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Optimisation of Cutting Parameters Using Taguchi Method in Composite Materials

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Abstract— Glass fiber reinforced polymer (GFRP) composite materials have many applications in engineering and constructional fields. For achieving a better result an accurate way of optimization is required; for that optimum cutting parameters are used. In this paper the characteristic nature that involved in the turning operation of GFRP composite material using uncoated aluminum oxide ceramic inserts at various cutting operations are calculated. The cutting parameters used in this experiment are feed rate, length of the tool from tool holder, depth of cut and the cutting operations are done under constant speed of rotation at 320rpm. MINITAB is the software used for the experiment for determining the orthogonal array. The parameters mentioned above are optimized by considering multiple performance characteristics such as cutting forces and surface roughness. When cutting force was taken into consideration parameters such as the tool from tool holder and depth of cut have contributed significantly and with the help of grey base method optimum parameter combination of surface roughness is also calculated

Index Terms— Optimisation, Orthogonal array, surface roughness, Taguchi method, ANOVA method, Turning parameters, Grey base method

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1 Introduction

Glass fiber reinforced polymer materials are finding applications in variety of engineering fields especially in the filed of aeronautical and automotive engineering. the machining process required for the fiber reinforced polymer composite is quite different from that of the normal metals that we use. The major problems that we have to face are rapid tool wear, defective sub layer with cracks, rough surface finishes on finished components.at present the technology related to cutting tools and inserts are increased in a rapid way. In earlier days ferrous materials made tools. But now in recent times industries employ tools made from various materials such as sintered carbides, ceramics and cubic boron nitride. In recent years of processing new tooling materials are being introduced and secondary processes are being explored to improve the tool lives, such as heat treatment and employment of surface coatings on tool inserts [3]. The machine tool that performs turning operations in which unwanted material is removed from a work piece rotated against a cutting tool. The rotating horizontal spindle to which the work holding device is attached is usually power driven at speeds that can be varied. On lathe the cutting tool is supported on a tool post and is controlled by hand. The researchers from time to time for the process planning of such turning operations adopt procedures. Linear programming, quadratic programming, lagrangian multiplier, geometric program-Ming, particle swarm optimization, genetic algorithm, Taguchi method are some of the techniques.

used for the optimizing process. Taguchi method is an experimental method. It is effective methodology to find out the effective performance and machining conditions. Taguchi parameter design offers a simple, systematic approach and can reduce number of experiment to optimize design for performance, quality and manufacturing cost.

Signal to noise ratio and orthogonal array are two major tools used in robust design. The process of optimization may be based on various parameters like best possible surface finish, maximum production rate; minimum production cost etc. in machining operations this is possible by suitable representation of the parameters in terms of objective function and constraints. It has long been recognized that conditions during cutting, such as feed rate, cutting speed and diameter of cut, should be selected to optimize the economics of machining operations. The objective of this research is to study the effect of feed, length of the tool from tool holder, depth of cut in an experimental approach. The machinability of materials is determined by surface finish. Surface roughness and dimensional accuracy are the important factors required to predict machining parameters of any machining operations, optimization of machining parameters not only increases the utility for machining economics, but also the product quality is also increased. In this context, an effort has been made to estimate the surface roughness using experimental data. Since turning is the primary operation in most of the production process in the industry, surface finish has greater influence on the quality of the product. Surface finish in turning operation has been found to be influenced in varying amounts by number of factors such as feed rate, material characteristics, hardness, built up edge, cutting speed, tool nose radius, cutting time, depth of cut and tool cutting edge angles, stability of machine tool and work piece setup, and chatter, and use of cutting fluids [2]. Taguchi method consists of a plan of experiments with the objective of acquiring data in a controlled way, which executes these experiments and analyzes the data, in order to obtain the information about the behavior of given process. Orthogonal array is used to define the experimental plans and the treatment of the experimental results is based on the analysis of variance (ANOVA).

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LITERATURE SURVEY

Traditionally, the selection of cutting conditions for metal cutting is left to the operator. In certain cases, experience of such operator plays a major role, but even for a skilled operator it is difficult to attain the optimum values each time. Machining parameters mainly used in turning operations are feed rate, depth of cut and cutting speed. The setting of these parameters determines the quality characteristics of turned work piece. Following the pioneering work of Taylor (1907) and his famous tool life equation, different experimental and analytical approaches for the optimization of machining parameters have been investigated. J.paulo davim [1] this paper presents a study of the influence of cutting conditions (cutting velocity and feed) and cutting time on turning metal matrix composites. Experiments, based on the techniques of Taguchi, were performed and machining with cutting conditions is prefixed in work pieces. M. Nalbant, H. Go˙kkaya, G. Sur [2] investigated the signal to noise ratio, the analysis of variance, and orthogonal array and are employed to study the performance characteristics in turning operations of AISI 1030 steel bars using Tin coated tools. *V.N. Gaitonde, S.R. Karnik, J. Paulo Davim[3]* reported the Minimum quantity of lubrication (MQL) in machining is established alternative to completely dry or flood lubricating system from the viewpoint of cost, human health issues and ecology. Hence, it is necessary to take a proper MQL and cutting conditions in order to enhance machinability for a given work material. The work aims at determining the optimum amount of MQL and the most appropriate cutting speed and feed rate during turning of brass using K10 carbide tool. Yu-Hsin Lin, Yung-Kuang Yang, Ming-Chang Jeng [4] investigated the optimization of CNC turning operation parameters for SKD11 (JIS) using the Grey relational method. Nine experiments based on an orthogonal array of Taguchi method were performed. Yung-Tien Liu , Wei-Che Chang , Yutaka Yamagata [5] in this research, the optimization process of compensation cutting for eliminating the residual form error of an aspheric surface using the Taguchi method was performed.

T.G Ansalam Raj and V.N Narayanan Namboothiri [6] formed an improved genetic algorithm for the prediction of surface finish in dry turning of SS 420 materials..Kantesh Balani, Sandip P. Harimka , Anup Keshri , Yao Chen

,Narendra B. Dahotre , Arvind Agarwalng[7] had studied the multiple length scale of plasma-sprayed Al_2O_3–carbon nanotube (CNT) Nano composite coating. CNT content and dispersion have been shown to enhance the macro-wear resistance (pin-on-disk) by more than 49 times, and Nano-wear (scratch) resistance up to 19 times. CNTs showed a way to reduce the wear of Al_2O_3 matrix by (i) increasing densification, (ii) CNT bridging and (iii) CNT lubrication. Dependence of wear volume loss on the micro structural features is described at different length scales, and disparity of the material loss which is observed in the macro- and Nano-wear tests are explained. A wear model has been established inorder to numerically quantify wear loss dependence in terms of bulk material properties and correlating these with wear parameters from Nano-scratch testing. C. Z. Huang1, Wang and X. Ai[8] had carried out an experimental investigation to coat two types of carbide powders TiC and (W, Ti)C, with an alumina ceramic using a solution-gel technology. The coated carbide powder is fabricated into two kinds of new ceramic tool materials by the hot pressing method. A scanning electron microscope (SEM) observation reveals that in general the matrix (carbide) grains are uniformly coated with the alumina ceramic and the microstructure of the new tool materials is more homogeneous than that of conventionally made uncoated aluminum oxide ceramic. The tests of mechanical properties and wear resistance in machining are finally conducted. It is shown that when machining mild carbon steel the new tool materials can increase the tool-life by up to 100% as compared to other two ceramic tool materials that have the same matrix but fabricated in the conventional way, and the fracture toughness of the material is improved by up to 33%. When compared with hard coated carbide tool, the new materials posses superiority ability in maintaining the wear resistance during the entire tool-life.

Ilhan Asilturk, Harun Akkus [9] they conducted experiments on hard turning operations in lathe by the orthogonal array of L9 method. LB Abhang and Hameedullah [10] carried out the experiment on a steel turning operation on the basis of Taguchi method. LB Abhang and Hameedullah [11] carried out the experiment on a steel turning operation on the basis of Taguchi method. For analyzing significance of each parameter they used analysis of variance method known as the ANOVA method in their experiment. Ali R. Yildiz [12]he proposed the optimization approach can be applied to two case studies for multi-pass turning operations to illustrate the effectiveness and robustness of the proposed algorithm in machining operations. Fabrício José Pontes, Anderson Paulo de Paiva, Pedro Paulo Balestrassi, João Roberto Ferreira,Messias Borges da Silva [13]discussed the study on the applicability of radial base function (RBF) neural networks for prediction of Roughness Average (Ra) in the turning process of SAE 52100 hardened steel, taguchisorthogonal array is used as a tool to design parameters of the network.

EXPERIMENTAL CONCEPT

Traditional method of doing experiments are too complex and a large number of experiments must be carried out in it. When we consider a large number of parameters and large number of levels the number of experiment increases and a lot of time is consumed for doing that work. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments. The experiments were carried out with three independent factors (feed rate, length of the tool from the tool holder and depth of cut at three levels each. Here

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a standard L27 orthogonal array is used. The various factors and their levels are shown in table I.

TABLE I. Different parameters and levels

Factors	Level 1	Level 2	Level 3
The Feed rate (mm/rev) "A"	0.130	0.260	0.520
Length of the tool from tool holder (mm) "B"	10	20	30
Depth of cut (mm) "C"	1	2	3

Using MINITAB15 software orthogonal array required for the experiment is calculated. Experiment is conducted on the level based values from the orthogonal array it is mentioned in the table II

TABLE II. Orthogonal array using MINITAB

SL NO.	Feed rate (A)	Length of the tool from tool holder (B)	Depth of cut (C)
1	1	1	1
2	1	1	2
3	1	1	3
4	1	2	1
5	1	2	2
6	1	2	3
7	1	3	1
8	1	3	2
9	1	3	3
10	2	1	1
11	2	1	2
12	2	1	3
13	2	2	1
14	2	2	2
15	2	2	3
16	2	3	1
17	2	3	2
18	2	3	3
19	3	1	1
20	3	1	2
21	3	1	3
22	3	2	1
23	3	2	2
24	3	2	3
25	3	3	1
26	3	3	2
27	3	3	3

Work piece material

The work piece material used is glass reinforced fiber polymer (GFRP) in the form of cylindrical bar of diameter 30mm and length of 150 mm.

Cutting tool material

The cutting tool material used in this experiment is uncoated aluminum oxide ceramic insert.

Machine tool

The turning operation is carried out on a rigid lathe with 2.25kw (spindle speed 54-1200rpm) motor drive.

Turning Dynamometer

Cutting tool is mounted rigidly on the tool post. The terminals from the respective amplifiers are connected to the dynamometer display unit. Initially the reading is set to a zero value, such that the errors are eliminated.

Surface roughness tester (perthometer)

Test principle: inductance type
Measurement range: 160 µm
Stylus tip radius: 2 µm
Stylus tip material: diamond
Measurement force: 4MN

Constraints

Range of depth of cut (1 to 3mm)
Range of cutting speed (at constant speed of 320 rpm)
Range of feed rate (0.130-0.520)
Range of length of the tool rom tool holder (10 to 30mm)

RESULTS AND DISCUSSIONS

Experiments are conducted according to the standard orthogonal array of L27 with the help of MINITAB15. The cutting force in x and y direction is measured thrice using a dynamometer of each work piece. The results obtained are tabulated in table III and analysis of variance of the data with the cutting forces with the objective of the analyzing the influence of each variable on the total variance of the results is performed and the results obtained are tabulated in table IV for F_x and F_y in table V. It shows percentage contribution of each parameter towards the cutting forces.

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TABLE III. Experimental design of L27 orthogonal array

Sl no				A (mm/rev)	B (mm)	C (mm)	Fx (N)	Fy (N)	Fz (N)	Fx (N)	Fy (N)	Fz (N)	Fx (N)	Fy (N)	Fz (N)
1	1	1	1	0.130	10	1	35	155	165	35	150	165	35	155	170
2	1	1	2	0.130	10	2	40	80	165	45	85	165	55	80	170
3	1	1	3	0.130	10	3	55	125	255	55	130	260	60	125	260
4	1	2	1	0.130	20	1	50	110	160	50	115	165	55	110	165
5	1	2	2	0.130	20	2	80	270	360	90	270	340	90	280	330
6	1	2	3	0.130	30	3	20	120	130	20	120	120	30	130	120
7	1	3	1	0.130	30	1	50	230	260	50	230	250	50	230	250
8	1	3	2	0.130	30	2	90	320	350	90	310	345	85	320	345
9	1	3	3	0.130	30	3	20	210	255	25	210	255	20	220	260
10	2	1	1	0.260	10	1	60	140	185	60	145	185	60	140	185
11	2	1	2	0.260	10	2	40	70	155	45	70	155	40	75	155
12	2	1	3	0.260	10	3	50	90	185	55	90	185	50	90	185
13	2	2	1	0.260	20	1	45	145	190	45	150	190	45	145	190
14	2	2	2	0.260	20	2	70	120	150	70	120	125	75	125	155
15	2	2	3	0.260	20	3	55	320	355	55	320	320	55	320	360
16	2	3	1	0.260	30	1	30	120	145	35	120	120	35	120	145
17	2	3	2	0.260	30	2	80	130	140	80	130	135	85	135	140
18	2	3	3	0.260	30	3	60	260	300	65	260	295	60	260	300
19	3	1	1	0.520	10	1	55	120	165	55	120	155	55	120	165
20	3	1	2	0.520	10	2	80	110	210	80	115	215	80	115	220
21	3	1	3	0.520	10	3	40	130	190	40	130	210	45	135	195
22	3	2	1	0.520	20	1	70	230	280	75	230	285	70	230	285
23	3	2	2	0.520	20	2	20	230	265	20	235	270	25	230	265
24	3	2	3	0.520	20	3	35	165	185	35	165	165	35	170	190
25	3	3	1	0.520	30	1	80	255	320	80	260	260	80	255	310
26	3	3	2	0.520	30	2	55	175	215	55	175	225	55	175	210
27	3	3	3	0.520	30	3	40	130	185	40	130	190	45	130	185

TABLE IV. ANOVA table for F_x

Factor	DOF	SS	MSS	$P=(SS/SS_T)\times100$
A	2	743.20	371.5	1.65%
B	2	789.50	394.75	2.76%
C	2	2822.987	1411.4935	9.87%
AB	4	3296	824	11.52%
BC	4	7391	1847.75	25.84%
AC	4	13552.461	3388.115	47.39%
Total		28595.148	8237.608	100%

TABLE V. ANOVA table for F_y

Factor	DOF	SS	MSS	$P=(SS/SS_T)\times100$
A	2	8889	4444.5	0.2%
B	2	126678.39	63339.195	3.9%
C	2	3584.432	1792.21	0.1%
AB	4	306619.85	76654.96	9.6%
BC	4	2618645.66	654661.415	82.04%
AC	4	127287.02	31821.755	3.9%
Total		3191704.31	832714.035	100%

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From the table IV, it is observed that the interaction factors between feed rate and depth of cut (47.39%) have great influence on cutting force F_x. In the case of parameters depth of cut (9.87%) has great influence on cutting force F_x. But feed rate (1.65%) and length of the tool from tool holder (2.76%) have less significant contribution on cutting force F_x..

DOF = degrees of freedom
SS = sum of squares
MSS= mean sum of squares
SST= $\sum X_I^2 - T^2/N$
T= sum of forces in x direction
N= total number of experiments

From the table V, it is observed that the interaction factors between length of the tool from tool holder and depth of cut (82.04%) have great influence on cutting force F_y. In the case of parameters length of the tool from tool holder (3.9%) has great influence on cutting force F_y . But feed rate (0.2%) and depth of cut (0.1%) have less significant contribution on cutting force F_y

From the table V, it is observed that the interaction factors between length of the tool from tool holder and depth of cut (82.04%) have great influence on cutting force F_y. In the case of parameters length of the tool from tool holder (3.9%) has great influence on cutting force F_y . But feed rate (0.2%) and depth of cut (0.1%) have less significant contribution on cutting force F_y

TABLE VI. Optimized solution of F_x for the experiment

Sl	**Orthogonal array**			**A**	**B**	**C**	**Fx**	**Fy**	**Fz**	**Fx**	**Fy**	**Fz**	**Fx**	**Fy**	**Fz**
6	1	2	3	0.130	20	3	**20**	120	130	**20**	120	120	**30**	130	120

TABLE VII. Optimized solution of F_y for the experiment

Sl	**Orthogonal array**			**A**	**B**	**C**	**Fx**	**Fy**	**Fz**	**Fx**	**Fy**	**Fz**	**Fx**	**Fy**	**Fz**
10	2	1	1	0.260	10	1	60	**140**	185	60	**145**	185	60	**140**	185

Dividing the values of three level parameters by the number of experiments carries out optimization procedure and in this case the number of experiments is 27. From the divided values the least values are taken into consideration and their respective level is identified
Optimized solution for F_x can be obtained from table VI and optimized value for F_x are feed (0.130mm), length of the tool from tool holder (2mm), depth of cut (3mm).
Optimized solution for F_x can be obtained from table VI and optimized value for F_x are feed (0.260mm), length of the tool from tool holder (1mm), depth of cut (1mm).

GREY BASE

The surface roughness of each work piece is measured using a surface roughness measuring instrument (perthometer). Roughness value is initially measured twice and after that mean of that value is considered. The results obtained are tabulated in table VIII and grey base method on surface roughness with the objective of the analyzing the influence of each variable on the total is performed and the results obtained are tabulated in table IX. It shows contribution of each parameter towards the surface roughness.

Grey relational co efficient =

$$\xi ij = \Delta Min+(\xi\Delta Max\div(\Delta_{ij} + \xi\Delta Max))$$

$\Delta Max = 1$ $\Delta Min = 0$ $\xi = 0.5$

By applying above equation grey relational co efficient is obtained and are tabulated in table IX. The value of 'ξ' always remains same as 0.5 in all the three cases of F_x ,F_y and R_a

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TABLE VIII. Grey base

Sl.No	Orthogonal Array			F_x(N)	F_y(N)	R_a (µm)
1	1	1	1	35	150	4.32
2	1	1	2	45	85	5.40
3	1	1	3	55	130	2.39
4	1	2	1	50	115	3.67
5	1	2	2	90	270	3.65
6	1	2	3	20	120	4.36
7	1	3	1	50	230	5.65
8	1	3	2	90	310	3.86
9	2	3	3	25	210	3.90
10	2	1	1	60	145	3.04
11	2	1	2	45	70	4.45
12	2	1	3	55	90	5.40
13	2	2	1	45	150	6.64
14	2	2	2	70	120	6.42
15	2	2	3	55	320	3.80
16	2	3	1	35	120	5.92
17	2	3	2	80	130	4.25
18	2	3	3	65	260	4.19
19	3	1	1	55	120	5.20
20	3	1	2	80	115	4.61
21	3	1	3	40	130	3.54
22	3	2	1	75	230	2.88
23	3	2	2	20	235	5.99
24	3	2	3	35	165	4.43
25	3	3	1	80	260	3.66
26	3	3	2	55	175	3.21
27	3	3	3	40	130	4.42

TABLE IX. Grey relational co- efficient and grade

Sl no	Orthogonal Array			Grey relational co- efficient				
	A	B	C	Fx	Fy	Ra	Grade	Grey order
1	1	1	1	0.699	0.423	0.478	0.523	15
2	1	1	2	0.582	0.347	0.632	0.520	16
3	1	1	3	0.500	0.396	0.333	0.409	26
4	1	2	1	0.538	0.378	0.417	0.444	21
5	1	2	2	0.333	0.714	0.415	0.487	19
6	1	2	3	1	0.384	0.482	0.622	6
7	1	3	1	0.538	0.581	0.683	0.600	9
8	1	3	2	0.333	0.555	0.433	0.440	23
9	2	3	3	0.874	0.531	0.437	0.614	8
10	2	1	1	0.466	0.416	0.371	0.417	25
11	2	1	2	0.582	0.352	0.492	0.646	1
12	2	1	3	0.500	0.384	0.632	0.505	17
13	2	2	1	0.437	0.423	1	0.620	7
14	2	2	2	0.636	0.384	0.907	0.642	2
15	2	2	3	0.500	1	0.420	0.640	3
16	2	3	1	0.778	0.384	0.747	0.636	4
17	2	3	2	0.778	0.396	0.470	0.548	13
18	2	3	3	0.583	0.675	0.464	0.574	10
19	3	1	1	0.500	0.384	0.596	0.493	18
20	3	1	2	0.778	0.378	0.511	0.555	12
21	3	1	3	0.411	0.396	0.406	0.404	27
22	3	2	1	0.700	0.581	0.361	0.547	14
23	3	2	2	0.333	0.595	0.766	0.564	11
24	3	2	3	0.389	0.446	0.490	0.441	22
25	3	3	1	0.778	0.675	0.416	0.623	5
26	3	3	2	0.500	0.462	0.382	0.448	20
27	3	3	3	0.411	0.396	0.489	0.432	24

The grade value is calculated by adding three values of F_x ,F_y and surface roughness and taking theirs average give the grade according to the grade grey ordering is done .

CONCLUSION

For solving machining optimization problems, several conventional techniques had been used so far, but they are not robust in nature and have problems when applied to the turning process, which involves a number Of variables and constraints. To overcome the above problems, Taguchi method is used in this work. Since Taguchi method is experimental method it is realistic in nature. From this experiment the prime factor affecting cutting forces are length of the tool from the tool holder and depth of cut and in order to obtain the best surface finish on composite material the optimal parameter combination obtained is feed rate(0.260mm/rev),length of the tool from tool holder(10mm), depth of cut (2mm).

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