Optimization of Surface Roughness during Hard Machining of Hard Chrome Plated Surfaces on EN24 Base Substrate

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***Abstract*—**As humankind progresses towards implementing very tight precision standards, the total production concept needs re-assessment in its manufacturing practices, especially in finishing operations. The better finishing can be achieved by the grinding operation, which is currently in practice. However, during the finishing of the internal surfaces, the grinding operation also faces some fixture problem. In the present study the authors have investigated the surface roughness produced during hard turning of hard chrome plated surfaces with various cutting inserts. The optimization of the surface roughness was carried out with Taguchi's Design of Experimentation technique. The results of the experimentations revealed that the hard turning operation can be extended to the hard chrome plated surfaces.

***Keywords*—**Hard Turning, Hard Chrome Plated Surfaces, Surface Roughness, Taguchi Technique.

I. Introduction

A. *Machining and Hard Turni*

METAL cutting is the process of producing a finished part, by shearing a layer of material from the workpiece with the help of relative movement of cutting tool. During this process, a layer of material is detached from the workpiece, in the form of chip. The cutting tools employed in this process can be classified as single point cutting tool and multi point cutting tool. The plain turning, step turning, taper turning, etc. are preformed using the single point cutting tool, whereas the drill bit, milling cutter are the examples for the multi point cutting tool.

One of the solutions the researchers proposed was the hard turning which can be considered as the alternate to the grinding. Hard turning is a simple turning operation which operates on the harder material having hardness above 45 HRc [1,2,3]. The hard turning machines are normal CNC lathes with more rigid fixtures for the workpiece mounting. With close cutting conditions, the hard turning operation produces the surfaces similar to the grinding operation. Hard turning can machine the complex workpieces in one step. It is a less time consuming, more flexible, and the cost-effective process. Although grinding is the typical finishing process employed in industry, in many cases hard turning is a better option for the internal and external finishing. Figure 1 shows the Hardinge Quest 8/51 Special Purpose make hard turning machine used for the hard turning operation.

Fig. 1 Quest 8/51 Special Purpose hard Turning

B. *Hard Chrome Coating*

The increased demand for hard surface applications has resulted in the development of coated materials with hard substances. One such coated material is chrome plating. The chrome plating is a method of electroplating a thin layer of chromium onto the base substrate. This type of coating increases the corrosion resistance, the wear resistance and reduces the friction. The hardness of the hard chrome plating measures around 62 – 70 HRc [4].

The hard Chrome plating is produced by electro-deposition from a solution containing chromic acid (CrO3) and a catalytic anion in the proper proportion. These types of coatings increase the hardness and resistance to corrosion. This type of coating finds its applications in the production of piston rings, shock absorbers, struts, brake pistons, engine valve stems, cylinder liners, hydraulic rods, aircraft landing gears, plastic rolls, rebuilding of worn parts, etc. The hard chrome coating finds it applications in landing gear seal systems and shock absorbers of the aircraft due to its long lasting anti wear capabilities.

C. *Surface Roughness*

The surface finish or the surface roughness produced during machining operations is considered to be one of parameters in deciding the machinability of the machined parts. These surfaces are mainly dependent on the cutting parameters

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involved, workpiece to be machined, tool material, geometry of the tool and the cutting conditions such as dry or wet, etc [5,6,7]. The practical machining operation results in two independent effects on the final surface roughness. One of them is the ideal surface roughness, which is a result of the geometry of the tool and the feed or feed speed. The other one is the natural surface roughness, which is a result of the irregularities in the cutting operation.

The surface profile is the instrument used to acquire an enlarged tracing of the surface irregularities. The standard instruments for determination of the surface roughness operate by amplifying the vertical motion of the stylus, as it slowly moves across the surface. In modern instruments, the surface profile is digitally sampled and the arithmetical mean surface roughness value is calculated continuously over a selected cutoff distance.

D. Design of Experimentation

The cutting speed, feed and the depth of cut were the three major parameters in any machining operations. Taguchi's design of experimentation technique was used to arrive at the optimum cutting conditions during the experimentation. Minitab software version 15 was used in the present optimization [8,9].

II. Experimentation

A. Selection of Base Substrate

The most common base substrates used for the hard chrome coating are EN24 and C45 steels. The presence of chromium and nickel elements in EN24 steels has increased the wear resistance and the corrosion properties of the base substrate. In this experiment, EN24 was selected as the base substrate. EN24 has a high quality and high tensile strength. This grade of steel has a very good compatibility with the chrome particle. The spectroscope was used to find the composition of the EN24 base substrate. Base substrate was selected with a dimension of 50mm diameter and 70mm length. The machining was carried out to a length of 50mm. Table I shows the composition of the EN24 substrate.

TABLE I
CHEMICAL COMPOSITION IN WEIGHT PERCENTAGE OF EN24

Element	C	Si	Mn	S	P	Ni	Cr	Mo
%	0.36	0.22	0.52	0.005	0.007	1.52	1.17	0.27

The hard chrome coating is created on the EN24 substrate by electro-depositing chromic acid (CrO3) and a catalytic anion in proper proportion. The current density, electrolyte used, temperature maintained and anode are the principle variables that must be controlled for satisfactory hard chrome plating. The figure 2 shows the chrome plated EN24 steel substrate to a thickness of around 170µm.

One of the major observations made during the analysis of the chrome plated surface was lack of self leveling effect on the coated surfaces. The roundness measurement revealed that the coated surface produced out-of-roundness surfaces. The chrome plating on the EN24 steel surface increased the hardness of the surface from 20HRc to 65 HRc. To level these surfaces, any of the finishing operations needs to be adopted as these machining requires better rigidity from the machine tool.

Fig. 2 Samples of chrome coated EN24 steel material

B. TiAlN coated CBN inserts

The TiAlN coated CBN inserts exhibit better hardness and the wear resistance properties. Therefore in this experimentation, TiAlN coated CBN inserts were selected. The grade of CBN inserts selected in the experiments was MBC 020. The main components of these inserts are CBN in micro grain with TiN and Al2O3 which is coated with TiAlN layer. Generally negative rake angles are preferred during the machining of the hard components. The inserts used in the experiments were provided with a negative rake angle of 50. Table II shows the specifications of TiAlN coated PcBN inserts and table III shows the cutting parameters selected with three levels.

The cutting conditions like speed and feed rate were selected based on the PcBN tool material specifications. The experimentation was decided based on Taguchi's Gray Relational Analysis. L9 orthogonal arrays were used in the experiments. Table IV illustrates the experimentation based on the Grey Relational Analysis.

TABLE II
SPECIFICATIONS OF TIALN COATED PCBN INSERTS.

Sl. No.	Insert	Cutting edge angle	Nose radius (mm)
1.	CNGA 120404	80^0	0.4
2.	CNGA 120408	80^0	0.8
3.	DNGA 150404	55^0	0.4
4.	DNGA 150408	55^0	0.8

TABLE III
CUTTING PARAMETERS WITH LEVELS

Cutting Parameters	Level 1	Level 2	Level 3
Cutting Speed, *v* (rpm)	300	400	500
Feed Rate, *f* (mm/rev)	0.04	0.06	0.08
Depth of Cut, *d* (µm)	40	80	120

C. Measurement of Surface Roughness

The Talysurf surface roughness measuring instrument was used to measure the surface roughness of the hard turned components. The cylindrical hard turned components were kept on the fixture to measure the surface roughness. The probe of the Talysurf was moved on the surface to a definite distance.

TABLE IV
LEVELS AND FACTORS OF EXPERIMENTATION (L9 OA)

Trail No.	Speed (rpm)	Feed (mm/rev)	DOC (μm)
1	300	0.04	40
2	300	0.06	80
3	300	0.08	120
4	400	0.04	120
5	400	0.06	40
6	400	0.08	80
7	500	0.04	80
8	500	0.06	120
9	500	0.08	40

Fig. 3 The probe of the Talysurf Roughness tester

The probe which was moving on the surface of the sample recorded the waviness in the sample and this was transferred to the monitor to display the readings. The average surface roughness, Ra is one of the important parameter which decides the machinability of the sample. Therefore during the surface roughness measurement, Ra value was focused and extracted from the results.

III. RESULTS AND DISCUSSION

A. Surface roughness

The machined surfaces were measured using the Talysurf tester. The surface roughness was recorded for all the 36 samples. The samples were mounted on the V-block and with the movement of the probe, the surface waviness were measured. These graphs were displayed on the monitor. The sample of the surface roughness graph is shown in figure 4. The tables V shows the surface roughness values for various combinations of cutting regime parameters i.e., cutting speed, feed and depth of cut according to experimental layout for all cutting inserts used in the experimentation.

B. Optimization of surface roughness using Taguchi Technique

According to the Taguchi quality design concept, an L9 orthogonal array has been used to determine the S/N ratio (dB), analysis of variance (ANOVA) and 'F' test values for indicating the effect of most significant parameters affecting the machining performance criteria such as surface roughness. The main purpose of the ANOVA was to investigate the design parameters and to indicate which parameters are significantly affecting the quality characteristics. This analysis helped to find out the relative contribution of machining parameter in controlling the response of turning operation. Figure 5 shows the main effects of S/N ratio for the surface roughness for different cutting inserts selected for the experiments. The surface roughness developed during the turning require being minimum to get the optimized results. Therefore the S/N ratios were calculated for the optimum surface roughness as per "the smaller-the better" and this has been shown in equation 1.

$$\frac{S}{N} = -10\log_{10}[\frac{1}{n}(\sum y^2)] \quad (1)$$

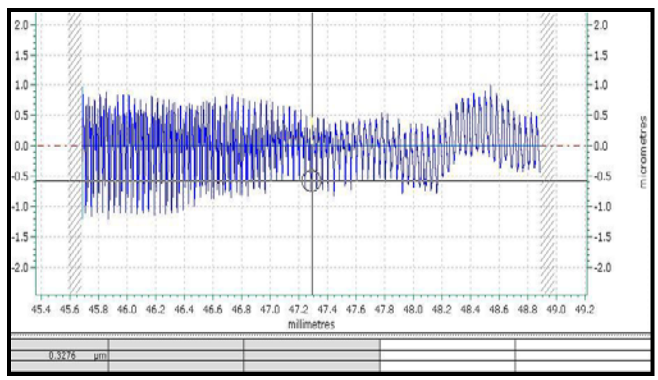
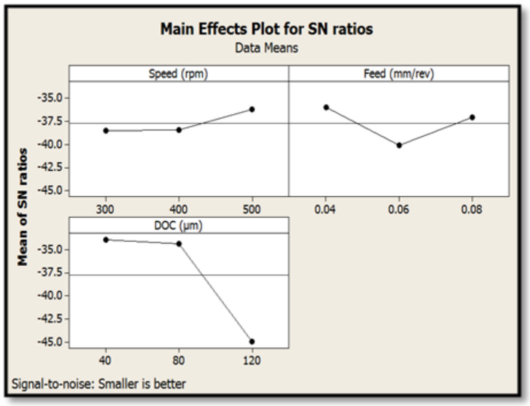


Fig. 4 Sample of surface roughness graph

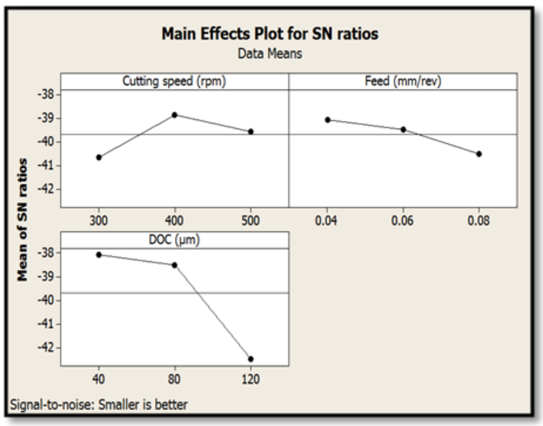
TABLE V
SURFACE ROUGHNESS VALUES IN μM WITH DIFFERENT INSERTS

Exp. No.	Cutting speed (rpm)	Feed (mm/rev)	Depth of cut (μm)	CNGA 120404	CNGA 120408	DNGA 150404	DNGA 150408
1.	300	0.04	40	0.32	0.29	0.36	0.14
2.	300	0.06	80	0.39	0.64	0.44	0.32
3.	300	0.08	120	0.35	3.71	1.23	0.53
4.	400	0.04	120	0.55	0.37	1.38	0.65
5.	400	0.06	40	0.41	0.52	0.32	0.85
6.	400	0.08	80	0.58	0.46	0.46	0.55
7.	500	0.04	80	0.37	0.33	0.50	0.57
8.	500	0.06	120	0.86	0.21	0.62	0.96
9.	500	0.08	40	0.32	0.42	0.41	0.28

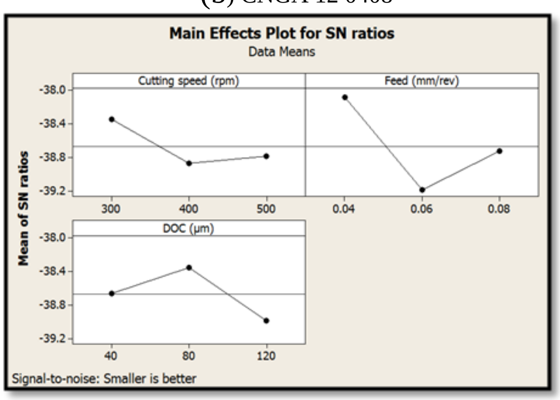
Where, y is the surface roughness values



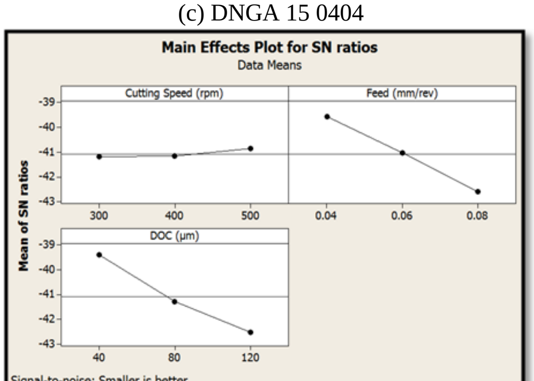
(a) CNGA 12 0404



(b) CNGA 12 0408



(c) DNGA 15 0404



(d) DNGA 15 0408

Fig. 5 The main effects of S/N ratio for the surface roughness for different cutting inserts

These graphs can be consolidated to find the optimum cutting conditions in terms of surface roughness for all four different cutting inserts and mentioned in table VI.

The results of the experiment showed that the optimum depth of cut was observed at 40µm.

TABLE VI
OPTIMUM CUTTING CONDITIONS FOR SURFACE ROUGHNESS FOR DIFFERENT TYPE OF INSERTS

Sl. No	Cutting Insert	Optimum Cutting speed (rpm)	Optimum Feed (mm/rev)	Optimum Depth of cut (µm)
1.	CNGA 12 O4O4 MBC020	300	0.08	40
2.	CNGA 12 O4O8 MBC020	500	0.04	40
3.	DNGA 15 O4O4 MBC020	500	0.06	40
4.	DNGA 15 O4O8 MBC020	300	0.04	40

IV. CONCLUSION

Concluding remarks on the basis of experimental results, optimal parametric combinations for the better surface finish using Taguchi design the following points as listed below:

- The hard chrome plated surfaces can be finish-turned using the conventional machining process. This is an alternate method to the grinding process.
- The better surface finish was produced for smaller length of cut by optimum cutting conditions, the life of the tool can be enhanced.
- By designing proper cutting inserts for finish turning, the productivity of the hard turning of hard chrome plated surfaces can be increased.

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