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Research Article

Optimization of Cutting Parameters on AISI H11 Steel using Multi-Coated Carbide Tool by Taguchi Method

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Abstract

Hard Turning is a technique can be used in machining the steel with hardness greater than 45 HRC (hardness on the Rockwell test c-scale). We consider AISI H11 as work piece and Multi-coated carbide TH1500 (CVD) as cutting tool. For this experiment, the L_9 Taguchi method is used. The Taguchi method is an Experimental design technique, which is useful in reducing the number of experiments dramatically by using an orthogonal array and also tries to minimize effects out of control. During an investigation the cutting conditions for an experiment are Speed = 100, 120 & 140 m/min, Feed = 0.1, 0.2 & 0.3 rev/min , D.O.C = 0.2, 0.4, & 0.6 mm . It is observed that the tool wear (flank wear) is mainly effected by the cutting speed is found to be the most contributing factor with percentage contribution of 89.83% while in case of surface roughness also the cutting speed is found to be the most contribution factor with 67.11%. The optimized machining condition for minimizing tool wear from Taguchi Method are: cutting speed 100 m/min, feed 0.20 mm/rev, depth of cut 0.60 mm with an estimated flank wear 130 μm. The optimized machining condition for minimizing tool wear from Taguchi Method are: cutting speed 120 m/min, feed 0.20 mm/rev, D.O.C 0.25mm with an estimated surface roughness of 0.86 μm. Also, CVD Multi-coated carbide cutting tool inserts employed in current investigation have been observed to be an economical alternative to costly CBN, PCBN, Ceramic tools, for continuous hard turning application over the range of parameters selected for this study. In future, the effect of varying in work piece hardness may also be investigated. The Chips forms using the same material with CVD Multi-coated Carbide cutting tool inserts may be carried out to improve machining performance.

Keywords: *Flank wear, Taguchi, PVD, CVD & Surface roughness*

1. Introduction

Hard Turning is a technique that can be used to remove an unwanted material from hardened steel in order to get its required shape and size. The hard turning process is defined as machining of steel with hardness greater than 45 HRC (hardness in Rockwell test on C-scale). The temperature generated during hard turning is substantially higher when compared to conventional machining.

1.1 Background

Modern manufacturers, seeking to remain competitive in the market, rely on their manufacturing engineers and producing to quickly and effectively setup manufacturing process for new products (Dr. E. Daniel Kirby *et.al* 2006). Due to the development in the machine tool as well as in process technology focus on cutting hardened steel & rapidly lead to a high raised industrial relevance of hard turning (Miroslav Neslusan *et.al* 2011). Hard turning is a method that can be used to remove unwanted material from hardened steel in order to get its required shape and size. The hard turning process is defined as machining of steel with hardness greater than 45 HRC. The temperature generated during hard turning is substantially higher when compared to conventional machining (Wojciech Zębala *et.al* 2012). Hard turning eliminates the series of operations required to produce the component and thereby reducing the cycle time and hence resulting in productivity improvement (S.Z. Qama 2009).

This process becomes normal in industry because of its high productivity and reduces energy consumption. It play a vital role in determining the energy consumed and machining power required for the process, tool and work piece deflections. Due to high hardness in the work piece, it results in high cutting force than usual and this reduces the performance of the cutting tool (R. Suresh *et.al* 2012). Hard machining is performed dry using ceramics and polycrystalline cubic boron nitride (PCBN, commonly used CBN) cutting tools due to the required tool material hardness (S. Thamizhmanii & S. Hasan 2008). The surface integrity as well as tool wear are influenced to a large extent by cutting parameters such

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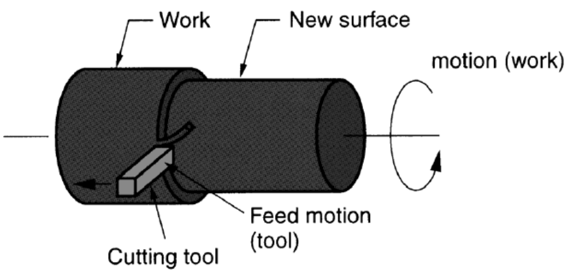
as cutting speed, feed and depth of cut as well as the geometric parameters such as approaching angle, rake angle and nose radius. In order to minimize the machining time and hence the cost of machining in an industrial environment there is a need for optimization of cutting parameters. However, due to lack of reliability of suitable models relating machining variables with cutting parameters, these models have not found proper implementation in industry Many researchers have developed theoretical models (correlations between machining variables and cutting parameters) for some specific materials. Machine tool structure and cutting process dynamics, however, are so complex that these theoretical models cannot be completely relied upon. Some researchers have experimentally explored the influence of cutting parameters on machining variables considering one or two variables either on-line or off-line. There is a need to know the cumulative influence of cutting parameters on all the machining variables and hence envisage the development of suitable models both theoretical as well as experimental which could be directly applied in an industrial set up (E. Daniel Kirbya 2006).

The Turning process can be of different types such as straight turning, taper turning, profiling or external grooving. Turning process can produce various shapes of materials such as straight, conical, curved, or grooved work pieces. In general, turning uses simple single-point cutting tools. Each group of work piece materials has an optimum set of tools angles which have been developed through the years (Shivraj Bhagat *et.al* 2014).



Turning operation (Jitendra Thakkar *et.al* Feb, 2014)

In turning process, parameters such as cutting tool geometry and materials, number of passes, depth of cut for each pass, the depth of cut, feed rates, cutting speeds as well as the use of cutting fluids will impact the production costs, MRRs, tool lives, cutting forces, and the machining qualities like the surface roughness, the roundness of circular and dimensional deviations of the product.

1.2 Types of Coating Technology

Surface coating of tri-bological applications is associated with deposition temperatures ranging from room temperature to over 1000°C. The coating thickness ranges from microns to several millimeters. Typically, the atomistic methods produce the thinnest coatings. Some methods involve high deposition temperatures that may give undesired phase transformations, softening or shape changes of the coated component. An important benefit of PVD and CVD processes is the high flexibility as to composition and structure of the coatings, and these processes are today successfully utilized to coat a large variety of mechanical components (Anand Kumar *et.al* 2013).

1.3 CVD (Chemical Vapour Deposition)

CVD method deposits thin films on the cutting tools through various chemical reactions. CVD coated cemented carbides have been a huge success since their introduction in the late 1960's. Since then, chemical vapour deposition technologies have advanced from single layer to multilayer versions combining Ti-N, Ti-CN, Ti-C and Al_2O_3. Modern CVD coatings CVD method deposits thin films on the cutting tools through various chemical reactions.CVD coated combine high temperature and medium temperature processes in complex cycles that produce excellent wear resistant coatings with a total thickness of 4-20 µm. However, the high deposition temperature (950-1059°C) during CVD results in diffusion of chemical elements from the carbide substrate to the coating during growth. The main effect is an embrittlement of the coating edge. In addition, the chemistry of the CVD process results in more rapid growth at the cutting edge resulting in an even coating thickness. Therefore, there was a strong driving force to find coatings that could be deposited at lower temperatures in order to allow tools with sharper edges to be coated without any embrittlement effect. The solution is PVD where deposition temperature can be kept at around 500°C (Rohit Garg *et.al* 2010).

Advantages of CVD Multi-coated Carbide

1. A wide range of applications from low to high speed and finishing to roughing.
2. Stable Machining is obtained due to high toughness and crack resistant.
3. Possible to reduce machining time and maintain good chip control with various chip breakers.

1.4 Types of coatings

Single layer coating

The first coating was a single layer of TiC.10 to 12 micrometers thick, which was deposited by a process known as chemical vapour deposition (CVD) onto a substrate of hard metal. During the deposition process some carbon was taken up from the surface of the hard metal as part of coating and this changed the carbon balance at the junction of the coating and the hard metal substrate. This lowering of the carbon balance caused the formation of a brittle compound at the interface between the coating and the substrate and made early coated index able inserts sensitive to chipping of cutting edge.

The next development was to put down a coating of Ti-N which prevented any decarburizing of the hard metal substrate but the coating which is gold in colour, did not adhere well to the hard metal base. Ti-N is an even better diffusion barrier than Ti-C but Ti-C has better abrasion resistance (Anand Kumar *et.al* 2013)

Multilayer coatings

Although single-layer coatings are finding a range of applications in many sectors of engineering, there are an increasing number of applications where the properties of a single material are not sufficient. One way to solve this problem is to use a multilayer coating that combines the attractive properties of several materials, each chosen to solve a problem in the application. Multi layer coatings can consist of as many as eight layers within a total thickness of 10 micrometers or less. Simple examples of this include the use of interfacial bonding layers to promote adhesion, or thin inert coatings on top of wear-resistant layers to reduce the corrosion of cutting tools. There is, however, mounting evidence that the multi-layer structure produced when many alternating layers of two materials are deposited can lead to improvements in performance over a mixed coating (by virtue of the introduction of new interfaces) even if the two materials do not have specific functional requirements in the intended application (M. Narasimha *et.al* 2013).

1.5 Why Ti-N?

The majority of inserts presently used in various metal cutting operations are carbide tools coated with nitrides (Ti-N, Cr-N, etc.). The Ti-N deposited as a mono-layer holds a dominant position in the field of hard coatings (Supriya sahu *et.al* 2012).

Ti-N coating is usually used as an outermost layer as

1. It increases the wear resistance
2. Reduces the sticking of the work material.
3. The golden color of the Ti-N coating helps in wear detection by allowing the operator to distinguish between a used and a new cutting edge corner.

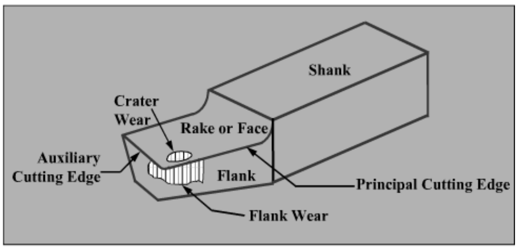
1.6 Surface roughness

Surface finish is an important parameter in the manufacturing engineering. It is the characteristic that could influence the performance of mechanical parts and the production costs. Various failures, sometimes catastrophic, leading to high costs, have been attributed to the surface finish of the components in question. The cutting tool nose radius play a critical role in the surface finishing of the work piece. Within the presented research framework, the discussion of surface roughness is focused on the universally recognized Ra. Surface roughness (Ra) value is recognized universally as the commonest international parameter of roughness. The average roughness is the area between the roughness profile and its centre line.

1.6 Tool wears in hard turning

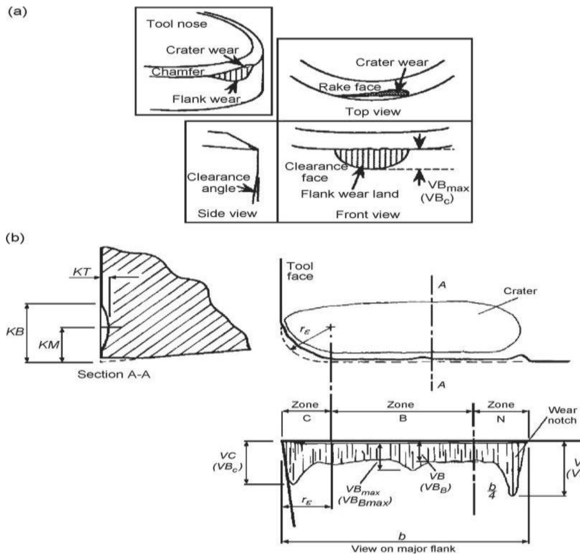
On the basis of cutting speed and depth of cut, the tool wear is broadly classified in two categories: Flank wear and Crater wear as depicted.

During the machining process, the cutting tools are loaded with the heavy forces resulting from the deformation process in chip formation and friction between the tool and work piece. The heat generated at deformation and friction zones overheats the tool, the chip and partially the work piece.



Types of the cutting tool wear at a single point cutting (Dr. P C Sharma (2010)

Flank wear: it occurs on the side of the cutting edge as a result of friction between the side of the cutting tool edge and the metal being machined. Too much flank wear increases friction and makes more power necessary for machining.



Typical wear in a single point cutting tool (S. Hasan *et.al* 2008)

Crater wear: it is due to the abrasion between the chip and the face of the tool, a short distance from the cutting edge resulting in a crater being formed on the tool face.

1.7 Objectives

The present study will be focused on hard turning of AISI H11steel with the Multi-coated Carbide TH1500 cutting tool inserts. The study will attempt to investigate the following objectives:

1. Investigation of the effect of cutting speed, feed rate and depth of cut on tool wear (flank wear VB).
2. Investigation of the effect of cutting speed, feed rate and depth of cut on surface roughness (Ra).

1.8 Scope of work

The data obtained from this study will provide a better understanding of the effect of process parameters on tool wear (flank wear), surface finish during hard turning of H11 steel. The results obtained will enrich the existing database and may be helpful in selecting the optimum values of process parameters during machining of H11 steel.

Problem formulation

From the literature review, it is revealed that a number of studies pertained to the hard turning of various grades of hardened steels with CBN, PCBN and ceramic tools have been conducted. CBN tools are used for continuous or interrupted cutting and Multi-coated carbide are used for continuous cutting. These types of tools are considered for the application in industry like: Gears, Hubs, Shafts, Bearings, Tool parts, Nozzles & Clutch discs etc.

In the study newly developed multi-coated carbide (CVD) is being used as the material for cutting tool in the hard turning. H11 steel is an air hardening, high-carbon, high-chromium tool steel. It has properties of high wear and an abrasion resistant.

Most of the investigation done on hard turning was on hardened steel b/w 35-50 HRC using carbide cutting tool inserts. The literature on the research related to H11 steel using Multi-coated carbide tool with hardness more than 50 HRC is not very rich.

2. Methodology

The work piece material was AISI H11 steel. It was hardened to 55 HRC. H11 steel is an air hardening, high-carbon, high-chromium tool steel. It has high wear and an abrasion resistant properties. It is heat treatable and will offer hardness in the range 50-60 HRC, and is machinable in the annealed condition.

C	Si	Mn	P	Cr	Al	Fe
0.4%	0.79%	3.21%	0.02%	5.69%	0.02%	90.3%

H11steel shows little distortion on correct hardening. H11 steel's high chromium content gives it mild corrosion resisting properties in the hardened condition. Among the more important applications of H11 are the following:

- Rotor blade of a helicopter.
- Moulds & Dies.
- Bullet proof car door.
- Bearings
- Rock Drills
- Clutch Discs
- Nozzles
- Axles
- Conveyor
- Gears
- Tool parts

2.1 Cutting Tool Material

Multi-coated carbide cutting tool inserts are chosen to hard turn the work piece. The inserts with designation CNMG120408-MF2 coated with CVD super fine grained grade intended for machining of steel components with both hardened and soft areas was used in the study. The combination of properties in CNMG120408-MF2 makes this grade ideal for hard turning steel having hardness in the range of 45-65 HRC. Because of the coating, this grade provides high wear resistance while maintaining the strength and toughness of the carbide tool.

Advantages of Multi-coated Carbide tool over CBN, PCBN and Ceramic inserts:

- Outstanding wear and deformation resistance
- Performance alternative to carbides
- Cheaper than CBN , PCBN and Ceramic inserts
- Capable of machining both hard and soft steel
- Good edge toughness
- Good chip control

The Chemical composition of Multi-Coated Carbide TH1500 (CVD) tool as following:

Chemical composition of carbide cutting tool in (wt %)

Elements	Co	Cr_3C_2	Wr
Wt %	6.0	0.5	93.5

The Chemical name of carbide:

$Co + Cr_3C_2 + Wr$ = Cobalt + Chromium Carbide + Wrought Iron

The Chemical treatment done to provide the protected layer on the Carbide tool inserts. The phenomena is known as CVD (Chemical Vapour Deposition). It helps to increase the life of the cutting tool inserts.

The Chemical name of Coating on Carbide tool CVD (Chemical Vapour Deposition) composition is:

TH1500= TI (C, N) + Al_2O_3

Titanium Carbo-Nitride + Aluminum Oxide

The ISO designation inserts is CNMG120408-MF2. The coating has a high wear resistance while maintaining the strength and the violet colored employed for easy detection. The inserts were clamped on 25/25 M left hand tool holder.

2.2 Machine tool and Equipments:

1 Engine lathe: Rough turning of the specimens was carried out on an engine lathe prior to heat treatment. The outermost 2 mm layer present on all the specimens was turned off to avoid machining of oxidized layer during the subsequent hard turning tests.
2 CNC lathe: The prepared specimens after heat treatments were hard turned on CNC centre Lathe.
3 Tool Makers Microscope
4 Surface Roughness Tester

2.3 Experimental Plan

In this experiment, Taguchi OA Design L9 was used to design the experimental plan. Cutting speed, feed rate and depth of cut were varied in this experiment.
Cutting condition for an Experiment

Cutting parameters	Unit	Level 1	Level 2	Level 3
Cutting speed	m/min	100	120	140
Feed rate	mm/rev	0.1	0.2	0.3
Depth of cut	mm	0.2	0.4	0.6

2.4 Experimental orthogonal array

Exp. no	A	B	C	Averages	Averages
	Speed (m/min)	Feed (mm/rev)	D.O.C (mm)	Avg. VB (µm)	Avg. Ra (µm)
1	100	0.1	0.2	138.67	0.74
2	100	0.2	0.4	125	0.62
3	100	0.3	0.6	126.67	0.43
4	120	0.1	0.4	16.67	0.62
5	120	0.2	0.6	143.67	0.98
6	120	0.3	0.2	148.33	0.99
7	140	0.1	0.6	170	1.15
8	140	0.2	0.2	183.33	0.99
9	140	0.3	0.4	195	1.16

3. Taguchi Analysis and Discussion of Results

Main effects due to parameters and interactions

The main effects can be studied by the level average response analysis of raw data or of S/N data. The analysis is done by averaging the raw or S/N data at each level of each parameter and plotting the values in graphical form. The level average responses from the raw data help in analyzing the trend of the performance characteristics with respect to the variation of the factor under study. The level average response plots based on the S/N data help in optimizing the objective function under consideration. The lower points of these plots correspond to the optimum condition for average Tool wear (flank wear) and average surface roughness.

3.1 S/N Ratio and ANOVA analysis for Flank wear (VB)

Analysis of VB versus Speed, Feed, DOC

Response for Signal to Noise Ratios Smaller is better.

Level	Speed(A)	Feed(B)	DOC(C)
1	-42.28	-43.79	-43.85
2	-43.49	-43.45	-43.89
3	-45.23	-43.77	-43.27
Max-Min	2.95	0.34	0.62
Rank	1	3	2

Response for Means

Level	Speed (A)	Feed (B)	DOC (C)
1	130.11	155.11	156.78
2	149.56	150.67	158.89
3	182.78	156.67	146.78
Max-Min	52.67	6	12.11
Rank	1	3	2

ANOVA results for flank wear (VB) ANOVA results for flank wear

Sources	DOF	Sum of squares	Mean square	F- ratio	Percentage (%)contribution of factors
Speed	2	13.18	8.12	19.7	89.83
Feed	2	0.21	0.31	0.76	1.44
DOC	2	0.70	0.69	0.66	4.79
Error	2	0.58	.41		3.93
Total	8	14.67			

3.2 S/N Ratio and ANOVA analysis for Surface Roughness (Ra)

Analysis of Ra versus Speed, Feed, DOC

Response for Signal to Noise Ratios Smaller is better

Level	speed	feed	DOC
1	4.57	1.78	0.86
2	1.40	1.42	2.29
3	-0.86	1.92	1.97
Max-min	5.43	0.5	1.43
Rank	1	3	2

Response for Mean

Level	speed	feed	DOC
1	0.60	0.84	0.91
2	0.87	0.87	0.80
3	1.10	0.86	0.86
Max-min	0.5	0.03	0.11
Rank	1	3	2

ANOVA results for Surface roughness (Ra)

Sources	DOF	Sum of squares	Mean square	F- ratio	Percentage (%)contribution of factors
Speed	2	4.61	22.30	2.46	67.1166
Feed	2	0.38	0.19	0.02	0.58
DOC	2	0.35	1.68	0.18	5.04
Error	2	8.12	0.06		27.26
Total	8	30.22			

3.3 Optimal parameters for (Ra) and (VB)

Optimal parameters	Speed (m/min)	Feed (mm/rev)	D.O.C (mm)
Flank wear(VB)	100	0.2	0.6
Surface roughness(Ra)	120	0.2	0.4

Conclusions and Scope for Future Work

Based on analysis of data and discussion of results, several important conclusions are drawn during hard turning of AISI H11steel using CVD Multi-coated carbide cutting tool inserts as under:

The percentage contribution of input parameters on flank wear (VB) is: Speed = 89.83%, Feed rate = 1.44% and D.O.C. =4.79%, signifying the cutting speed to be the most contributing factor influencing in the Flank wear.

1. The percentage contribution of input parameters on Surface roughness (Ra) is: Speed = 67.11%, Feed rate = 0.58% and D.O.C. =5.04%, signifying the feed rate to be the most contributing factor influencing in the Surface roughness.
2. The optimized machining conditions for minimizing tool wear from Taguchi analysis are approaching: cutting speed 100 m/min., feed 0.20 mm/rev., depth of cut 0.60 mm with an estimated flank wear 130 µm.
3. The optimized machining conditions for minimizing tool wear from Taguchi analysis are approaching: cutting speed 120 m/min., feed 0.20 mm/rev., depth of cut 0.4 mm with an estimated surface roughness of 0.86 µm.
4. CVD Multi-coated Carbide cutting tools employed in current investigation have been observed to be an economical alternative to costly CBN, PCBN and ceramic tools, for continuous hard turning application, over the range of parameters selected for this study.

Recommendations for future work

The current study investigates the effect of cutting speed, feed and depth of cut on flank wear and surface roughness, while keeping constant work piece hardness.

1. In the future, the effect of varying work hardness may also be investigated.
2. The detail investigation of chips forms using the same material with CVD Multi-coated Carbide cutting inserts may be carried out to improve machining performance.

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