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An Experimental Study on the Optimization of Machining Parameters in Turning Operation on EN-56 Martensitic Stainless Steel

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Abstract—*This paper presents an experimental investigation to determine the optimal machining parameters for minimizing surface roughness (Ra) of work piece in turning operation. The experiments were conducted on a CNC lathe considering spindle speed (RPM), feed rate and depth of cut as the three input parameters. EN-56A (AISI 410) Martensitic Stainless Steel specimens were taken as the work material, which were machined with coated cemented carbide inserts under flood cooling conditions. The surface roughness of the machined samples were measured with the help of a Mitutoyo Surftest and the correlation of the different input parameters with surface roughness was generated by Response Surface Methodology (RSM). Thereafter Genetic Algorithm (GA) was utilized to find those values of machining parameters at which the surface roughness was minimized. It was observed that high levels of RPM and depth of cut and low level of feed rate produced the best surface finish.*

1. INTRODUCTION

High quality products are desired by every customer. Today's demand driven industries thus have to produce good quality products and that too in a short time. This necessitates the knowledge of certain optimum machining parameters, which not only enhances the quality of output products but saves machining time as well, thereby increasing productivity. The component material chosen for this particular optimization study was EN 56A (which is equivalent to AISI 410) grade Martensitic Stainless Steel. This steel is chromium rust resisting low carbon stainless steel. Carbon content is in the range of 0.12-0.18% and chromium 12-14%. Its Brinell Hardness No. varies from 152-207 and it is always magnetic.

AISI 410 is used mainly in manufacturing blades of pumps and turbines, pump shafts, valves, compressor components, etc. because of its high strength and resistance to corrosion. Again, its machinability is poor while turning, due to its high surface hardness.

Surface roughness was considered as the output parameter which was to be optimized. Surface roughness has a great importance in determining product quality, as minimum surface roughness implies lesser friction, higher lubrication and lower rates of corrosion, which in turn means increased life of the component. This is specifically more significant when the part or component has to work in a corrosive environment, e.g. as in a pump.

Ciftci[1] performed a machining study involving dry turning of austenitic stainless steels (AISI 304 and AISI 316) and found that cutting speed had a significant effect on the machined surface roughness. Sardiñas *et al.*[3] utilized Genetic Algorithm and Pareto front graph to perform multi-objective optimization of tool life and operation time in turning a steel bar. Nalbant *et al.*[4] conducted a study to find the optimal cutting parameters for surface roughness in turning AISI 1030 steel by Taguchi method. It was found that larger insert radius, low feed rate and low depth of cut yielded better surface finish. Thamizhmanii *et al.*[5] observed that high values of cutting speed and feed rate together with low value of depth of cut provided best surface finish. However, when flank wear was also considered, moderate level of cutting speed, with same values of feed rate and depth of cut provided the most ideal cutting conditions. Ranganathan *et al.*[6] conducted an evaluation of machining parameters in hot turning of AISI 316 Stainless Steel by using Artificial Neural Network (ANN) and Response Surface Methodology (RSM). They observed that feed rate was the most important factor affecting the surface roughness followed by the combination of cutting speed and feed rate. Furthermore, best surface finish was obtained at high level of workpiece temperature.

Asiltürk & Neşeli[7] studied the optimization process in turning of AISI 304 austenitic stainless steel and found that minimum surface roughness was achieved at high level of cutting speed and low levels of feed rate and depth of cut. Barik & Mandal[8] investigated the turning operation of EN-31 alloy steel and optimization of its machining parameters based on Genetic Algorithm (GA). They concluded that surface roughness decreased with increase in spindle speed and depth of cut but increased with increase in feed rate. Selvaraj *et al.*[10] optimized the cutting parameters in dry turning of two different grades of nitrogen alloyed duplex stainless steel (DSS ASTM A 995 grade 5A and grade 4A). It was seen that maximum influence was exerted on surface roughness and cutting force by feed rate followed by cutting speed, while cutting speed had the most effect on tool wear followed by feed rate. Nayak *et al.*[11] studied the multi objective optimization of material removal rate (MRR), cutting force and surface roughness during dry turning of AISI 304 austenitic stainless steel, by Grey Relational Analysis. High level of cutting speed, low level of feed rate and medium level of depth of cut was found to produce the optimum result for all the three output responses.

Thus we see that although much work has been done on austenitic stainless steel, few works are available on martensitic stainless steel.

2. EXPERIMENTATION

The turning experiments were performed on a a Computerized Numerical Control (CNC) lathe (Fanuc series Oi Mate-TC) with CVD coated cemented carbide insert (specification: CNMG120408 EN TMR) CTC1115 of Ceratizit make. Flood cooling technique was used.

Chemical composition of AISI 410 (% max)

C	Mn	Ni	Cr	Mo	Others
0.12	1.0	1.0	12/14	___	Si 1.0 S&P 0.045

Fig. 1: CNC Turning Centre used for the experiments

The surface roughness measurements were carried out with a Mitutoyo Surftest SJ-301 with cutoff length 0.8 mm and number of sampling length 5, provided with a stylus probe type surface texture-measuring instrument. The Root-mean-square profile of surface roughness is measured with this instrument.

Fig. 2: Some of the machined samples

Fig. 3: Mitutoyo Surftest surface roughness tester

2.1. Design of Experiment

In order to determine the effect of input factors on the turning operation, three levels of each factor, viz. RPM, feed rate and depth of cut were selected.

Table 1: The input process parameters and their levels

Factors	Low level	Medium level	High level
RPM	800	1000	1200
Feed (mm/rev)	0.1	0.15	0.2
Depth of cut (mm)	1	1.5	2

2.2. Response Surface Methodology

Response Surface Methodology (RSM) comprises certain statistical and mathematical methods for generating empirical relationships between some specified input factors and output responses. This can be explained using the second-order polynomial model as under:

$$\eta = \beta_0 + \Sigma_{i=1}^{k}\beta_i X_i + \Sigma_{i=1}^{k}\beta_{ii} X_i^2 + \Sigma_i\Sigma_j\beta_{ij}X_iX_j + \varepsilon$$

where η is the estimated response (here, surface roughness), β_0 is constant, β_i, β_{ii} and β_{ij} represent the coefficients of linear, quadratic and cross-product terms, respectively. X reveals the coded variables.[7]

Table 2: Experimental design matrix

Ex. No	Spindle speed (RPM)	Feed (mm/rev)	Depth of cut (DOC) (mm)	Surface roughness Ra(µm)
1	800	0.1	1	2.18
2	800	0.1	1.5	2.29
3	800	0.1	2	2.64
4	800	0.15	1	2.56
5	800	0.15	1.5	3.34
6	800	0.15	2	3.58
7	800	0.2	1	5.30
8	800	0.2	1.5	5.26
9	800	0.2	2	5.27
10	1000	0.1	1	3.61
11	1000	0.1	1.5	2.94
12	1000	0.1	2	2.57
13	1000	0.15	1	2.50
14	1000	0.15	1.5	2.07
15	1000	0.15	2	1.63
16	1000	0.2	1	2.44
17	1000	0.2	1.5	2.85
18	1000	0.2	2	2.79
19	1200	0.1	1	0.82
20	1200	0.1	1.5	0.97
21	1200	0.1	2	0.85
22	1200	0.15	1	1.15
23	1200	0.15	1.5	1.80
24	1200	0.15	2	1.63
25	1200	0.2	1	2.74
26	1200	0.2	1.5	2.24
27	1200	0.2	2	3.08

Using the values of Ra, the following regression equation is obtained from RSM:

Ra= 7.06 - 0.0024*RPM - 32.9*Feed + 0.09*DOC + 0.000001*RPM*RPM + 230*Feed*Feed - 0.04*DOC*DOC - 0.0274*RPM*Feed - 0.00051*RPM*DOC + 4.01*Feed*DOC

2.3. Genetic Algorithm

Genetic Algorithms (GA) are actually iterative search algorithms mimicking the Darwinian concept of natural selection. It is based on the idea of "survival of the fittest", where an interbred population produces more favourable offsprings. GA begins by creating an initial set of random solution points called "initial population", which are thought of as a group of chromosomes. These chromosomes undergo successive iterations to generate optimum solutions. Next, a new generation of individuals is produced by recombination of the parent chromosomes, based on their respective fitness. The produced offsprings are again mutated with some pre defined probability so as to achieve more optimum solutions. This process is repeated until the optimization conditions are met.[2] Individuals with high fitness values in comparison to their offsprings go on to the next generation in place of the latter, so that good chromosomes are not lost, a process known as Elitism[9]. Thus the GA process comprises the following steps:

a. Representation of solution points as chromosomes
b. Generation of random population
c. Evaluation of fitness function for each individual
d. Selection and reproduction
e. Crossover and mutation

In this study GA has been implemented in a MATLAB environment so as to find out the optimal solution points. The solution obtained is as follows

No. of iterations: 131

Population type: Double vector

Population size: 50

Fitness scaling: According to rank

Selection function: Stochastic uniform

Obtained optimal solution:

RPM	Feed	Depth of cut
1200	0.125	2

3. RESULTS AND DISCUSSION

Thus we see that surface roughness is optimized at high level of spindle speed (1200 RPM), low level of feed (0.125 mm/rev) and high level of depth of cut (2 mm). This data seems to confirm well with the experimental data, where minimum surface roughness was achieved at nearly the same conditions. Thus we can say that RSM modeling of the obtained experimental data has been satisfactory, which has been validated by Genetic Algorithm.

4. SCOPE OF FUTURE WORK

In this paper surface roughness of martensitic stainless steel specimen has been optimized by Genetic Algorithm technique. Other researchers can perform optimization of more machining parameters like material removal rate (MRR), cutting force, etc. Furthermore, other types of non-conventional optimization methods, such as Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Artificial Bee Colony (ABC) Optimization, etc. can also be studied.

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