm/min, 15-kW drive motor capacity, and a table Size of 800x500x550 mm^3. CNC part programs for tool paths were prepared. Aluminum silicon carbide composite material is used in the form of a 52mm x 52mm x 22mm block. A flat end mill (25mm diameter, 45*1* helix angle, 4-flutes) of make Addison was used in the tests. In this paper, linear and non-linear relationship has been established between input and output parameters and applied GSA to minimize surface roughness. Figure-2 shows the working of surface roughness tester and High Speed CNC vertical milling machine as used in experimental work.

Figure 2 Surface roughness tester and its working

4. RESULT AND DISCUSSION

Based on the selected range, data is collected by varying the selected combinations of speed, feed, depth of cut and step over ratio. In this experiment, coolant was not used and other indirect factors such as, machine vibration and its tolerance, operator efficiency and environmental condition are assumed to have negligible effect on surface roughness. Table 1 shows the selected range of input parameter and Table 2 shows the experimental results. The range is chosen from

5000 to 7000 for speed in order to study the influence of speed on surface roughness at higher ranges. This is attempted by very few researchers. Similarly the feed range is also higher in contract to conventional ranges as higher range of feed value assures higher productivity. For depth of cut, relatively wider range is chosen so as to ensure the best value of depth of cuts as the objective. The step over ratio is chosen such that the surface obtained is smooth.

Following are the ranges of input parameters used in this study.

Table1 Selected Range of Input Parameters

Parameter	**Lower**	**Higher**
Speed (x1)(m/min)	5000	7500
Feed/tooth(x2)	200	300
Depth of cut (x3)	0.2	0.4
Step over ratio(x4)	0.6	0.7

Table 2 Data high speed CNC milling

S.N0	X1	X2	X3	X4	Ra
1	2500	100	0.2	0.5	0.3096
2	2500	100	0.2	0.6	0.3714
3	2500	100	0.3	0.5	0.3362
4	2500	100	0.3	0.6	0.4001
5	2500	200	0.2	0.5	0.3459
6	2500	200	0.2	0.6	0.4098
7	2500	200	0.3	0.5	0.3745
8	2500	200	0.3	0.6	0.4364
9	5000	100	0.2	0.5	0.1689
10	5000	100	0.2	0.6	0.2328
11	5000	100	0.3	0.5	0.1976
12	5000	100	0.3	0.6	0.2594
13	5000	200	0.2	0.5	0.2072
14	5000	200	0.2	0.6	0.2691
15	5000	200	0.3	0.5	0.2339
16	5000	200	0.3	0.6	0.2978
17	7500	100	0.2	0.5	0.0882
18	7500	100	0.2	0.6	0.1501
19	7500	100	0.3	0.5	0.1149
20	7500	100	0.3	0.6	0.1787
21	7500	200	0.2	0.5	0.1245
22	7500	200	0.2	0.6	0.1884
23	7500	200	0.3	0.5	0.1532
24	7500	200	0.3	0.6	0.2151

General form of non linear equation is

$$Ra = K.x1^{a1} .x2^{a2} .x3^{a3} .x4^{a4} \quad (4.1)$$

By taking logarithmic on both sides

$$Log(Ra)= Log(K)+a1*log(x1) + a2*log(x2) + a3*log(x3) + a4*log(x4) \quad (4.2)$$

$$RA= a1*log(x1) + a2*log(x2) + a3*log(x3) + a4*log(x4) + C, \quad (4.3)$$

where $RA=log(R_a)$ and $C=log(K)$

With the help of Minitab software using 24 experimental data values, non-linear regression equation is developed, which is given equation 4.4.

$$RA= 1.9863 -0.2014.log(x1) +0.05382. log(x2) + 0.0682.1og(x3) +0.3447. log(x4) \quad (4.4)$$

This non-linear equation is based on Gauss Newton having tolerance .00001 and 200 iteration. In this paper, GSA applied. The result of GSA techniques in terms of surface roughness and corresponding parameters are x1, x2, x3 and x4 shown in table 5.

Table 5 Optimum Result as obtained by GSA method

Parameter	**GSA**
X1(rpm)	7132
X2(mm/min)	120.8
X3(mm)	0.3
X4	0.6
Result (Ra in micron)	.1986
Iteration	5

4.1 Summary of non-linear regression analysis

In this study, non-linear regression analysis performed with experimental data is given in Table-7. Four input parameters, a1, a2, a3, and a4 are chosen and their estimates are given in table. Standard error estimates are very low for all five parameters including constant, C. This indicates that this model is fit for prediction of surface roughness.

Table6 parameter constraints

Parameter	**Value**	**Constraints**
a1	1	-10 < a1 < 10
a2	1	-10 < a2 < 10
a3	1	-10 < a3 < 10
a4	1	-10 < a4 < 10

Table 7 ParameterEstimates

Parameter	Estimate	SE Estimate
a1	0.20151	0.0000511
a2	0.05385	0.0000663
a3	0.06818	0.0001133
a4	0.34483	0.0002593
C	1.98650	0.0029059

Table 8 Summary

Item	**Value**
Iterations	3
Final SSE	0.0000
DFE	19
MSE	0.0000003
S	0.0005620

5. CONCLUSION

Application of the heuristic algorithms has been the latest trend by researchers to find out best solution in optimization problems related to selection of metal cutting conditions. Most of these algorithms are influenced by physical law and the natural behavior of organisms. GSA is introduced as a heuristic algorithm which utilizes the law of gravity and motion. GSA emerges as a most promising option now for the researchers to solve metal cutting optimization problems. In our study, we adopted this algorithm for optimizing process parameters at the higher ranges of speed using CNC machine. Out of the four input parameters selected for study, it is found that all the four parameters have significant influence on surface roughness and GSA is found to be an effective tool to solve complex computational problems. The method may be extended by future researchers for optimization of machining time and metal removal rate using GSA. If necessary, some more input parameters may be tested for their influence on surface roughness at higher speed ranges of metal cutting.

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