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Influence of cutting parameters on thrust force and Torque in drilling of 6061Aluminum and EN31

J. SARATH CHANDRA
Research Scholar[M.Tech –Production Engineering], Department of Mechanical Engineering,
Sri Venkateswara institute of Technology, Hampapuram,
Ananthapur, Andhra Pradesh, India.

A. HARINATH
Assistant Professor, Department of Mechanical Engineering,
Sri Venkateswara institute of Technology, Hampapuram,
Ananthapur, Andhra Pradesh, India

J. SREEHARI
Assistant Professor, Department of Mechanical Engineering,
Sri Venkateswara institute of Technology, Hampapuram,
Ananthapur, Andhra Pradesh, India

N. PHANI RAJA RAO
Assistant Professor, Department of Mechanical Engineering,
Sri Venkateswara institute of Technology, Hampapuram,
Ananthapur, Andhra Pradesh, India

Abstract

In recent years, aluminum-matrix composites (AMCs) have been widely used to replace cast iron in aerospace and automotive industries. Machining of these aluminum and EN31 requires better understanding of cutting processes regarding accuracy and efficiency. In this study, multiple regression analysis (MRA) and genetic algorithm (GE) were using to investigate the influence of parameters on the thrust force and torque in the drilling processes of hybrid composite materials.

The models are identify by using cutting speed, feed, and volume fraction of the reinforcement particles as input data and the thrust force and torque as the output data. A comparison between two prediction methods is developing to compare the prediction accuracy. Here we are finding the spindle speed is insignificant or significant, it directing us to set it either at the highest spindle speed to obtain high material removal rate or at the lowest spindle speed to prolong the tool life depending on the need for the application.

Keywords: genetic algorithm; Multiple Regression Analysis; Statistical Methods; Machining EN-31.

Introduction

Manufacturing of components from manufacturing processes have different stages, these are preliminary production processes such as casting, rolling, forging, welding etc. However the manufactured components from preliminary operations are not suitable for working conditions, because those are not having any close tolerance values. A lot of secondary operations are available for making the components to close tolerances by using machining operations. Turning, milling, grinding and drilling are the predominant processes in machining operation.

Generally machining is a material removal processes from the work piece in the form of chips. From these drilling plays a vital role, because it is a final stage of manufacturing the component for assembly. The drilling has significant role on assembling of components rather than welding, riveting and else. So this work concentrates to investigate the drilling process parameter analysis on various materials. In the sense, various materials considered for an investigation like copper, brass and stainless steel, titanium and composite materials because of their technical role in automobile and aeronautical are very huge.

Today's manufacturing firm's key point is to achieve the economical machining condition. Due to this reason, many researchers have developed the mathematical models for respective outputs. Mathematical modeling of machining parameters has more significant for process planning engineers to select the required parameter for achieving desired output. The various researchers have worked for modeling the drilling process to get the best performance with response surface methodology.

The reduction of experimental time and cost have vital role for selecting the best parameter in economical way. And also various techniques were utilized for drilling operation. These are 1. Fuzzy logic 2. Neural networks A very few researchers have worked on fuzzy logic and neural network rather than response surface methodology. So this work tries to model the drilling process with fuzzy logic, neural network and response surface methodology also, and a performance of developed models has been evaluated with experimental data. The experimental procedure has followed the design of experiments concept.

Cutting force is a key factor that reflects metal cutting condition, such as work piece quality, cutting power as well as tool wear in metal cutting operation. By measuring real-time cutting forces, cutting condition is observed and the cutting parameters can properly be adjusted in time, which will in turn improve cutting efficiency, extend tool life and decrease

machining cost.

With the development of machining technique in terms of high precision and high speed, it becomes a growing demand of measuring cutting forces during the high-speed metal cutting process with high precision. Thus, a cutting force sensor with high accuracy and high natural frequency is in great demand.

Research about cutting force measurement has been carried on for many years since the middle of twentieth Century and different kinds of cutting force sensors have been created, such as current, vibrant, fiber-optical, strain gauge, piezoelectric sensors, *etc.*. However, few of them can satisfy the requirement of high accuracy and high natural frequency. To date, much more effort is dedicated to strain gauge and piezoelectric sensors because of their high stability and favorable performance.

For example, Ergun Ates and Kadir Aztekin developed a one piece lathe sensor for measuring cutting forces in two axes based on strain gauge. The sensor possesses favorable measuring error (≤3.75%), but it was only capable of detecting two of the three cutting force components and the author did not clarify the cross-interference between the measured cutting forces. With the same principle, Tulio Hallak Panzera developed a triaxial cutting force sensor with its repeatability less than 8.4% .

However, the natural frequency is neglected in his paper. What is more, the developed sensor was not compatible with a lathe system because a lathe tool post has to be removed for installing the sensor. This may affect the original lathe system.

Süleyman Yaldiz introduced a strain gauge type cutting force sensor for turning, too. However, his work concentrated on low cross-sensitivity (0.17%–0.92%) and low output errors (0.12%–0.8%) while sacrificing its natural frequency (159.2 Hz).

G. Totis and M. Sortino proposed a modular-piezoelectric sensor for triaxial cutting force measurement in turning. This work exhibits a good performance with its static relative errors less than 5.91% and its natural frequency was about 1 kHz, according to the finite element method (FEM) calculation.

Methods

Multiple Regression Analysis:

Regression analysis is a statistical tool for the investigation of relationships between variables. Usually, the investigator seeks to ascertain the causal effect of one variable upon another. Multiple regression analysis (MRA) is widely used to model the cause and effect relationship between inputs and outputs and can be generally.

Multiple Regression Analysis refers to a set of techniques for studying the straight-line relationships among two or more variables. Multiple regression estimates the β's in the equation

$$Y_j = \beta_0 + \beta 1\ X1j + \beta 2\ X_{2j} + \ldots\ldots\ldots + \beta_P X_{PJ} + \varepsilon_J$$

The X's are the independent variables (IV's). Y is the dependent variable. The subscript j represents the observation (row) number. The β's are the unknown regression coefficients. Their estimates are represented by b's. Each β represents the original unknown (population) parameter, while b is an estimate of this β. The εj is the error (residual) of observation j.

Although the regression problem may be solved by a number of techniques, the most-used method is least squares. In least squares regression analysis, the b's are selected so as to minimize the sum of the squared residuals. This set of b's is not necessarily the set you want, since they may be distorted by outliers--points that are not representative of the data. Robust regression, an alternative to least squares, seeks to reduce the influence of outliers.

Regression Analysis: Regression analysis is a mathematical measure of the average relationship between two or more variables in terms of the original units of the data. Regression clearly indicates the cause and effect relationship between the variables. In regression, the variable corresponding to cause is taken as independent variable and the variable corresponding to effect is taken as dependent variable.

The results of data analysis are presented in the thesis. Regression analysis is the relationship between dependent variable and independent variable. Regression equation is y = a0 + b1 X, where y is the dependent variable, a0 is constant, b1 is slope of the regression line, X is independent variable. For example, the relationship between marks and study hours, where marks is dependent variable and study hours is independent variable. Multiple regression is the relationship between dependent variable and more than one independent variables. Multiple regression equation is

$$y = a0 + b1\ X1 + b2\ X2 + \ldots + bn\ Xn$$

For example, vehicle performance is depending on fuel efficiency, horse power of the engine, condition of the vehicle etc. Employee performance is dependent variable. Employee performance is depending up on recruitment selection process, performance in training, team work, appraisal process, mentoring etc. Below are the results of the several tests conducted with the help of regression analysis.

A large part of a regression analysis consists of analyzing the sample *residuals*, *ej*, defined as

$$e_j = y_j - \hat{y}_j$$

Once the *β's* have been estimated, various indices are studied to determine the reliability of these estimates. One of the most popular of these reliability indices is the correlation coefficient. The correlation coefficient, or simply the correlation, is an index that ranges from -1 to 1. When the value is near zero, there is no linear relationship. As the correlation gets closer to plus or minus one, the relationship is stronger. A value of one (or negative one) indicates a perfect linear relationship between two variables.

The regression equation is only capable of measuring linear, or straight-line, relationships. If the data form a circle, for example, regression analysis would not detect a relationship. For this reason, it is always advisable to plot each independent variable with the dependent variable, watching for curves, outlying points, changes in the amount of variability, and various other anomalies that may occur.

If the data are a random sample from a larger population and the *εj* are independent and normally distributed, a set of statistical tests may be applied to the *b's* and the correlation coefficient. These *t*-tests and *F*-tests are valid only if the above assumptions are met.

TAGUCHI METHOD OF ANALYSIS

According to Taguchi "Quality is the loss imparted to society from the time a product is shipped." Taguchi concept attempts to reduce the impact of noise rather than eliminate it. Taguchi also proposes a three-stage design operation to determine the tolerances and target values for relevant parameters in the product and the process which are the system design, parameter design and the tolerance design.

In system design, scientific and engineering principles and experience are used to create a prototype of the product that will meet functional requirements. Parameter design aims to minimize the performance variability by finding out the optimal settings of the product and process parameters.

And in tolerance design, tolerances are set around the target values of the control parameters identified in the parameter design phase and are done only when the performance variation achieved by the settings identified in the parameter design stage is not acceptable.

Taguchi also defined a performance measure known as the signal to noise ratio (S/N) and aims to maximize it by properly selecting the parameter levels. Signal here, represents the square of the mean value of the quality characteristic whereas noise is a measure of the variability of the characteristic, or the uncontrollable factors.

Usually there are three categories of quality characteristic in the analysis of the S/N ratio, i.e; the lower is better, the higher is better and the nominal is better. The S/N ratio for each level of process parameters is computed based on the S/N analysis. But irrespective of the quality characteristic, a greater S/N ratio corresponds to better quality characteristic.

For this concerned project, which aims at optimizing the turning parameters for reduced vibration, the smaller is better technique is used.

The Full Factorial Design requires a large number of experiments to be carried out as stated above. It becomes laborious and complex, if the number of factors increase. To overcome this problem Taguchi suggested a specially designed method called the use of orthogonal array to study the entire parameter space with lesser number of experiments to be conducted. Taguchi thus, recommends the use of the loss function to measure the performance characteristics that are deviating from the desired target value. The value of this loss function is further transformed into signal-to-noise (S/N) ratio.

Usually, there are three categories of the performance characteristics to analyze the S/N ratio.

They are: nominal-the-best, larger-the-better, and smaller-the-better

Sreenivasalu and Dr. Ch Srinivasa Rao [1], the influence of drilling parameters on surface roughness and the roundness error were studied in drilling of Al6061 alloy with High Speed Steel twist drill. The most favorable control factors for hole quality were find out using Taguchi grey relational analysis method. The Cutting speed, feed , drill diameter, point angle and cutting fluid mixture ratio were deliberated as the control factors. L18 orthogonal array was decided for experiment . Grey relational analysis was used to minimize surface roughness and the roundness errors.

Tyagi et al. [2] employed Taguchi method and studied the effects of machining parameters like spindle speed, feed and depth of cut on the surface roughness(SR) and material removal rate(MRR). And find out the results that the spindle speed of drilling machine tool mainly affects the surface roughness (SR) and the feed rate largely affects the material removal rate (MRR).

Anjaneyulu et al. [3] L27 Orthogonal array was adopted to investigate the effects of fibre orientation angle, Helix angle, Spindle speed, and feed rate on the machining force. The results showed that the Fibre orientation angle exerted the greatest effect machining force, feed rate, Helix angle and, lastly the Spindle speed.

Koklu [4] studied the effect of the mechanical properties of aluminium alloys in drilling process by changing feed rate, cutting speed and the drill diameter on burr height and surface roughness with the help of Taguchi method. The results of the statistical analysis represents that feed rate and cutting speed to minimize both the height of the exit burrs and the surface roughness in a significant manner.

Tosun [5] worked on a statistical analysis of process parameters for surface roughness in drilling of Al/SiCp metal matrix composite. The experimental investigation were carried out under the fluctuating feed rate, spindle speed drill type, point angle of drill, and heat treatment conditions. The decided noticeable factors were the feed rate and tool category.

Kilickap et al. [6]concentrated on the effects of machining parameters such as cutting speed, feed rate and cutting circumstances on the surface roughness achieved in drilling of AISI 1045. The optimal parametric combination of the three control variables for the minimum surface roughness was achieved at 7.62 m/min cutting speed, 0.1 mm/rev feed rate, and Minimal quantity lubricant (MQL) cutting environment

Kurt et al. [7] enhanced the surface finish and hole diameter correctness in the dry drilling of Al 2024 alloy. They notice that the feed rate , cutting speed , and differently coated drills affect surface finish by 35.46 %, 6.15%, and 53.84 % and the depth of drilling, feed rate , cutting speed and differently coated drills affect the hole roundness errors by 8.18%, 74.09%, 6.04%, and 0.10% for the dry drilling of Al 2024 alloy.

Kurt et al. [8] studied the role of different coatings, point angles, cutting speeds and feed rates on the hole quality (hole size, surface roughness, roundness and radial deviation of created hole) in drilling of Al 2024 alloy. They concluded that using low cutting speed and feed rate .The best hole quality produced near the bottom of the drilled hole.

Archit Shrivastava [9] explained the optimum working condition for High Speed Steel drill bit which represents that cryogenic Treated tool is better than non cryogenically treated tool using Taguchi analysis method.

Dhavamani et al. [10] emphasized to find out the desirable machining condition for maximizing metal removal rate(MRR) and minimizing the surface roughness(SR) in drilling of Aluminum Silicon Carbide (AlSiC) by using suitable function approach. An effort was made to form a comprehensive mathematical model for comparing the interactive and higher order effects of different machining parameters using Taguchi technique. A multiple regression

model was employed to represent relationship between input and output parameters and a multi-objective optimization method based on a Genetic Algorithm (GA) was employed to optimize the process.

Kadam Shirish, M. G. Rathi, [11] have examined the influences of the input machining parameters cutting speed, feed rate, point angle and diameter of drill bit on CNC milling machine under dry situations. The variations in chip load, torque and machining time are achieved through series of experiments according to the central composite rotatable design to develop the equations of responses. They carried out some experiment using commercially available single layer Titanium Aluminum Nitride (TiAlN) and HSS tool. Drilling is done on the work piece of T105CR1 EN31 steel material. ANOVA analysis is taken to confirm the validity and accuracy of the established mathematical models for in depth analysis of effect of finish drilling process parameters on the chip load, torque, and machining time.

Shivapragash et al. [12] focused on multiple response optimization of drilling process for composite Al-TiBr2 to minimize the damage events occurring during drilling process. Taguchi method with grey relational analysis was employed to optimize the machining parameters with multiple performance characteristics in drilling of MMC Al-TiBr2 and found that the maximum feed rate, low spindle speed are the most important variables which affect the drilling process and the performance in the drilling process can be effectively improved by using this approach.

Haq et al.[13] implemented a new approach for the optimization of drilling parameters on drilling Al/SiC metal matrix composite with multiple responses based on orthogonal array with grey relational analysis. Experiments are carried out on LM25-based aluminum alloy reinforced with green bonded silicon carbide of size 25 µm. Drilling tests were carried out using TiN coated HSS twist drills of 10 mm diameter under dry condition. Drilling parameters like cutting speed, feed and point angle were optimized with the considerations of multi responses such as surface roughness, cutting force and torque.

Sureshkumar et al.[14] studied the performance of TiAlN coated and uncoated carbide drill bits. When drilling titanium alloy were studied on vibration, thrust force, torque, machine timing, burr size and surface roughness. In response, the experiments were conducted on CNC vertical milling machine with two factors and each factor consists of three levels. For experimentation, the limits of spindle speed and feed rate choice is depend on tool manufacturer suggestions. Including, the effects of spindle speed and feed rate on observed reactions were explored.

Strenkowski et al. [15] had described a three-dimensional drilling model for determining the thrust force and torque in drilling. Their model was based on representing the drill point geometry as a series of oblique sections. The model is applicable to general drill geometries, as characterized by the point and flute geometry,under different workpiece material and cutting conditions.

Tsao and Hocheng [16] developed a new device to solve the problems of relative motion and chip removal between the outer and inner drills in drilling. In addition, this study investigates the influence of drilling parameters (cutting velocity ratio, feed rate, stretch, inner drill type, and inner drill diameter) on thrust force of compound core-special drills. Their experimental results show that the cutting velocity ratio, feed rate, and inner drill type are the most important variables among the five control factors that influence the thrust force.

Khashaba et al. [17] investigated the effects of the drillingparameters, speed and feed, on the required cutting forces,torques, and delamination that occur at drill entrance and exitin drilling composites with different fiber volume fractions.No clear effect of the cutting speed on the delamination size is observed, while the delamination size decreases with decreasing the feed.

Palanikumar [18] presents an effective approach for the optimization of drilling parameters with multiple performance characteristics based on Taguch's method with grey relational analysis. The drilling parameters such as spindle speed and feed rate are optimized with consideration of multiple performance characteristics, such as thrust force, workpiece surface roughness, and delamination factor.

Palanikumar et al. [19] studied the evaluation of delamination in drilling using HSS twist drill and 4-flute cutter. Empirical models were developed by Taguchi and ANOVA for the prediction of delamination factor in drilling process.A statistical analysis of finish surface and hole diameter accuracy was performed by

Table 1: Aluminum Properties:

Property	**Value**
Density (kg/m3)	2700
Melting point (°C)	660
Thermal conductivity (W/m°C)	220
Coefficient of linear expansion at 20°C (µm/m/°C)	23.0

Table 2: Chemical composition of the aluminum powder

Fe	Si	Cu	Mn	Zn	Al
0.09	0.05	0.0005	0.001	.0.31	Balance

Table 3: machining parameters in 9 levels of experiments

Test Number	Input Machining Parameters		
	Drill Dia (mm)	Speed (rpm)	Feed (mm/s)
1	8	500	0.1
2	8	1000	0.2
3	8	1500	0.3
4	10	500	0.2
5	10	1000	0.3
6	10	1500	0.1
7	12	500	0.3
8	12	1000	0.1
9	12	1500	0.2

Table3 shows the exact combinations of the machining (input) parameters which have to done in 9 levels of experiments. This combination is obtained by giving the input parameters in DOE software which is used in several optimization techniques.

Taguchi Analysis: TORQUE versus DRILL DIA, SPEED, FEED

Response Table for Signal to Noise Ratios (Larger is better)

Table 4: Response Table

Test Number	Input Machining Parameters		
	Drill Dia (mm)	Speed (rpm)	Feed (mm/s)
1	8	500	0.1
2	8	1000	0.2
3	8	1500	0.3
4	10	500	0.2
5	10	1000	0.3
6	10	1500	0.1
7	12	500	0.3
8	12	1000	0.1
9	12	1500	0.2

Aluminum

Main Effects Plot for SN ratios Of Torque

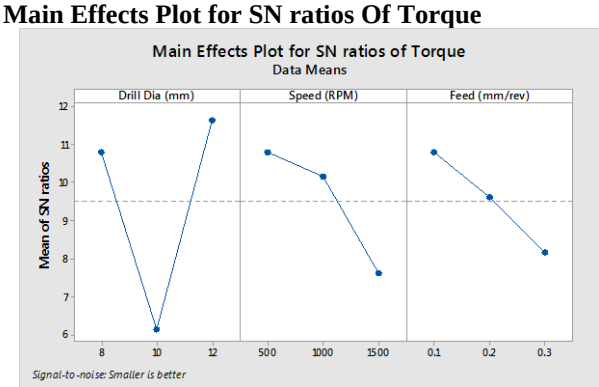

Figure 1: Main Effects Plot for SN ratios Of Torque

Main Effects Plot for SN ratios of Thrust Force

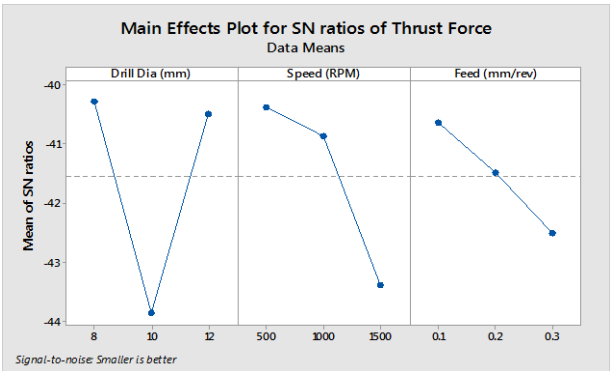

Figure 2: Main Effects Plot for SN ratios of Thrust Force

EN-31

Main Effects Plot for SN ratios Of Torque

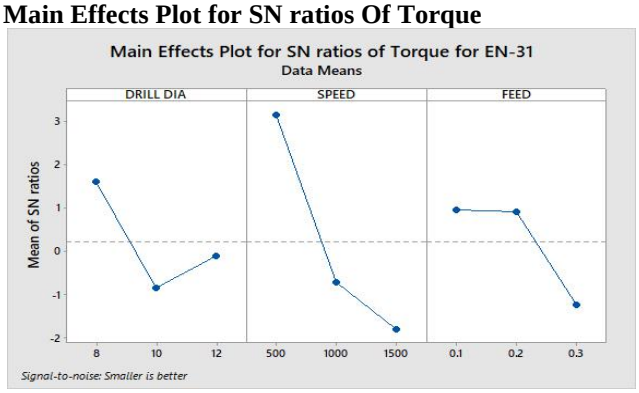

Figure 3: Main Effects Plot for SN ratios Of Torque

Main Effects Plot for SN ratios of Thrust Force

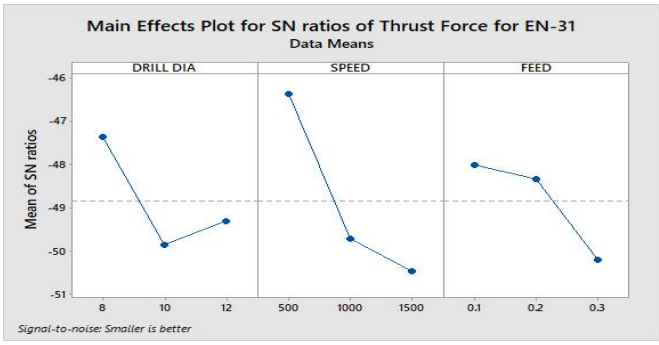

Figure 4: Main Effects Plot for SN ratios of Thrust Force

Regression Equation for Thrust Force

THRUST FORCE = 59.3 + 0.33 Drill Dia + 0.0433 Speed + 88 Feed

Regression Equation for Torque

TORQUE = -0.194 + 0.0417 DRILL DIA + 0.000533 SPEED + 1.333 FEED

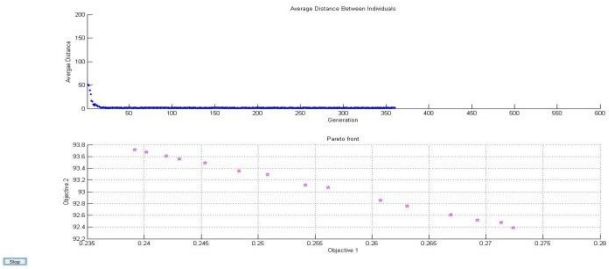

Figure 5: Average Distance and Pareto Indicators for Aluminum

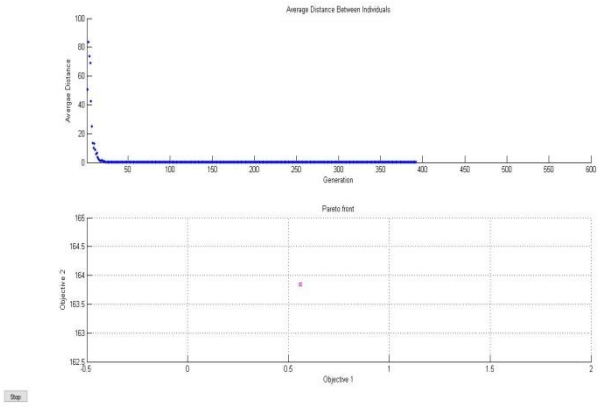

Figure 6: Average Distance and Pareto Indicators for EN-31

Conclusion

In this experimental study, the materials used is Aluminum and EN-31which materials and has got peculiar characteristics which makes it difficult to machine. Therefore, the selections of optimal parameters are important to minimize the higher unit cost per machined part and service life. Analysis of results showed that in the Drilling of Aluminum

and EN-31 Materials are helps for tool life in appropriate machining conditions, which are obtained by thaguchi method in MINI TAB in this the thaguchi analysis given S/N Ratios and means of means for the aluminum and EN-31 in thaguchi sequence of operations.

The experimental results showed that the Genetic Algorithm parameter design is an effective way of determining the optimal cutting parameters for the Torque and Thrust force evaluation compare to Taguchi. The optimal parameters are cutting speed 500 rpm, feed 0.1 mm/sec and Drill dia 8 mm gives the low Torque and Thrust force for Aluminum within the range of experiments. And for the EN-31 the optimal parameters are cutting speed 518.109 rpm, feed 0.1mm/sec, Drill Dia 8.277

Two modeling techniques were used to predict the thrust force and torque, namely multiple regression analysis (MRA) and Genetic Algorithm (GA). Modeling the drilling process using MRA and GA approach pro-vides a systematic and effective methodology for the prediction. Both MRA and GA revealed that reinforcement fractions were the important factors that in-fluency the responses (*i.e*. thrust force and torque) followed by the cutting feed rate. However, spindle speed seemed insignificant in both models.

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