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Application of Genetic algorithm for the determination of optimum machining parameters in turning Al-SiC Metal Matrix Composites

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ABSTRACT

In machining of parts, surface quality is one of the most important requirements. Finish turning using Cubic Boron Nitride (CBN) tools allows manufacturers to simplify their processes by achieving the desired surface roughness. There are various machining parameters having an effect on the surface roughness, but those effects have not been adequately quantified. Optimum selection of cutting conditions importantly contributes to the increase of productivity and the reduction of costs. This paper attention is paid to this problem in this contribution. A Genetic Algorithm (GA) based approach to complex optimization of cutting parameters is proposed. It describes the multi-objective technique of optimization of cutting conditions by means of genetic algorithm taking into consideration.

***Keywords*— Metal matrix composites, Green cutting, Genetic algorithm, Composite machining.**

I. INTRODUCTION

Surface roughness has received serious attention of manufacturers for many years. It has been an important design feature and quality measure in many situations, such as parts subjected to fatigue loads, precision fits, fastener holes and esthetic requirements. In addition surface roughness provide adequate tolerances,which imposes one of the most critical constraints for cutting parameter selection in process planning. While the previous research focused on tolerance study [1-2], this one attempts to develop empirical models with some data mining techniques, such as regression analysis (RA) and computational neural networks (CNN), to help the selection of cutting parameters and the improvement of surface roughness[3-4]. A considerable amount of studies have investigated the general effects of the speed, feed, and depth of cut, nose radius and others on the surface roughness. Empirical models have been developed based on metal cutting experiments using Taguchi designs, and it will include the feed, spindle speed, and depth of cut with different coolants as input variables[5].

The past modeling methods on surface roughness prediction can be classified into two categories: geometric modeling [6] and regression analysis [7]. Geometric modeling is based on the motion geometry of a metal cutting process, regardless the cutting dynamics. Analytical models tend to be general and computationally straightforward. The major drawback of this method is, they miss other parameters in cutting dynamics including speed, depth of cut and the work piece material in their models[6].On the other hand regression method is a kind of empirical modeling method, is that these studies did not apply the factorial experimentation approach to design the experiments. Therefore, the data and conclusions obtained were biased and factorial interactions were not clearly examined[7].This research work contains the Taguchi experimentation approach to design several rounds of experiments following the sequential experimentation strategy [10-11] for an in-depth discussion of the strategy. Therefore, the impact of each individual factor and factor interactions on surface roughness are clearly examined with a reasonably small amount of time and cost. Secondly, with the improved accuracy of today’s machine tools and surface roughness measuring devices with the help of computers and software, the research work is able to include more parameters simultaneously with more accurate experimental data[12].

II. METHODOLOGY

Al-SiC MMC workpeice specimen having aluminum alloy 6061as the matrix and containing 15% vol of silicon carbide particles of mean diameter 25µm in the form of cylindrical bars of length 120mm and diameter Φ40mm was manufactured at vikram sarbhai space center Trivandrum by stir casting process with pouring temperature 700-710^{o}C, Stirring rate 195rpm, extrusion at 457^{o}C, extrusion ratio 30:1, direct extrusion speed 6.1m/min to produce Φ40mm cylindrical bars. The specimens were solution treated after 2 hours at a temperature of 540^{o}C in a muffle furnace, Temperature were accurate to within ±2^{o}C and quench delays in all cases were within 20 seconds. after solutionising, the samples were water quenched to room temperature, and subsequently aged for six different times to obtain samples with different Brinelll Hardness number(BHN), out of which two samples where selected, one with 94BHN obtained at peak age condition i.e. 2 hours at 220^{o}C and other with overage condition i.e. 24 hours at 220^{o}C respectively. All aged and solutionnized samples were kept in a refrigerator right after the heat treatments. In order to observe the effect of matrix hardness on turning of the composite materials with steam, compressed air, water vapor as coolant and dry cutting four samples has been selected. The selected material was manufactured by stir casting process[12-13]. As the matrix materials 99.9% pure aluminum was used, while 15 vol.% SiC particles with an average size of 25µm were applied as the reinforcement element. The chemical composition of specimens given in Table.1

Element	Cu	Mg	Si	Cr	Al
Weight percentage	0.25	1.0	0.6	0.25	Balance

Nominal chemical composition of Base metal (6061 Al alloy): Table 1

The experimental study was carried out in panther lathe(2.5KW) for turning machining process. Cubic boron nitride(CBN) inserts KB-90(ISO code) are used as cutting tool for machining of MMC materials. The ISO codes of cutting tool insert and tool holder were shown in Table 2.

Tool holder specification	STGCR 2020K-16
Tool geometry specification	Approach angle:91^o Tool nose radious:0.4 mm, Rake angle:0^o Clearance angle:7^o
Tool insert CBN(KB-90) specification	TPGN160304-LS

Details of cutting tool and tooling system used for experimentation: Table 2

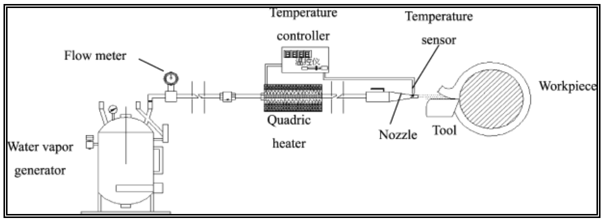
The selected machining condition is given in Table 3. Surface condition of machined work piece was observed using JEOL JSM-6380LA analytical scanning electron microscope. Surface roughness was measured using Taylor/Hobson surtronic 3+ surface roughness measuring instruments.

Condition of machining	**Turning**
Machine tool used	Panther lathe(2.5KW)
Cutting speed(m/min)	150 m/min
Feed(mm/rev)	0.2 mm/rev
Depth of cut(mm)	0.5mm,1mm,1.5mm,2mm
Coolant used	Water vapor
Coolant pressure(Mpa)	0.7Mpa
Cooling distance(mm)	30mm

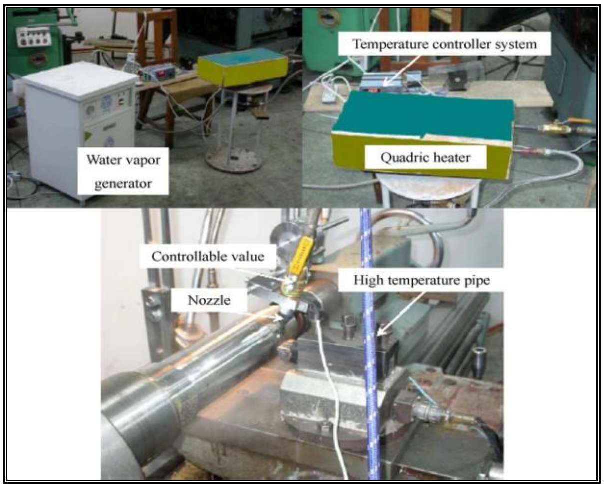
Machining conditions: Table 3

III. EXPERIMENT SETUP

The water vapor generator and vapor feeding system are developed in which jet flow parameters (pressure, temperature, flow velocity and humidity) and cooling distance (it is the distance between nozzle and cutting zone) are controllable. Figure.1 shows the principle of mechanism and Figure. 2 shows the water vapor generator and vapor feeding system[8].



The principle skeleton of vapor gene:rator device and vapor feeding System: Figure 1



Vapor generator and vapor feeding system: Figure 2

A) Experimental details

Taguchi method was used for the execution of the plan of experiments, with three factors at three levels, The factors to be studied and the attribution of the respective levels are indicated in Table 4. The chosen array was L9 , which has 3 rows and 3 columns. The plan of the experiments consists of 9 tests[10-11].

B) Taguchi design of experiments

Taguchi orthogonal Array design.
L9(3*3)
Factors:3
Runs:9

Orthogonal array for Taguchi Design L9: Table 4

Speed (mm/rev)	**Feed (mm/min)**	**Doc (mm)**	**Surface roughness(µm)**
50	0.1	0.5	3.52
50	0.2	1.0	2.363
50	0.3	1.5	2.893
100	0.1	1.0	2.783
100	0.2	1.5	2.677
100	0.3	0.5	2.297

150	0.1	1.5	0.877
150	0.2	0.5	0.873
150	0.3	1.0	0.75

IV. PROBLEM OF OPTIMIZATION OF CUTTING CONDITIONS

The cutting parameters must be so selected that the machine is utilized to the maximum possible extent and that the tool life is as long as possible, when there are two conflicting objectives, a compromise must be reached. In general, the selection of easier operating conditions is not economically justified. If the cutting speed, feed and cutting depth are decreased, the work efficiency is reduced and the tool resistance to wear is prolonged[16]. In this way, the tool life is increased and the cost of the tool replacement reduced, but the labor costs are increased. Inversely, it is not always our aim to produce as much as possible within the shortest possible time. When selecting the optimum cutting conditions for some machine operation, we make a compromise between maximum material removal rate and the minimum tool wear[17-18]. The purpose of the optimization is to determine such a set of the cutting conditions v (cutting speed), f (federate), a (depth of cut) that satisfy the limiting equations and balances the conflicting objectives. The operation of turning is defined as a multiple-objective optimization problem with limiting non-equations and with three conflicting objectives (production rate, operation cost, and quality of machining). All the above-mentioned objectives are represented as a function of the cutting speed, feed rate and depth of cutting.

A) Objectives of Optimization

1. Production rate: Usually, the production rate is measured in terms of the time necessary for the manufacture of a product (T_p). It is the function of the metal removal rate (MRR) and of the tool life (T) [19]:

$$T_p = T_s + V\frac{\left(1+T_c/T\right)}{MRR} + T_i, \qquad \ldots(1)$$

Where T_s, T_c, T_i and V are the tool set-up time, the tool change time, the time during which the tool does not cut and the volume of the removed metal respectively. In some operations, the T_s, T_c, T_i and V are constants so that T_p is the function of MRR and T.

- The MRR: MRR can be expressed by analytical derivation as the product of the cutting speed, feed and depth of cut:

MRR = 1000vfa …. (2)

- Tool life (T): The tool life is measured as the average time between the tool changes or tool sharpening. The relation between the tool life and the related parameters is expressed by the well-known Taylor's formula:

$$T = \frac{k_T}{v^{a_1} f^{a_2} a^{\alpha_3}}, \qquad \ldots.(3)$$

where k_T, α_1, α_2 and α_3, which are always positive constant parameters and are determined statistically[20-21].

2. Operation cost: The operation cost can be expressed as the cost per product (C_p). In the cost of the operation, two values connected with the cutting parameters (T, T_p) [22] are distinguished:

$$C_p = T_p\left(\frac{C_1}{T} + C_l + C_o\right) \qquad \ldots..(4)$$

where C_t, C_l and C_o are the tool cost, the labor cost and the overhead cost, respectively. In some operations, C_t, C_l and C_o are independent of the cutting parameters.

3. Quality of machining: The most important criterion for the assessment of the surface quality is roughness calculated according to

$$R_a = kv^{x_1} f^{x_2} a^{x_3} \qquad \ldots..(5)$$

where x_1, x_2, x_3 and k are the constants relevant to a specific tool-work piece combination. In the presence of many incomparable and conflicting objectives, the ideal solutions satisfying all requirements are very rare. In order to ensure the evaluation of mutual influences and the effects between the objectives and to be able to obtain an overall survey of the manufacturer's value system, it is recommendable to determine the multi-attribute function of the manufacturer (y) [23-24] representing the company's/manufacturer's overall preference. A multiattribute value function is defined as a real –valued function that assigns a real value to each multi-attribute alternative, according to the decision maker's preferential order, such that more preferable alternative is associated with a larger value index than less preferable alternative. One global approach for the determination of the most desirable cutting parameters is by maximization of the manufacturer's implicit multi-attribute function.

B) Limitations

There are several factors limiting the cutting parameters. Those factors originate usually from technical specifications and organizational considerations. The following limitations are taken into account:

- Permissible range of cutting conditions: Due to the limitations on the machine and cutting tool and due to the safety of machining, the cutting parameters are limited with the bottom and top permissible limit.

$$v_{\min} \le v \le v_{\max}, \quad f_{\min} \le f \le f_{\max}, \quad a_{\min} \le a \le_{\max}$$

- Implied limitations arising from the tool characteristics and the machine capacity: For the selected tool, the tool maker specifies the limitations of the cutting conditions. The limitations on the machine are the cutting power and the cutting force. Similarly, the machining characteristics of the work piece material are determined by physical properties.
- Cutting power and force: The consumption of the power can be expressed as the function of the cutting force and cutting speed.

$$P=Fv/6122.45\eta \quad \ldots. \qquad (6)$$

Where η the mechanical efficiency of the machine and F is is given by the following formula

$$F= k_n f^{\beta 1} d^{\beta 2} \ \ldots\ldots. \qquad (7)$$
$$P= k_n f^{\beta 1} d^{\beta 2}, \text{ where } k_n = k_f / 6122.45\eta$$

The problem of the optimization of cutting parameters can be formulated as the following multi-objective optimization problem:

min subject to limitations.

$$T_p(v, f, a), \min C_p(v, f, a), \min R_a(v, f, a)$$

The limitations of the power and cutting power and cutting force are equal to

$P(v, f, a) \le p_{\max}$, $F(v, f, a) \le F_{\max}$
Force $\le$ 500 N
Power $\le$ 2.5 Kw
Surface roughness $\le$ 2.5 µm

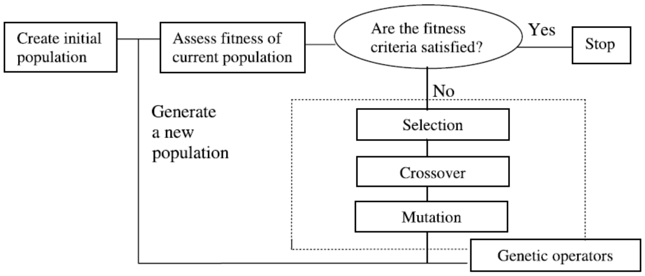
V. WORKING OF GA's

In GAs each variable is treated as a binary string corresponding to a gene. The variable set constitutes an individual, codified in a structure like the chromosomal one, having the genes one next to the other and more individuals constitute a population. In some cases decimal strings are used instead of binary ones, with the advantage of having strings with decimal ciphers much similar between them for two values near to one another. The population evolves owing to the modifications performed by the operators of crossover (interchange of chromosome segments between mating pairs) and mutation (variation of bits). Different strategies can be employed in the GAs and their efficiency can depend on the analyzed problem. On the basis of the efficiency of each individual, evaluated by a fitness, the genetic operator of selection chooses the good individuals, based on the principle of 'survival of the fittest', and are destined to the generation of a new population, by using both the genetic operators. Few worse individuals are destined to be modified deeply for the possible random change of all their genes[22-25].

Like it is known, the next generations have new characteristics, which can produce a better solution and however can favour the exploration of the feasible domain, reducing the risk of obtaining only local optima, with respect to traditional algorithms. Particularly the mutation on the worse individuals allows to renew the individuals destined to extinction, not dispersing their genetic patrimony, and, at the same time, increasing the diversity in the population and thus favouring the exploration of the design domain.

The employed strategy involves also the transfer of the best individual of each population into the next generation without transformations, replacing the worse one. Since for problems with few individuals, the best individual is usually transferred, it is believed that the higher the individual number, the higher must be the number of the transferred copies, replacing as many ones extracted randomly, in order to increase the possibility to enhance the population quality and to make the analyses faster; obviously the copy number must not be too high, in order to avoid that the solution tends to get stuck at a local optimum.

The process of going from the current population to the next population constitutes one generation in the evolution process of a genetic algorithm. Naturally, like in other optimization algorithms, the process is halted when the fitness stops to improve or a prefixed fitness has been achieved or the maximum iteration number has been reached.



Flow chart of the basic genetic algorithm: Figure 3

A) GA results:

GA parameters: Table 5

Genetic Algorithm Values	
Population size	100
Total no of generation	200
Cross over Probability	0.70
Mutation probability	0.03

Total string length	24
Number of variables	3
Total runs to be performed	2

Lower and Upper bounds: Table 6

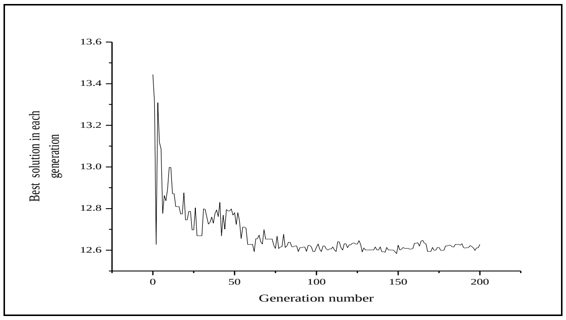
Speed(m/min)		Feed(mm/rev)		Depth of cut(mm)	
Min	Max	Min	Max	Min	Max
50	150	0.1	0.4	0.5	2.0

Out put Results cost of Production (Rs): Table 7

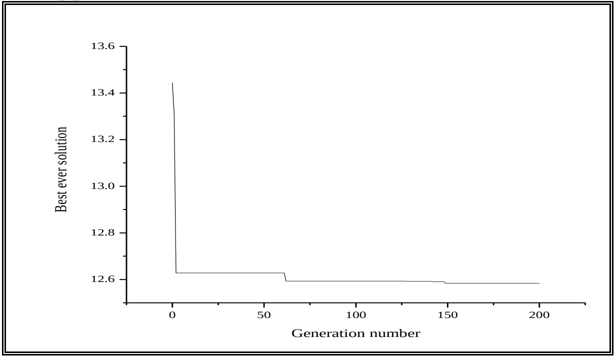
Best ever fitness	12.583372(From generation - 149)
Average fitness	13.77505
Worst ever fitness	70.92124

Optimized cutting parameters: Table 8

Speed(m/min)	Feed(mm/rev)	Depth of cut(mm)
70	0.102	1.617



Number of feasible solution in each generation Vs Generation Number: Figure 4



Generation Number Vs Best ever solution: Figure 5.

VI. CONCLUSION

Based on the GA parameter selected, it is observed from the figure 4, that best solution for cost optimization is observed at generation number 149 and is almost consistent there onwards (figure 5). These results are based on range of input machining parameters chosen. The same logic can be generalized to manufacturing environment by appropriate selection of range values for the input parameters. The involvement of surface response methodology and GA based optimization leads to an effective method of determining the process parameter values to achieve surface quality operational cost or production rate.

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