NOVATEUR PUBLICATIONS
INTERNATIONAL JOURNAL OF INNOVATIONS IN ENGINEERING RESEARCH AND TECHNOLOGY [IJIERT]
ISSN: 2394-3696
VOLUME 2, ISSUE 10, OCT.-2015

OPTIMIZATION OF METAL REMOVAL RATE FOR SS316L IN DRY TURNING OPERATION USING TAGUCHI METHOD

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ABSTRACT

This research work deals with an optimization of turning process by the effect of machining parameters applying ANOVA &Taguchi methods to improve the quality of manufactured goods and engineering development of designs for studying variation. Moreover, iron in steel has greater affinity towards carbon of WC of the tool. P grade is more diffusion resistant grade due to presence of more stable carbides like TiC, TaC and NbC. Therefore, P grade is also known as mixed carbide grade and more suitable for machining steel. Since P 30 grade of cemented carbide would provide excellent balance of hardness, wear resistance and toughness, the same grade has been chosen for machining of stainless steel. Turning is a metal cutting process by which metals from the outer periphery of a cylindrical work piece is removed and the volume of metal removed per unit time is known as metal removal rate or MRR. Basically MRR is an important criterion in production engineering to increase the productivity and quality. MRR varies with the variation of cutting parameters of different metals. In this project work, Austenitic stainless steel AISI 316L is considered as work piece while spindle speed, feed rate and depth of cut are considered as cutting parameters. During turning process it is expected that the highest material removal rate is accomplished in order to achieve highest production at reduced time and cost and therefore it becomes very important issue to precisely study the effect of turning parameters. The results of analysis show that depth of cut and spindle speed have the most significant contribution on the material removal rate and feed rate has less significant contribution on the material removal rate.

KEYWORDS: Analysis of Variance (ANOVA), Material Removal Rate (MRR), Taguchi Method, Depth of Cut.

INTRODUCTION

The need for selecting and implementing optimal machining conditions and the most suitable cutting tool has been felt over the last few decades. In machining, the speed and motion of the cutting tool is specified through several parameters. These parameters are selected for each operation based upon the workpiece material, tool material, tool size, and more. Machining parameters that can affect the processes are: a) Cutting speed - The speed of the work piece surface relative to the edge of the cutting tool during a cut, the cutting speed is measured in meter per minute, b) Feed rate - The speed of the cutting tool's movement relative to the work piece as the tool makes a cut. The feed rate is measured in mm per revolution. c) Depth of cut - The depth of the tool along the radius of the work piece as it makes a cut, as in a turning or boring operation.

In the turning operation, vibration is a frequent problem, which affects the result of the machining and in particular the surface finish. Tool life is also influenced by vibrations. Severe acoustic noise in the working environment frequently results as a dynamic motion between the cutting tool and the work piece. In all cutting operations like turning, boring and milling vibrations are induced due to deformation of the work piece. In the turning process, the importance of machining parameter choice is increased, as it controls the surface quality required.

The Taguchi method is a well-known technique that provides a systematic and efficient methodology for process optimization and this is a powerful tool for the design of high quality systems.Dr Genichi Taguchi is a Japanese quality management consultant who has developed and promoted a philosophy and methodology for continuous quality improvement in products and processes. Within this philosophy, Taguchi shows how the statistical design of experiments (DOE) can help industrial engineers design and manufacture products that are both of high quality and low cost. His approach is primarily focused on eliminating the causes of poor quality and on making product performance insensitive to variation. DOE (Design of Experiment) is a powerful statistical technique for determining the optimal factor settings of a process and thereby achieving improved process performance, reduced process variability and improved manufacturability of products and processes. Taguchi (1986) advocates the use of orthogonal array designs to assign the factors chosen for the experiment. Taguchi method in the automotive, plastics, semiconductors, and metal fabrication and foundry industries. [1]

Moreover, the Taguchi method employs a special design of orthogonal array to investigate the effects of the entire machining parameters through the small number of experiments. By applying the Taguchi technique, the time required for experimental investigations can be significantly reduced, as it is effective in the investigation of the effects of multiple factors on performance as well as to study the influence of individual factors to determine which factor has more influence. [4] The aim of this experimental investigation is to estimate the effects of cutting speed, feed rate, and depth of cut on Material Removal Rate in Turning of mild steel. Design of experiment techniques, i.e. Taguchi's technique have been used to accomplish the objective and to generate optimized value. Here L9 orthogonal array used for conducting the experiments and ANOVA technique was employed to analyze the percentage contribution and influence of Process Parameters.

METHODOLOGY

1 Specification of Work Material

For performing turning operations AISI SS 316 L material have been used. They were in the form of cylindrical bar of diameter 32mm and length 100mm. The material composition of AISI SS 316L steel has given below

Table 1 Chemical composition of AISI SS 316Lsteel.

C	Mg	P	S	Si	Cr	Ni	Mo	N	I
0.03	2.00	0.045	0.03	0.75	16-18	10-14	2.-3.	0.10	Bal

2 Process parameters

Table 2 Process parameter for investigation.

Code	parameters	Unit	Level 1	Level 2	Level 3
A	Cutting velocity vc	mm/ min.	48	77	107
B	Depth of cut, d	mm.	0.25	0.5,	0.75
C	Feed ,f	mm/ rev.	0.067	0.111	0.133

3 Taguchi Method

Taguchi methods are most recent additions to the tool kit of design, process, and manufacturing engineers and quality assurance experts. In contrast to stastical process control which attempt to control the factors that adversely affect the quality of production .The significance of beginning quality assurance with an improved process or product design is not difficult to gauge .Taguchi method systematically reveal the complex cause and effect relationship between design parameter and performance . These lead to building quality performance into process and product before actual production begins .Taguchi method have rapidly attained prominence because wherever they have been applied, they lead to the major reductions into process, and it is widely used for analysis of experiment and product or process optimization. Taguchi has developed a methodology for the application of factorial design experiments that has taken the design of experiments from the exclusive world of the statistician and brought it more fully into the world of manufacturing [5]. Traditional experimental design methods are very complicated and difficult to use. Additionally, these methods require a large number of experiments when the number of process parameters increases. In order to minimize the number of experiments required, Taguchi experimental design method, a powerful tool for designing high quality system. This method uses a special design of orthogonal arrays to study the entire parameter space with minimum number of experiments Taguchi strategy is the conceptual framework or structure for planning a product or process design experiment

4 Analysis of Variance (ANOVA)

Analysis of variance (ANOVA) is a statistical method for determining the existence of differences among several population means. While the aim of ANOVA is the detect differences among several populations means, the technique requires the analysis of different forms of variance associated with the random samples under study- hence the name analysis of variance. The original ideas analysis of variance was developed by the English Statistician Sir Ronald A. Fisher during the first part of this century. Much of the early work in this area dealt with agricultural experiments where crops were given different treatments, such as being grown using different kinds of fertilizers. The researchers wanted to determine whether all treatments under study were equally effective or whether some treatments were better than others [7].
ANOVA is used to determine the influence of any given process parameters from a series of experimental results by design of experiments and it can be used to interpret experimental data. Since there will be large number of process variables which control the process, some mathematical model are require to represent the process.
However these models are to be developing using only the significant parameters which influences the process, rather than including all the parameters.

EXPERIMENTATION AND MATHEMATICAL MODELING

1 Choice of orthogonal array design

The choice of a suitable orthogonal array (OA) design is critical for the success of an experiment and depends on the total degrees of freedom required to study the main and interaction effects, the goal of the experiment, resources and budget available and time constraints. Orthogonal arrays allow one to compute the main and interaction effects via a minimum number of experimental trials (Ross, 1988). ‘‘Degrees of freedom’’ refers to the number of fair and independent comparisons that can be made from a set of observations. In the context of SDOE, the number of degrees of freedom is one less than the number of levels associated with the factor. In other words, the number of degrees of freedom associated with a factor at *p*-levels is (*p*-1). As the number of degrees of freedom associated with a factor at two levels is unity. The number of degrees of freedom associated with an interaction is the product of the number of degrees of freedom associated with each main effect involved in the interaction(Antony, 1998)

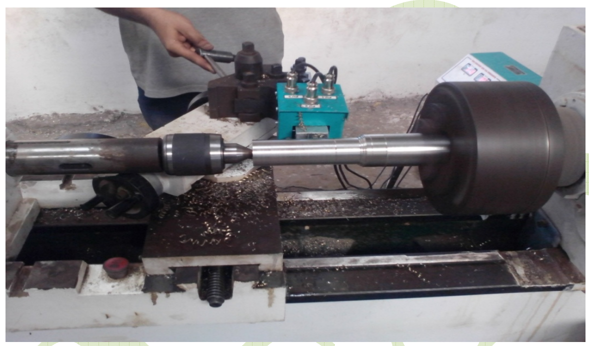

Fig.1 Experimental Setup In this research work

Dia.50mmx250mm length of SS316L with Rockwell hardness B79 used as workpiece material a lathe machine MAXICUT PRH 175 with 2H.P. Power electric motor is used in above experimentation. The matching operation performed with Tin coated cemented carbide inserts CNMG 120408 of K25 M grade (Widia make) .the photographic view of cutting tool is
Shown in fig.2

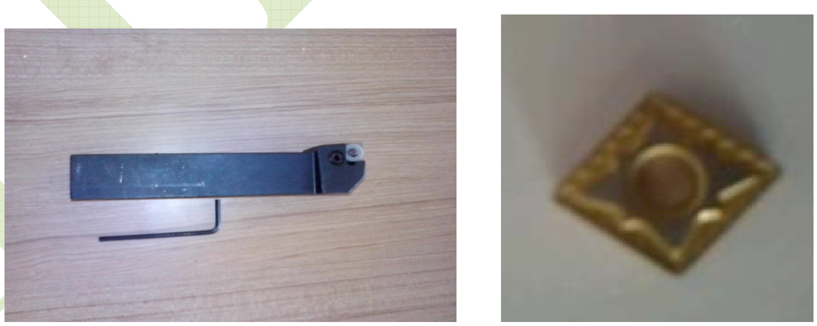

Fig.2 tool holder and insert

Tool geometry and tool designation is described in table no.2

Table No.2. Tool geometry of CNMG120408

Sr.No	Tool Angles	Value
1.	Inclination angle ß	-6^0
2.	Orthogonal Rake angle α	-6^0
3.	Orthogonal Clearance angle ɵ	6^0
4.	Auxiliary Cutting Edge angle C_e	15^0
5.	Principle cutting edge angle C_s	8^0
6.	Nose Radius	0.8mm

2 Mathematical formulation and experimental data

The experiment is conducted for Dry turning operation (without cutting fluid) of using mild steel as work material and high speed steel as tool material on a conventional lathe machine. The tests are carried for a 100 mm length work material. The process parameters used as spindle speed (rpm), feed (mm/rev), depth of cut (mm). The response variable is material removal rate and the experimental results are recorded in Table 3.

Material removal rate is calculated by following formula.

Let,

D i = Initial diameter of the metal bar,

D f = Final diameter of the metal bar,

L = Cutting length of workpiece,

t = time

Now,

$$Volume = \pi/4L\ D2_i - \pi/4L\ D2_f$$
$$= \pi/4L\ (D2i - D2f)$$
$$= \pi/4L\ (D\ i + D\ f)\ (D\ i - D\ f)$$
$$= \pi\ L\ \{(D\ i + D\ f)/2\}\ \{(D\ i - D\ f)/2\}$$
$$= \pi\ L\ (\text{Average diameter})\ (\text{Depth of cut})$$

$$D\ i - D\ f = 2d\ [\text{Where, } d = \text{Depth of cut}]$$
$$d = (D\ i - D\ f)/2$$

And, (D i + D f)/2 = Average diameter of the cutting section = D avg

So, Experimental formula for M.R.

$$MRR = \frac{\pi \times L \times d \times D_{avg}}{T}\ \text{mm3/sec}$$

Where

L = Cutting length of work piece

D = Depth of cut

D_{avg} = Average diameter of work piece

T = time

Creating orthogonal arrays for the parameter design indicates the number of condition for each experiment. The selection of orthogonal arrays is based on the number of parameters and the level of variation for each parameter.

For the maximum material removal rate, the solution is

"Larger is better" and S/N ratio is determined according to the following equation:

S/N = 10 log10 {n-1Σy-2}

Where,

S/N = Signal to Noise Ratio,

n = No. of Measurements,

y = Measured Value

Table 3 Experimental data and results for L9 Orthogonal array

Sr. no	Speed rpm	Vc m/min	F mm/rev	Depth of cut mm	Dia mm	Time min	MRR mm^3/min
1	303	48	0.133	0.25	27.55	2.40	113.16
2	303	48	0.133	0.5	27.02	3.15	360.48
3	303	48	0.133	0.75	26.23	4.13	599.83
4	455	77	0.167	0.5	25.67	1.18	967.23
5	455	77	0.167	0.75	24.88	1.26	1866.4
6	455	77	0.167	0.25	24.60	1.10	252.25
7	683	107	0267	0.75	23.78	0.39	5772.6
8	683	107	0.267	0.25	23.45	0.33	927.00
9	683	107	0.267	0.5	23.00	0.36	2684.7

STASTICAL ANALYSIS OF EXPERIMENTAL RESULTS

The analysis of variance (ANOVA), the regression equation and confirmation test are applied for stastical analysis experimental results the objective of Anova is to investigate which design parameter significantly affect for MRR

Response Table means for MRR

Level	A	B	C
1	357.8	**2284.4**	430.8
2	1028.6	1051.3	1337.5
3	**3128.1**	1178.9	2746.3
Delta	2770.3	1233.0	2315.5
Rank	1	3	2

From the above table of means for MRR it is observed that the cutting velocity has more influence on MRR From the graph of nean of MRR it is observed that as the cutting velocity increase ,MRR increases.it is also observed that the feed rate increases and MRR descries upto certain extent then increases. The depth of cut increases MRR increases.

Table 2 ANOVA for the response Material Removal Rate (MRR) for means

source	DOf	Seq SS	Adj SS	ADj MS	F	% of contribution
A	2	12532550	12532550	6266275	4.94	48.21
B	2	2758626	2758626	1379313	1.09	10.61
C	2	8168454	8168454	4084227	3.22	31.42
Error	2	2534967	2534967	1267483	-	-
Total	8	25994596		--	--	-

S=1126 R.Sq= 90.2 R.Sq(Adj) = 61.0

4. Analysis of S/N Ratio:

The performance new optimal cutting conditions are analysed by Tguchi's quality characteristics(S/N ratio) higher is the better for MRR The S/N ratio is calculated by using the equation

Higher the Better:

(S/N) HB = -10 log (MSDHB)

Where

$$MSDHB = \frac{1}{R}\sum_{i=1}^{R}\left(\frac{1}{Yi}\right)^2$$

MSDHB =Mean Square Deviation for higher-the-better response

Results of MRR were analysed by using ANOVA for identifying significant factors affecting the performance measures the results of ANOVA for S/N Ratio of MRR at 95% confidence interval is shown in table no.4.2

Table 4.1 Response of Experiments and calculations of S/N Ratio

Sr.no	Vc m/min	F mm/rev	Depth of cut mm	Dia mm	Time min	MRR mm^3/min	S/N Ratio for MRR
1	48	0.133	0.25	27.55	2.40	113.16	41.07
2	48	0.133	0.5	27.02	3.15	360.48	51.13
3	48	0.133	0.75	26.23	4.13	599.83	55.56
4	77	0.167	0.5	25.6	1.18	967.	59.7

				7		23	1
5	77	0.167	0.75	24.88	1.26	1866.4	65.42
6	77	0.167	0.25	24.60	1.10	252.25	48.03
7	107	0267	0.75	23.78	0.39	5772.6	75.22
8	107	0.267	0.25	23.45	0.33	927.00	59.34
9	107	0.267	0.5	23.00	0.36	2684.7	68.57

Response table for S/N Ratio for MRR

Level	A	B	C
1	49.26	**58.67**	49.48
2	57.72	58.63	59.81
3	**67.72**	57.39	65.40
Delta	18.40	1.28	15.92
Rank	1	3	2

From the above response table for S/N ratio of MRR it is observed that cutting velocity is first rank which is more influence on MRR
Graph:

Table 4.2 ANOVA for the response Material Removal Rate (MRR)

source	DOf	Seq SS	Adj SS	ADj MS	F	% of contribution
A	2	512.23	512.23	256.118	6538.27	56.48
B	2	3.178	3.178	1.589	40.57	0.35
C	2	391.30	391.30	195.650	4994.63	43.15
Error	2	0.078	0.078	0.039	-	-
Total	8	906.79	--	--	--	-

S=1126 R.Sq= 90.2 R.Sq(Adj) = 61.0

From the above Table 4, it is observed that the cutting speed have (56.48%) have great influence on metal removal rate. The parameter feed rate (0.35%) has small influence. Since this is a parameter based optimization design, from the above values it is clear that cutting speed is prime factor to (56.48%) has effectively selected to get the effective material removal
Rate.

ISSN: 2394-3696
VOLUME 2, ISSUE 10, OCT.-2015

Theoretical Optimum value of MRR

Above value is calculated by using formulae

$$S/N_{optimum} = (\text{ AverageMean})+[(A+B+C)-3x(\text{ Average Mean})]$$

$$= 58.23+[(67.72+58.67+65.40)-3x(58.23)]$$

$$= 75.33$$

Above corresponding value of MRR

$$y^2 = \frac{1}{10^{-\frac{opt}{10}}} = 34119266.67$$

$$Y_{optimum} = 5841.17 mm^3/min$$

VALIDATION OF EXPERIMENTAL RESULTS

The optimum cutting parameters obtained from analysis of experimental results were confirmed by conducting validation experiment. Parameters for valedictory experiments

A=107 m/min , B=0.25mm ,C=0.133 mm/rev

The valedictory experimental results is as follows

Theoretical MRR in mm^3/min	Experimental MRR mm^3/min	% Difference
5841.17	4270.2	26.89

SCOPE OF FUTURE WORKS

Some recommendations are given below:

I. The verification of the model for MRR may be developed by using other parameters.

II. Same analysis can be conducted for milling, facing, drilling, grinding and other metal removing processes.

III. Same analysis may be done for other materials
(Like Copper, Brass and Aluminum etc.).

IV. Consideration of tool wear, surface roughness, and power consumption may be done.

V. Cutting fluids or lubricants are not used in this
Project work, cutting fluids can be used.

CONCLUSIONS

From the present investigation following conclusion are drawn

1. Parameter design (Taguchi method) in the optimization of metal removal rate of AISI SS316L steel in turning operation ,ANOVA is required to know the contribution of each factors and their quantitative percentage during Operation.

2. From the S/N ratio graph and ANOVA we conclude that the cutting speed and the depth of cut are highly influences the material removal rate as the feed rate increases average cutting force increases.

3. From the above MRR and S/N/ratio results the optimum cutting velocity value is 107m/min ,0.133 mm/rev and 0.75mm depth of cut

4. From the present study it is recommended to use cutting velocity in the range of 45-80m/min.particularly when machining under dry condition, so that time required will be reduced.

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