Optimisation of Drilling Parameters of Metal Matrix Composites using Genetic Algorithm in the Taguchi Method

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Abstract. This work presents the machining parameters optimization on machining metal matrix composites using genetic algorithm in the Taguchi method with the objectives of minimization of surface roughness, cutting force, maximization of metal removal rate, cutting power, specific cutting energy, cutting power and machining time. Experiments were conducted on aluminium silicon carbide Metal Matrix composite using TiN coated HSS twist drills. Optimal setting of parameters have been identified using Taguchi Technique and Genetic algorithm. Genetic algorithm is developed in 'C' language. The presented work gives a better results and it can be used for any machining parameter optimization in solving multiple response problems.

1. Introduction
Optimization of the operating parameters for radial drilling machine is an important step in order to utilize the machine effectively and efficiently. Selection of machining parameters relies heavily on the operator’s skills and his experience. Tables delivered by the machine builder cannot come across the operator requirements. So in order to optimize the machining parameters, it is required to frame the machining process and conditions as an optimization problem.

Metal matrix composites (MMC) are the materials, which are having a hard ceramic reinforcement. MMC a novel class of engineering materials which has sparked a great interest amidst the design engineers for its improved properties. Aluminium-matrix composites are generally used in automobile industries, aerospace industries and precision application etc. Due to the flaring range of application of MMC’s the machining of these materials has become a very essential subject for research. Previous studies provided limited information on drilling parameters of optimization of AL/Sic Composites.

The optimum setting parameters such as Cutting speed, Feed, and Point angle are obtained by using Genetic Algorithm and Taguchi method. Multi responses such as minimization of surface roughness,
allowable Cutting force, minimization of cutting power, specific cutting energy, torque, machining
time and maximization of metal removal rate are considered in this work.

2. Literature survey
Advanced wear resistance with increased oxidation resistance of TiN coating acts as thermal barriers
between the tool and the chip for dry drilling machining. Feed rate influence more followed by speed
for HSS drills in Al/SiCp on burr height. Francicus and Juze Balic, (2004) & Kishalay Minra and Ravi
Gopinath (2004) have optimized the cutting process by Genetic Algorithms. They stated that Genetic
Algorithm approach can obtain near-optimal solution. It can be used for obtaining optimal setting
machining parameters of complex machined parts which required many machining constraints.

Davim (2003) used Taguchi method for studying optimized parameters and cutting time on drilling
MMC’s. The hardness of the tool material influenced on the cutting edge wear and on the drilling
torque, surface finish and thrust force. Marimuthu and Chandrasekaran (2011) used Taguchi and
Neural network for optimal machining parameter study. Kaviaras et al (2019) used Neural Network
for drilling parameter optimization of Derling.

Saravanan et al. (2003) uses the genetic algorithm and simulated annealing algorithm for
machining parameters of turning operation. The range of independent variables such as speed, feed
and point angle was selected based on the machining data hand book (Alok Nayar 2002), past
experience and the available resource. Ranganathan and Senthilvelan (2011) used Multi-response
optimization of machining hot turning using grey analysis. Suresh et al. (2014), conducted
experiments for finding optimum major intervening parameters in microEDM of Stainless Steel (SS)
316L. Tripathy and Tripathy (2017) conducted experiments on of H-11 die steel for Multi-response
optimization using grey relational analysis and Topsis. Sanjay Krishna and Pavan Kalyan (2018) used
Multi-Response Optimization of Wire-EDM Process Variables for Machining Process. So far very few
have discussed the multi response optimization for machining parameter optimization. Genetic
algorithm in the Taguchi method is not used by the previous researchers for drilling Metal Matrix
Composites. Ram Prasad et al. (2019), conducted experimentation for solving Multi-Response
Optimization of Machining Process Parameters for Wire Electrical Discharge Machining of Lead-
Induced Ti-6Al-4V Alloy Using AHP–TOPSIS Method. Multi-response optimization of wire electric
discharge machining parameters of Ti-3Al- 2.5V alloy using Taguchi integrated grey relational
analysis” was used by Babu et al. (2020).

Taguchi method is the method for solving a single response problem. Multi response problems are
solved using Taguchi method. More than one quality characteristic is to be solved in actual practice
(Jeyapaul et al. (2006)).

3. Experimental setup (Noorul haq et al 2008)
Experiments are conducted using radial drilling machine. Aluminum silicon carbide metal matrix
composites plates were used as workpiece. Blackened HSS twist drill coated with TiN of 10 mm
diameter were used throughout experiment. No cutting fluid during drilling. The surface finish of
drilled hole was measured with the aid of a surf test III.

4. Plan of experiments
L_9 orthogonal array is used at three factors at three levels which is shown in the table 1. (Noorul haq et
al. 2008).
Table 1 Parameters and level (Noorul haq et al. (2008))

| PARAMETERS                   | LEVELS  |
|------------------------------|---------|
|                              | 1   | 2   | 3   |
| Cutting speed (m/min)        | 35.18 | 56.54 | 87.96 |
| Feed rate (mm/rev)          | 0.050  | 0.125  | 0.200  |
| Point angle (deg)           | 90  | 115  | 140  |

5. Methodology
Step by step procedure involved in GA to solve multi response problems is detailed below.
Step 1: Calculate the S/N ratio and it is to be normalized using the formula (Noorul haq et al (2008))
Step 2
Genetic algorithm:
Process of calculating fitness value using the normalized S/N ratio values, Initialization, Evaluation, Selection, Crossover, Mutation and Termination test are carried out as per Kishalay Minra and Ravi Gopinath (2004)
Step 3
Calculate weighted S/N ratio value using the following formula

\[ WSN_i = W_1Z_{1i} + W_2Z_{12} + \ldots + W_jZ_{ij} \]

Step 4
Find the optimal setting of parameters: To calculate the effect of parameter i, calculate the average of weighted S/N ratio values (WSN) for each level j, denoted as WSNij, then the effect, Ei, is defined as:

\[ E_i = \max (WSN_{ij}) - \min (WSN_{ij}) \]  \[ (5.1) \]

If the factor i is controllable, the best level j*, is determined by

\[ j^* = \max (WSN_{ij}) \]  \[ (5.2) \]

Step 5
Execute ANOVA to identify the significant parameters.

6. Implementation of Genetic Algorithm
Population of 20 chromosomes is generated to a feasibility condition and the fitness value is calculated using the following formula.

\[ f(x) = \sum_{j=1}^{k} \sum_{i=1}^{n} W_jZ_{ij} \]  \[ (6.1) \]

Where f(x) is the total weighted SN (WSN) ratio and it is to be maximized, Wj = weights, Zij = normalized SN ratio values, n=number of observations, and k = number of responses.
The individuals are sorted for ranking selection. Ps is allotted to the best individual and rank 1 to the worst individual.
To find the optimal weights, a modified two-point crossover (MTPX) operation used in the algorithm.

6.1. Check for feasibility
To continue feasibility, the following algorithm is used. Randomly chosen two crossover points is indicated by the arrow.
6.1.1. Algorithm for obtaining feasible condition

\[
\sum_{i=1}^{n} W_i = 1
\]

**Step 1:** \(W_1 + W_2 + W_3 + \ldots + W_n = \delta\)

**Step 2:** if \(\delta = 1\) then

Go to mutation

**Step 3:** if \(\delta < 0\) then

\[m = 1 - \delta\quad \text{and} \quad l = m / (n-2)\]

Add \(l\) to \(W_i\) for \(i=2\) to \(n-1\)

**Step 5:** if \(\delta > 0\) then

\[m = \delta - 1\quad \text{and} \quad l = m / (n-2)\]

Subtract \(l\) from \(W_i\) for \(i=2\) to \(n-1\)

Parent 1: feasible condition

\[
\begin{array}{cccccccc}
0.1 & 0.15 & 0.15 & 0.2 & 0.3 & 0.05 & 0.05 & 1.0 \\
\end{array}
\]

Parent 2: feasible condition

\[
\begin{array}{cccccccc}
0.05 & 0.1 & 0.2 & 0.15 & 0.05 & 0.3 & 0.15 & 1.0 \\
\end{array}
\]

After interchanging the parent chromosomes, the following offspring are produced.

Offspring 1: feasible condition

\[
\begin{array}{cccccccc}
0.05 & 0.15 & 0.25 & 0.2 & 0.3 & 0.05 & 0.15 & 1.05 \\
\end{array}
\]

Offspring 2: feasible condition

\[
\begin{array}{cccccccc}
0.1 & 0.1 & 0.2 & 0.15 & 0.05 & 0.3 & 0.05 & 0.95 \\
\end{array}
\]

After crossover, the feasible condition should be verified as per Jeyapaul et al. (2006).
6.2. Mutation
Mutation process gives new offspring as per the following.

Before mutation:

\[
\begin{array}{ccccccc}
0.05 & 0.14 & 0.14 & 0.19 & 0.29 & 0.04 & 0.15 \\
\end{array}
\]

After mutation:

\[
\begin{array}{ccccccc}
0.05 & 0.14 & 0.14 & 0.19 & 0.29 & 0.04 & 0.15 \\
\end{array}
\]

6.3. Stopping condition
In this case, the stopping condition is fixed at 10,000 number of generations.

6.4. Optimal setting of drilling parameters using Genetic Algorithm in the Taguchi Method

6.4.1. Identification of drilling parameters and their levels.

The identification of drilling parameters is important for the success of any industrial experiment. S/N ratio is used for measuring the functional performance. If the S/N ratio is great, then the product quality will be high (Ross, 1996). An L_{0} orthogonal array is used for experimentation. The trials are conducted and the results are given in Table 2. The optimal weights obtained are:

\[ [0.3, 0.0, 0.0, 0.2, 0.3, 0.05, 0.15] \]
Table 2 Experimental output data (Noorul haq et al. 2008)

| Trial no | Ra (µm) | Fc (N) | B (N·m) | Ka (N/mm²) | P (Watts) | MRR (mm³/min) | Tm (min) |
|----------|---------|--------|---------|------------|-----------|----------------|----------|
| 1 | 7.83   | 107.87 | 0.88    | 1408.0     | 103.21    | 4398.23        | 0.4464   |
| 2 | 4.01   | 254.96 | 2.06    | 1318.4     | 241.61    | 10995.57       | 0.1656   |
| 3 | 2.22   | 470.67 | 2.26    | 904.0      | 265.07    | 17592.92       | 0.0974   |
| 4 | 6.7    | 186.31 | 1.96    | 3136       | 269.45    | 7068.58        | 0.2577   |
| 5 | 5.8    | 539.33 | 1.28    | 898.2      | 241.27    | 17671.46       | 0.09698  |
| 6 | 6.09   | 1186.53| 3.24    | 1296.0     | 610.73    | 28274.33       | 0.0694   |
| 7 | 6.01   | 274.57 | 0.69    | 1104.0     | 202.32    | 10995.57       | 0.1559   |
| 8 | 8.27   | 1078.66| 2.55    | 1632.0     | 747.7     | 27488.94       | 0.0714   |
| 9 | 6.2    | 1274.78| 2.16    | 864        | 633.35    | 43982.3        | 0.0414   |

Consequently from step 4 we have,

\[
WSN_{i1} = 0.3Z_{i1} + 0.0xZ_{i2} + 0.0xZ_{i3} + 0.2Z_{i4} + 0.3Z_{i5} + 0.05Z_{i6} + 0.15Z_{i7}
\]

where \(Z_{i1}, Z_{i2}, Z_{i3}, Z_{i4}, Z_{i5}, Z_{i6}\) and \(Z_{i7}\) represents the normalized S/N ratio for the responses \(Ra, Fc, B, Ka, P, MRR, Tm\) at \(i^{th}\) trail correspondingly. The WSN values are calculated and it is shown in last column of Table 3.

Table 3: Weighted S/N ratio (WSN) values

| Trail no | Ra   | Fc   | B    | Ka    | P    | MRR   | Tm   | WSN   |
|----------|------|------|------|-------|------|-------|------|-------|
| 1        | 0.9584 | 0    | 0.1572 | 0.4035 | 0    | 1.0000 | 0    | 0.4182 |
| 2        | 0.4496 | 0.3483 | 0.7072 | 0.3534 | 0.4295 | 0.5830 | 0.3979 | 0.5079 |
| 3        | 0.     | 0.5966 | 0.7671 | 0.0734 | 0.4763 | 0.3598 | 0.6021 | 0.5044 |
| 4        | 0.8399 | 0.2213 | 0.6750 | 1.0000 | 0.6440 | 0.76895 | 0.2061 | 0.6827 |
| 5        | 0.7302 | 0.6517 | 0.3995 | 0.     | 0.4288 | 0.3580 | 0.6460 | 0.3911 |
| 6        | 0.7673 | 0.9709 | 1.0000 | 0.3417 | 0.8978 | 0.2179 | 0.8081 | 0.7750 |
| 7        | 0.7573 | 0.3783 | 0.     | 0.2222 | 0.3399 | 0.5576 | 0.3979 | 0.3339 |
| 8        | 1.0000 | 0.9324 | 0.8452 | 0.5134 | 1.0000 | 0.2292 | 0.7959 | 0.7407 |
| 9        | 0.7809 | 1.0000 | 0.7378 | 0.0397 | 0.9162 | 0     | 1.0000 | 0.6625 |
### Table 4 Main effects on WSN

| Parameters | 1   | 2    | 3    | Max-Min |
|------------|-----|------|------|---------|
| V          | 0.476 | 0.616 | 0.5790 | 0.14    |
| F          | 0.478 | 0.546 | 0.647 | 0.169   |
| PA         | 0.644 | 0.617 | 0.409 | 0.236   |

Table 4 shows the main effects on WSN. The larger value of WSN gives the better the quality. From table 4, we identified the optimal setting condition in the order $V_2 F_3 PA_1$.

6.5. Analysis of variance (ANOVA)

Table 5 shows the results of pooled ANOVA. From the table 5, point angle contributes more that affect the multi response characteristics. Point angle contribute 45.21% followed by Feed with the contribution of 21.5 % and the cutting speed with the contribution of 15.4 %. The optimized values for drilling parameters of metal matrix composites using Genetic algorithm are Point angle $90^\circ$, Feed $0.20$ mm/rev and Cutting speed $56.54$ m/min.

### Table 5 Results of the pooled ANOVA on WSN

| Parameters | DOF | SS      | MS      | $F$ - Test | % Contribution |
|------------|-----|---------|---------|------------|----------------|
| V          | 2   | 0.031253 | 0.01563 | 0.86       | 15.4           |
| F          | 2   | 0.0434  | 0.0217  | 1.2        | 21.5           |
| PA         | 2   | 0.0913  | 0.04565 | 2.5242     | 45.21          |
| Error      | 2   | 0.03617 | 0.0181  | 1          | 17.9           |
| Total      | 8   | 0.202123 | 0.0253  | -          | 100            |

7. Conclusions

Optimum setting of machining parameters for drilling metal matrix composites has been identified in this work. Taguchi method and Genetic algorithm used in this work were played major role for solving multi response problems. Optimal setting of machining parameters for drilling MMC is identified which are $V_1$ ($56.54$m/min) $F_3$ ($0.2$mm/rev), $PA_1$ ($90^\circ$). This methodology can be used for solving any machining parameters optimization with the multi responses.

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