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Machinability Investigations of Stainless Steel (304 L) using different Inserts

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Abstract: Austenitic stainless steel (304L) is one of the most important engineering materials with wide variety of applications because of its properties such as high hardness, toughness, yield strength, excellent ductility, and superior resistance to corrosion and oxidation. However, their machinability is more difficult as compared to other alloy steels due to low thermal conductivity, high built-up edge (BUE) formation tendency and high deformation hardening. Hence, the aim of this paper is to study the performance of different coated carbide inserts and to find out the optimum parameters while dry machining of SS304 L. The design of experiment was done using design expert, where cutting speed, feed rate, depth of cut and nose radius were taken as input parameters. The output responses were the surface roughness and tool wear. Total nine experiments were performed on CNC lathe machine using coated carbide, uncoated carbide and ceramite inserts. The overall results revealed that the optimum flank wear are found 0.12 mm against a combination of input parameters i.e. cutting speed 75m/min, feed rate 0.05mm/rev, depth of cut 0.25 mm using coated carbide inserts. Similarly, the optimum surface roughness were found 0.4 mm against a combination of input parameters i.e. cutting speed 125m/min, feed rate 0.05mm/rev, depth of cut 0.75mm using a tool uncoated carbide inserts.

Keywords: Dry turning, CNC, Inserts, steel, cutting speed

I. INTRODUCTION

Steels represent the most important engineering materials as they have the widest diversity of applications of any of the engineering materials. Basic classes of steel are: plain carbon steels and alloy steels. In plain carbon steels the amount of alloying elements are negligible as compared to carbon, hence do not have the effect on the properties of the steels. Further according to the percentage of carbon (1.0%wt.Max) the plain carbon steels are classified as: low carbon steel, medium carbon steel and high carbon steel. Whereas allow steels are those steels in when one or more allowing elements are added in sufficient amount intestinally to the plain carbon steels to induce the required properties. Stainless steel is the sub class of allow steels containing various allowing elements: chromium, silicon, nickel, manganese and molybdenum. Stainless steels are stainless as these have minimum of 11.5%chromium in them,which having more affinity for oxygen than iron. Chromium forms a very thin, protective and stable oxide (Cr_2O_3) film on the surface [1-2]. This film is continuous, impervious and passive to stop further reaction between the steel and the surrounding atmosphere. Thus chromium imparts to the steels corrosion resistance, oxidation resistance and pleasing appearance. Apart from the essential element chromium, the stainless steels also contain nickel, molybdenum and manganese to enhance other properties and improve the corrosion resistance. Stainless steels have become versatile because of its properties; good corrosion and oxidation resistance, good creep strength [3-4].

However, they are hard materials to machine, due to their high strength, high ductility and low thermal conductivity. The last characteristic results in heat concentration at the tool cutting edge. The challenges which are made during machining of stainless steel are focused on the achievement of high quality, in terms of work piece dimensional accuracy, surface roughness, high production rate, less tool wear on the cutting tools, economy of machining in terms of cost saving and increase the performance of the product with reduced environmental impact. A surface property such as roughness is critical and increasing component to the function ability of machined components. Tool wear which results in tool substitution is one of the most important parameter, so it is very important to minimize tool wear, and optimize all the cutting parameters. But, their machinability of stainless steels is more difficult compared to other alloy steels due to low thermal conductivity, high built-up edge (BUE) formation tendency and high deformation hardening. Austenitic stainless steel is one of the most important engineering materials with wide variety of applications. The problems such as poor surface finish and high tool wear are common while machining these materials [5-7].

A large number of articles are available in journals and books on machining performance of stainless steel and from these investigations many supportive results have been obtained. Noordin et.al.(2001) investigated the performance of two coated tungsten carbide inserts one with Alo3(black) with TiN (golden) and another is uncoated titanium based during the finish turning of

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AISI 1010 steel [8]. Noordin et.al.(2004) described the performance of a multilayer tungsten carbide tool using response surface methodology (RSM) when turning AISI 1045 steel with constant depth of cut and under dry cutting conditions [9]. Diniz &Oliveira (2004) carried out the machining experiments to find out the conditions in which dry cutting is satisfactory compared with the flood of fluid (called here wet cutting) usually used [10]. Ozcelik et. al. (2011) investigated the performance of dry and wet cutting during end milling of AISI 304 stainless steel. The experiments were conducted to compare the tool wear, milling force components and surface roughness under various operating conditions [11]. Saini et.al.(2012) utilized response surface methodology (RSM) for modeling to predict surface roughness and tool wear for variety of cutting conditions in finish hard turning of hardened AISI H-11 steel [12]. Kumar P.& Chauhan S.R.(2015) investigated the effects of machining parameters including workpiece hardness in a range of 45–55 HRC on cutting forces (Fc &Ft), surface roughness (Ra) and cutting edge temperature (T) in finish turning ofAISIH13 die tool steel with CBN inserts [13]. S.Y., K. & U.L, A. (2015) optimized turning process by the effect of machining of austenitic stainless steel AISI 316L parameters applying ANOVA &Taguchi methods to improve the quality of manufactured goods [14]. Özbeket.al.(2016) studied the effect of cryogenic treatment of tool on wear of uncoated tungsten carbide inserts in turning of AISI 316 stainless steel in dry condition [15].

From the previous published papers, it has been observed that the stainless steels are hard materials to machine, due to their high strength, high ductility and low thermal conductivity. The challenges which are made during machining of stainless steel by using various machining parameters (cutting speed, feed rate, depth of cut and different inserts) are still not optimized during dry turning. Lot of research papers are available wherein various machining parameters (Cutting Speed, Feed Rate and depth of cut), tool nose radius and cutting conditions (Cryogenic, MQL and Flood cooling) are experimented to overcome the problems of high cutting forces, short tool life and poor surface finish. But using cutting fluids pollute the environment, cause thermal cracking in interrupted cutting and harm to the health of the operators or workers. Even in MQL a minimum quantity of cutting fluid is used but still there is great power consumption is involved. So keeping in view of the pollution, thermal cracking, health challenges, economics imposed by cutting fluids in machining and high power consumption, dry machining specially shows positive effects in case of AISI 304 steels. Therefore to investigate the performance of different coated carbide inserts in dry machining of stainless Steel 304L was selected.

II. MATERIALS AND METHODS

A. *Work Material*

A cylindrical sample of austenitic stainless steel (SS304L) with 125 mm length and 50 mm in diameter was selected for this investigation. The bar was pre-machined to get uniform cylinder of 49.50 mm diameter. The chemical composition austenitic stainless steel (SS304L) is given in Table 1.

Table. Chemical composition (wt. %) of SS 304L

Elements	c	Si	Mn	S	P	Cr	Ni	Mo	Cu	Fe
Wt. (%)	0.05	0.34	1.08	0.01	0.01	16.5	10.7	2.08	0.55	68.31

B. *Cutting Tool*

Tough sub-micron substrate, 'SUMO TEC' TiAlN+TiN PVD coated inserts, uncoated carbide and ceramite were used. Inserts of rhombic shape with 80^o three different specifications, which were suitable for low-to-medium cutting speeds and developed for machining of heat resistant alloys i.e. austenitic stainless steel and hard steel for semi finishing and finishing. Inserts had also chip breaking capacity in moderate feed range and positive rake, low cutting forces.

C. *Turning Operation*

The machining (turning) was performed on high precision CNC Turning Centre shown in Fig. 1. The general specification of CNC machine has a spindle speed of 40–4000 rpm, maximum turning diameter and length of 225 mm & 325 mm and spindle nose of A 2–5.

Figure 1. CNC Turning Centre

D. Measurement Of Responses

The surface roughness tester(SJ301) MITUTOYO make was used find and record the values of machined surface roughness. The arithmetic average (Ra) parameter was used to evaluate the surface roughness. Further, the flank wear of tool was measured by measuring the width of the wear land formed on the flank face due to machining. Flank wear of tool was inspected by using tool maker microscope.

E. Design Of Experiment (Doe)

The turning tests were performed at different levels of cutting speed (Vc), feed rate (f) and depth of cut (ap). A premature tool failure was observed at higher level of cutting speed (>125 m/min). However, no such premature failure was occurred at lower cutting speed (>125 m/min). Therefore, the cutting speed range of 75 m/min-125 m/min were selected. Cutting speed, feed rate, depth of cut and nose radius were selected in view of the previous literature and tool manufactures recommendations. The input parameters i.e. cutting speed, feed rate, depth of cut and different inserts were selected within this range with uniform increments. Cutting Speeds wear 75m/min, 100m/min and 125m/min. The feed rates were 0.05mm/rev,0.10 mm/rev and 0.15mm/rev. The depths of cuts were 0.25 mm, 0.50 mm and 0.75mm. Further, The following nine combinations of input parameters were designed by using Taguchi L9 orthogonal array i.e., Design of Expert –L9 shown in Table 2.

Table 2. Design of experiment

Sr. No.	Cutting Speed *Vc*(m/min)	Feed Rate *r*(mm/rev)	Depth of cut a_p (mm)	Inserts *r*(mm)
1	75	0.05	0.25	Coated carbide
2	75	0.10	0.50	Uncoated carbides
3	75	0.15	0.75	Ceramits
4	100	0.05	0.5	Ceramits
5	100	0.10	0.75	Coated carbide
6	100	0.15	0.25	Uncoated carbides
7	125	0.05	0.75	Uncoated carbides
8	125	0.10	0.25	Ceramits
9	125	0.15	0.5	Coated carbide

III. RESULTS & DISCUSSIONS

A. Analysis of Tool Wear (Flank Wear)

The experimental results of various input parameters on tool wear and S/N Ratio are shown in Table 3. It shows the largest S/N ratio (18.41638) corresponds to the minimum flank wear (0.12 mm) during experiment no.1. The maximum value of flank wear (0.36 mm) is recorded at smallest S/N ratio (8.87395) during Exp. No. 6.

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Table 3. Experimental results for (tool flank) and *S/N* ratio

Exp. No.	Cutting Speed V_c (m/min)	Feed Rate f(mm/rev)	Depth of cut a_p(mm)	Inserts r(mm)	Tool Wear V_{Bmax}(mm)	*S/N* ratio
1	75	0.05	0.25	Coated carbide	0.12	18.416
2	75	0.1	0.50	Uncoated carbides	0.19	14.424
3	75	0.15	0.75	Ceramits	0.25	12.041
4	100	0.05	0.50	Ceramits	0.30	10.457
5	100	0.1	0.75	Coated carbide	0.16	15.917
6	100	0.15	0.25	Uncoated carbides	0.36	8.873
7	125	0.05	0.75	Uncoated carbides	0.15	16.478
8	125	0.1	0.25	Ceramits	0.32	9.897
9	125	0.15	0.50	Coated carbide	0.26	11.70053

The tool wear increases with the increase in cutting speed from lower to medium cutting speeds as observed in Fig. 2. Increase in cutting speed from lower to medium increased the cutting temperature at the cutting edge of the tool. The higher cutting temperature causes the tool to lose its strength and plastic deformation. But from medium to highest values of cutting force the tool wear decreased, due to reduced shear strength of workpiece material by further increase in temperature. The tools wear also increases with increase in feed rate. The larger the feed, the greater is the cutting force per unit area of chip-tool contact on the rake face and work-tool contact on the flank face. However, it has been observed that the effect of changes in feed rate on tool wear is almost proportional.

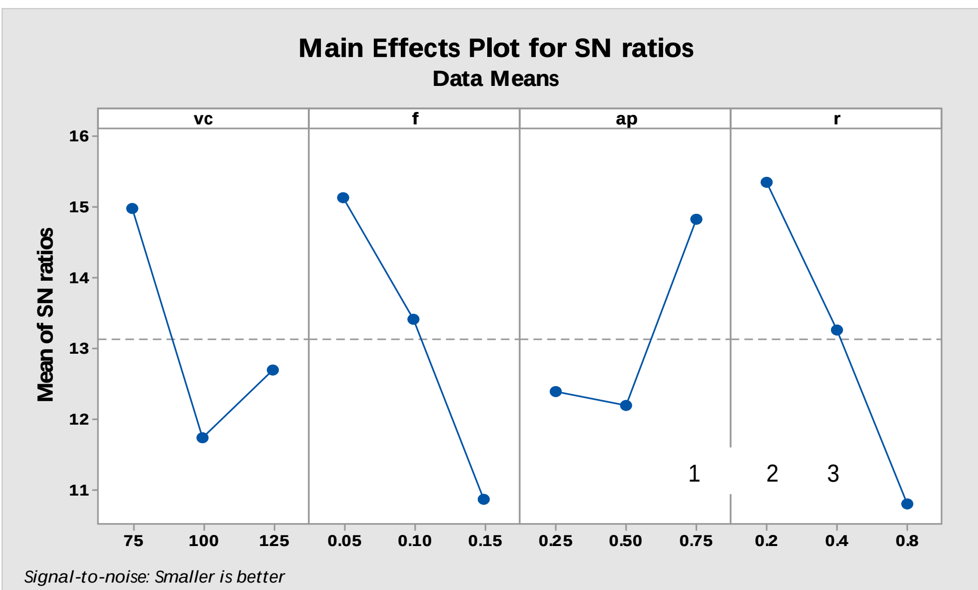

Figure 2. *S/N* graph of tool (flank) wear

The tool wear increased at very slow rate from lower to medium value ofdepth of cut, but suddenly starts decreasing at very fast rate from medium to highest value of depth of cut. This happened due to strength of the cutting edge which being increased with increase in depth of cut, as longer cutting edge is there to withstand the cutting force, moreover more surface area is there to absorb the heat generated. Hence the effect of further increased depth of cut decreased the tool wear. The tool wear increased with increase of different inserts. The graph shows almost proportional effect of increased tool nose radius on the tool wear. Different inserts was found the most significant factor for tool flank wear of contribution 35.49524 %, Feed Rate 31.28443%,Cutting Speed 18.67379 % and Depth of Cut 14.54655 %.

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B. Analysis of Surface Roughness

The experimental results of various input parameters on surface roughness and S/N ratio are shown in Table 4. Table shows the largest S/N ratio (7.9588) corresponds to the minimum surface roughness (0.4 Ra) during experiment No.7. The maximum value of surface roughness (3.47 Ra) is recorded at smallest S/N ratio (-10.8066) during experiment. No.9.

Table 4. Experimental results for surface roughness and S/N ratio

Exp.no.	Cutting speed V_c(m/min)	Feed rate f(mm/rev)	Depth of cut a_p(mm)	Inserts r(mm)	Surface roughness (Ra)	*S/N* ratio
1	75	0.05	0.25	Coated carbide	0.65	3.741
2	75	0.10	0.50	Uncoated carbides	1.15	-1.213
3	75	0.15	0.75	Ceramits	1.12	-0.984
4	100	0.05	0.50	Ceramits	0.58	4.731
5	100	0.10	0.75	Coated carbide	1.67	-4.454
6	100	0.15	0.25	Uncoated carbides	1.64	-4.296
7	125	0.05	0.75	Uncoated carbides	0.40	7.958
8	125	0.10	0.25	Ceramits	0.72	2.853
9	125	0.15	0.50	Coated carbide	3.47	-10.806

The influence of various parameters on surface roughness during experimentation is graphically shown in the Fig. 3.

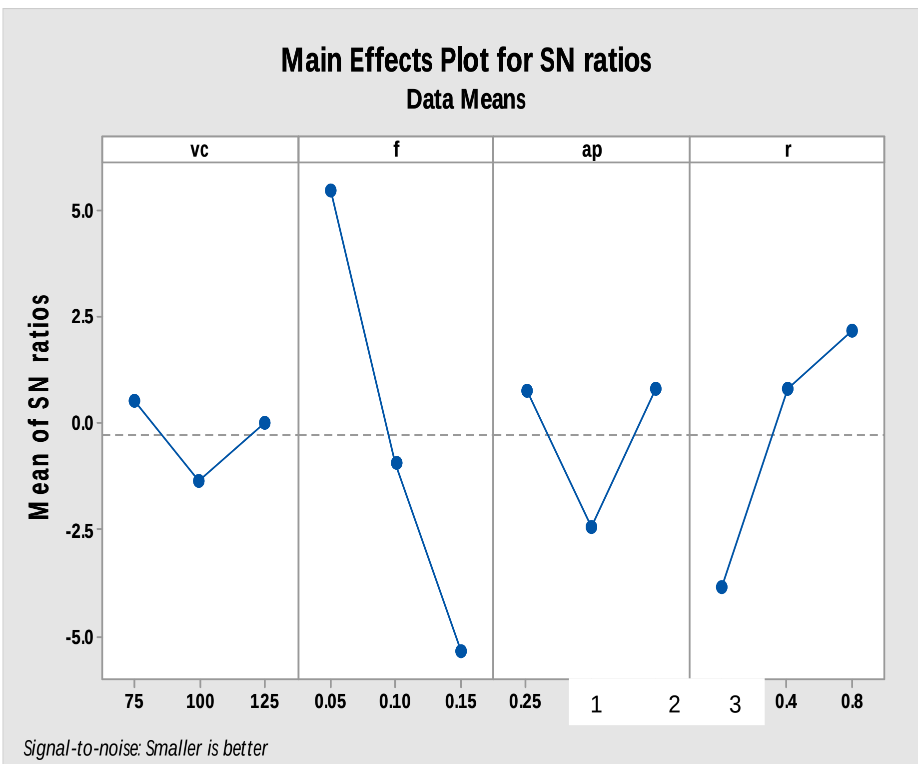

Figure 3. *S/N* graph of surface roughness1 means coated carbide, 2. uncoated carbide and 3 ceramites

The graph shows increase in surface roughness value from lower to middle values of cutting speeds. But, further increase in cutting speed from middle to highest values, decreased the surface roughness values. This happened due to formation of built up edge (BUE) in first instant. This BUE changed the tool geometry which resulted in reduced chip flow on the rake face. The increase in

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cutting speed from middle to highest values reduced the surface roughness value due to the reduction in BUE formation tendency. The influence of feed rate on surface roughness is very clear from the graph i.e. increase in feed rate increases the surface roughness , due to the increased friction between workpiece and tool interface and increased the temperature in the cutting zone. Hence, the shear strength of the material reduces and behaves in a ductile fashion [11]. With the increase in depth of cut the surface roughness first increase from lower to middle values but decrease from middle to highest value. Feed Rate was found the most significant factor for surface roughness of combination 67.33058 %, Nose Radius 22.69234 %, Depth of cut 7.898703 % and Cutting speed 2.078374.

IV. CONCLUSIONS

A. The optimum parameters for flank wear was found 0.12 mm against a combination of input parameters i.e., cutting speed 75m/min, feed rate 0.05mm/rev, depth of cut 0.25 mm while using a tool having coated carbide inserts.

B. Different inserts was found the most significant factor for tool flank wear of contribution 35.49524 %, Feed Rate 31.28443%, Cutting Speed 18.67379 % and Depth of Cut 14.54655 %.

C. The optimum parameters for surface roughness were found to be 0.4 mm against a combination of input parameters i.e., cutting speed 125m/min, feed rate 0.05mm/rev, depth of cut 0.75mm while using a tool having uncoated carbide.

D. Feed Rate was found the most significant factor for surface roughness of combination 67.33058 %, uncoated carbide 22.69234 %, Depth of cut 7.898703 % and Cutting speed 2.078374.

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