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CUTTING TOOL, CUTTING GEOMETRY, SURFACE INTEGRITY, TOOL WEAR AND LUBRICATION DURING MACHINING: A STATE OF ART

Ashu Tyagi, Mohit Singh, Pardeep Kumar
Department of Mechanical Engineering, Deenbandhu Chhotu Ram University of Science & Technology,
Murthal, Sonipat, Haryana

Abstract

The manufacturing sector relies heavily on machining techniques since they provide the foundation for forming materials into the necessary shapes. This study provides an in-depth analysis of the state of the art in several critical areas of machining, including tool wear, lubrication, surface integrity, cutting geometry, and cutting tools.The significance of cutting tools and their geometric attributes in attaining effective material removal and superior surface polish is examined. This paper examines surface integrity in depth, taking into account residual stresses, microstructure modifications, and surface roughness. Surface integrity is a vital aspect in assuring component performance and lifetime.In addition, the study explores the intricacies of tool wear mechanisms, offering insights into wear patterns, mechanisms, and their effects on machining operations. There includes discussion of lubrication techniques and how they affect heat generation, friction reduction, and tool life.This review provides a thorough understanding of the current state of knowledge in these important domains, which has implications for improving manufacturing technologies and machining process optimisation. It is a valuable resource for researchers, engineers, and practitioners in the field of machining.

1. INTRODUCTION

1.1 Hard Turning

Hard turning is defined as the process of single point cutting of part pieces tool that have hardness values near and above the 45 HRC is becoming an alternative to the grinding nowadays. Hard turning is a fine finishing process in which rough machining and grinding can be excluded. The hard turning is generally performed without a coolant. The process of hard turning provides many possible benefits compared to the conventional grinding operation. Additionally, life of tool, tool wear, surface quality, and the amount of material removed can also be determined. This has been made with possible with the advancement of Cubic Boron Nitride (CBN) tools. Compare to grinding, hard turning process generally takes less cycle time, require fewer operations and have lower costs and higher material removal rate. Despite of the fact that the process is done using small depths of cut and feed rates, the machining time is reduced to the 60% of the conventional turning [1].Hard turning has recently been a very important precision machining process in the manufacturing of circular part with high values of surface hardness such as bearings, shafts, pinions, gears, cams, values and a variety of automobile transmission part as well as some product like helicopter shaft in aerospace industry. In hard turning process, due to high hardness value of the work piece material and the high temperature created, the problems become more complex and very much coupled between the mechanical and thermal aspect of machining e.g. high value of mechanical stresses and temperature can cause early tool wear, and tool wear not only reduce tool life, but also increases the force and tensile residual stresses, affect the surface finish and tend to cause white layer surface damages.

To perform the hard turning successfully, the following requirements for the coolants, cutting tool, etc. should be fulfilled [2].

(i) The machining tool for hard turning should be capable of processing at high speeds. So, it should have high machine tool rigidity, high surface speed and constant surface speed capabilities to get the required finish.

(ii) As hard turning involves the machining of hardened materials of 45HRC and above, there is higher expectation of generation of higher forces. So, a tool with low wearing capabilities is required.

(iii) Generally, during hard turning the coolant is not used but to reduce the chance of white layer formation, some researchers have suggested using coolants [6]. Due to elevated temperatures at the cutting zones, the coolant starts boiling and results in the reduced tool life and deteriorated surface finish. Though coolant is not used in hard turning, its absence also reduces the tool life and lead to deteriorated surface finish [7].

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(iv) During the continuous cuts, the chips should appear as blazing orange and should flow off like any ribbon. The chips take away with it most of the heat produced which results in reduced work piece temperature. At a cutting speed of 360 m/min chip to work piece temperature ratio was found to be 16 [8].

The figure below shows various factors that affect the hard turning process. In the figure, the factors which are to be selected before the execution of the hard turning process are shown above the dashed line and are considered as inputs to the process. The parameters which are shown below the dashed line are the performance measure factors or the outputs of the process. (Tugrul Ozel · Tsu-Kong Hsu · Erol Zeren Effects of cutting edge geometry, workpiece hardness, feed rate and cutting speed on surface roughness and forces in finish turning of hardened AISI H13 steel, Int J Adv Manuf Technol (2005) 25: 262–269)

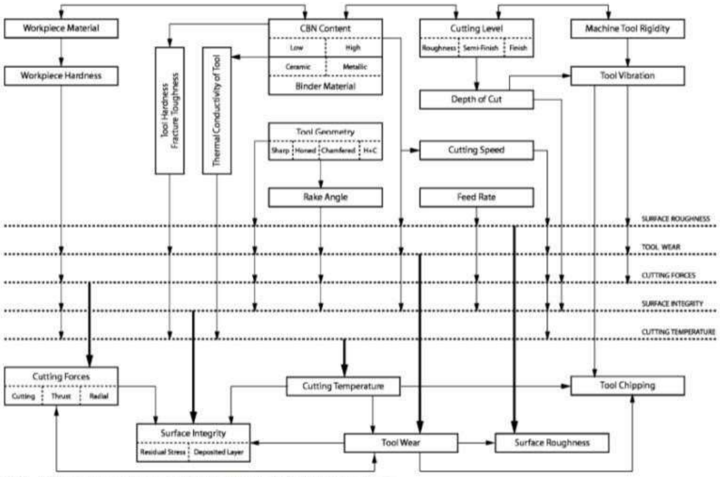


Fig. 1. A flow chart illustrating the relationships of factors in the hard turning process

The performance measures of any process tell about the accuracy and the efficiency of the process. Some of the major process measures are as listed below and description follows.

1. Tool wear
2. Surface roughness
3. Cutting forces
4. Surface Integrity

Other factors which affect the hard turning process can be the tool geometry, residual stresses generated, generation of white layers etc.

The figure shown below depicts the various error driving factors and sources.

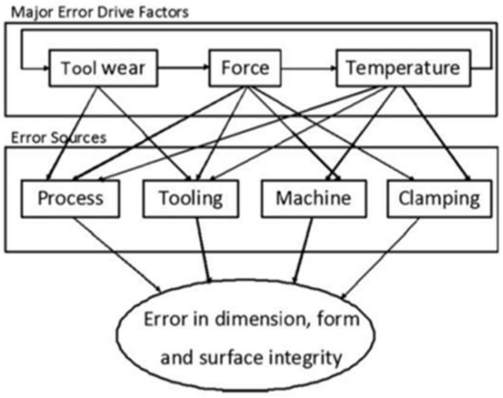


Fig. 12. Major error driver factors and error sources in precision hard turning [96].

For the better accuracy and finish in any operation, which any company has to adopt, these factors are needed to be taken care of.

2. LITERARURE REVIEW

2.1 Surface Roughness

Surface roughness is the indication of the state of any machined surface. Surface roughness is the random deviancy of the surface from the nominal surface which forms the 3D structure of the surface. Surface roughness includes the followings: (1) roughness, (2) waviness, (3) lay, (4) form error, and (5) roughness height.

Roughness: Roughness contains the surface irregularities which result from the numerous machining practices. These irregularities associate to form surface texture. The irregularities are mostly from the marks of tool that are left during the machining.

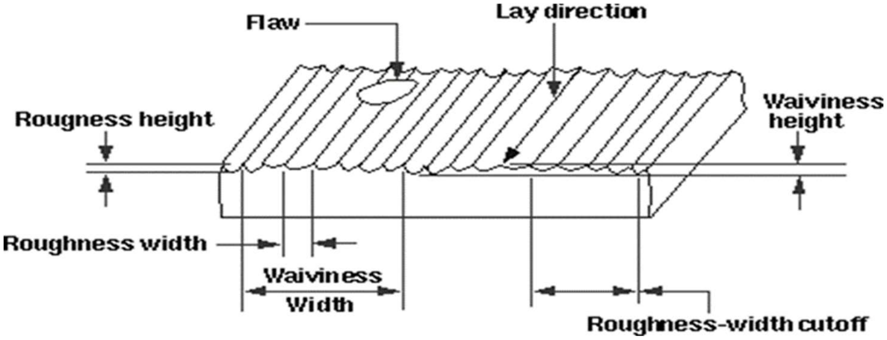
Roughness Height: It is that height of the irregularity which is measured from a reference line. It is generally measured in millimeters or microns. It is also called as the height of unevenness.

Lay: Lay signifies the direction of the principal surface pattern and reflects the type of machining process used to produce it.

Waviness: This denotes the irregularities lying outside the roughness width cut off value. Waviness is the broadly spaced factor of any surface texture. This may be due to the deflection of work piece or tool during machining, vibration, heat treatment or rapping strain.

Waviness Height: Waviness height denotes the peak to valley distance of any surface profile which is measured in millimeters.

Form Error: Any error during the manufacturing process results in form error. Distinct name of form error in the round work pieces at the cross section is roundness.



Surface roughness in machine

The resulting roughness produced after any machining process can be assumed as the combination of the following two independent quantities.

1. Ideal roughness
2. Natural roughness

1. Ideal Roughness: Ideal roughness is a function of the feed and geometry. It signifies the best potential finish which can be attained for the given shape of tool and feed. It can be attained only if the built-up edge, chatter and incorrectness in the movements of machine tool are eliminated totally.

2. Natural Roughness: During practical, it is generally not possible to attain such condition as described above, and usually the natural surface roughness procedures a large proportion of the actual roughness. One of the key factors that contribute to natural roughness is the formation of a built-up-edge. Thus, with the increase in built up edges the surface production becomes rougher, and factor tending to decrease chip-tool friction and to remove or reduce the built-up-edge would give improved surface.

Effects of machining parameters on surface Roughness

Kopac et al.[1] found that the cutting speed has greater influence on surface roughness i.e. higher the cutting speed better is the surface finish. Depth of cut also influences the surface roughness and is the third most important cutting factor. The TiN (PVD) coating of cutting tools has significant influence on surface roughness. Rech and Moisan [2] concluded that a low surface roughness is obtained when the cutting time is long. The surface roughness is mainly affected by the feed rate and the cutting speed does not affect significantly. When small feed is used, better surface finish can be obtained. Chou and song [3] investigated that as the tool nose radius increases, the surface roughness decreases. At low feed rate it is noticed that there is a departure from theoretical predictions of surface roughness because of the plowing actions of the uncut chip thickness. Noordin et al.[4]concluded that the ANOVA revealed that feed is the most significant factor influencing the response variables investigated(i.e. surface roughness and tangential force). The SCEA2 and the feed and SCEA interaction factors provide secondary contribution to the responses investigated. Additionally, the cutting speed also provided secondary contribution to the tangential force. Tamizharasan et al.[5] concluded that there is a negligible effect of depth of cut on the surface finish. The cutting tools perform well for the hard turning with better surface finish at the nominal speeds. Dhar et al.[6] concluded that there is better cutting performance of the MQL machining than the conventional and dry machining. An improved surface finish is obtained by using MQL machining [6]. Grzeisk and Wanat [7] found that a comparable surface finish is provided by using hard turning with the wiper inserts to the effects obtained by conventional operations at low feed rate. During the 30 minute wear test, the surface roughness changes similarly for the conventional operation and the finish hard turning with wiper inserts. The spacing roughness parameters are not influenced significantly by using the wiper geometry. Thamizhmanii et al. [8] concluded that the only significant factor which contributes to the surface finish is the depth of cut. Feed rate is the second significant factor which contributes to the surface roughness. Cutting speed comes to be with the less effect on the surface finish. Dhar and Kamaruzzaman [9] investigated the surface roughness under the cryogenic conditions and concluded that the dry machining does not show any improvement in surface roughness and the cryogenic cooling with the liquid nitrogen provides a better surface finish. Lalwani et al. [10] conducted an experiment to investigate the effects of cutting speed, depth of cut and feed rate on surface roughness. It is concluded that the surface roughness is not affected by the cutting speed and the feed rate affects the surface roughness the most. When the depth of cut and feed rate are set near to the higher values then a good surface roughness is obtained. Sharma et al. [11] used the neural network to investigate the effects feed, depth of cut, speed and approaching angle. They investigated that the surface roughness is highly influenced by the feed. A negative trend is observed in case of the approaching angle, depth of cut and speed. Cemal Carik et al. [12] created a mathematical model for the surface roughness to evaluate the effects of the cutting parameters. It investigated that though theoretically the surface roughness is affected by feed rate and nose radius the other parameters like cutting speed, cutting depth and tool wear also have effect on surface roughness when considered practically. Feed rate influences the surface roughness the most. Increase in cutting speed tends to increase the surface roughness. Paulo Davim et al. [13] used the artificial neural network models to investigate the effects of cutting conditions on the surface roughness. The analysis was carried out by taking the feed rate, depth of cut and cutting speed as process parameters. It concluded that highly non- linear relationships exist between the cutting conditions and the surface roughness parameters. Surface roughness decreases with the increasing cutting speed and decreasing feed rate. Thamizhmanii et al. [14] analysed surface roughness during turning process of hardened martensitic stainless steel. Various parameters used were feed rate, depth of cut and cutting speed. Low surface finish was observed at high cutting speed and low depth of cut and feed rates. Optimized parameters were taken at the moderate cutting speed and low depth of cut and low feed rate. Ramesh et al. [15] concluded that the surface roughness is mainly influenced by the feed rate. When cutting speed and depth of cut are increased, the surface roughness decreases but it increases with increase in the feed rate.

Table: Surface Roughness

S.NO	AUTHOR	YEAR	WORKPIECE MATERIAL	CUTTING TOOL	MOD. TECH.	PARAMETERS
1	Kopac et al.	2001	Cold-Formed carbon steel C15 E4 (case-carburising steel)	Cermet CCMT 09T308 NFP T12A	Taguchi	Cutting Speed: 250-400 (m/min) Depth of Cut: 0.3-0.5 (mm)
2	Reach and Moisin	2002	Case-hardened 27MnCr5 Steel	CBN	Not Defined	Cutting Speed: 50-250 (m/min)

						Feed Rates: 0.05-0.2 (mm/rev) Depth of Cut: 0.15 (mm)
3	Chou and Song	2003	AISI 52100	Alumina titanium carbide composite	Not Defined	Cutting speed: 2-3 (m/min) Feed Rate: 0.05-0.6 (mm/rev) Depth of Cut :0.2 (mm)
4	Noordin et al.	2004	AISI 1045 Steel Bars	Coated Carbide	RSM ANOVA	Cutting Speed:240,300,375 (m/min) Feed Rate: 0.18,0.23.0.28 (mm/rev) SCEA: -5º,-3º,0º
5	Tamizharasan et al.	2005	Different Workpiece hardness values over 45 HRC	CBN	Not Defined	Cutting speed: 100,150,200 (m/min) Feed Rate: 0.06,0.10,0.14 (mm/rev) Depth of Cut :0.2,0.3,0.4 (mm)
6	Dhar et al.	2005	AISI 4340 Steel	Uncoated Carbide Inserts	Not Defined	Cutting speed: 110 (m/min) Feed Rate: 0.16 (mm/rev) Depth of Cut :1.5 (mm)
7	Grzesik and Wanat	2006	AISI 5140	Ceramics Inserts	Not defined	For Wiper Tool Cutting speed: 100 (m/min) Feed Rate: 0.1-0.8 (mm/rev) Depth of Cut :0.25 (mm) For Conventional Tool Cutting speed: 100 (m/min) Feed Rate: 0.04-0.4 (mm/rev) Depth of Cut :0.2 (mm) Noise radius:0.8 (mm)
8	Thamizhmanii	2007	SCM 440 alloy	Coated	Taguchi	Cutting speed:

	et al.		steel	Ceramic Tool	Method	13,51,85,240 (m/min) Feed Rate: 0.04,0.05,0.063 (mm/rev) Depth of Cut :1,1.50 (mm)
9	Dhara and Kamruzzaman	2007	Aisi 4037	Coated Carbide inserts	Not Defined	Cutting speed: 165, 194, 239 and 264 (m/min) Feed Rate: 0.10, 0.13, 0.16 and 0.20 (mm/rev) Depth of Cut : 1.55 (mm) Dry, wet and cryogenic cooling by liquid nitrogen
10	Lalwani et al.	2008	MDN250 steel	Coated Ceramic tool.	RSM	Cutting speed: 55,74,93 (m/min) Feed Rate: 0.04,0.08,0.12 (mm/rev) Depth of Cut :0.1,1.5,0.2 (mm)
11	Sharma et al.	2008	Adamite	Coated Carbide Inserts	Neural Network	Cutting speed: 36.6,51.5,81.7,126.6,196 (m/min) Feed Rate: 0.1,0.17,0.27,0.13,0.21 (mm/rev) Depth of Cut :0.3,0.6,0.9,1.5 (mm) Approaching Angle: 45,60,75,90
12	Cemal Cakir et al.	2009	AISI P20 Steel	Carbide Inserts	Not Defined	Cutting speed: 12,01,60,200 (m/min) Feed Rate: 0.12,0.18,0.22 (mm/rev) Depth of Cut :1,1.5,2 (mm)
13	Paulo Davim et al.	2008	Free Machining Steel	Cemented Carbide	Taguchi Method	Cutting speed: 7,11,41,283 (m/min)

						Feed Rate: 0.10,0.16,0.25 (mm/rev) Depth of Cut :0.50,0.75,1.0 (mm)
14	Thamizhmanii et al.	2008	AISI 440C martensitic stainless steel	CBN	Not defined	Cutting speed: 15,01,75,225 (m/min) Feed Rate: 0.08,0.10,0.123 (mm/rev) Depth of Cut :0.50,0.75,1.00 (mm)
15	Ramesh et al.	2008	Titanium Alloy Grade 5	CVD Coated Carbide,	RSM ANOVA	Cutting speed: 40,60,80 (m/min) Feed Rate: 0.13,0.179,1.00 (mm/rev) Depth of Cut :0.50,0.75,1.00 (mm)
16	Prasad et al.	2009	En31 Steel	PCBN	Taguchi Method	Cutting speed: 9,11,37,183 (m/min) Feed Rate: 0.076 0.114 0.152 (mm/rev) Depth of Cut : 0.1 0.15 0.2 (mm)
17	Kaewkuekool et al.	2007	Main Shaft SCM4	CBN	Taguchi Method ANOVA	Cutting speed: 140 (m/min) Feed Rate: 0.08,0.12,0.16 (mm/rev) Depth of Cut :0.10,0.15,0.20 (mm)
18	Chavoshi et al.	2010	AISI 4140	CBN	ANOVA	Spindle Speed : 2500-3000 (rpm) Hardness: 35-65 (hrc)

19	Asiltürk & Akku	2011	AISI 4140 (DIN 42CrMo4) steel	Coated Carbide	Taguchi Method	Cutting speed: 90,120,150 (m/min) Feed Rate: 0.18,0.27,0.36 (mm/rev) Depth of Cut :0.2,0.4,0.6 (mm)
20	Saini et al.	2012	AISI H11 Tool Steel	Ceramic Tool	RSM	Cutting speed: 100,130,160 (m/min) Feed Rate: 0.05,0.13,0.2 (mm/rev) Depth of Cut :0.1,0.3,1.5 (mm) Nose raidus : 0.4,0.8,1.2
21	Hessainia et al.	2013	42CrMo4 hardened steel	Ceramic Cutting Tool	RSM	Cutting speed: 90,120,180 (m/min) Feed Rate: 0.08,0.12,0.16 (mm/rev) Depth of Cut :0.15,0.30,0.45 (mm)
22	RAO at el.	2013	AISI 1050 Steel	Ceramic Cutting Tool	Taguchi Method	Cutting speed: 50,75,95 (m/min) Feed Rate: 0.05,0.10,0.15 (mm/rev) Depth of Cut :0.25,0.50,0.75 (mm)
23	Srithara et al.	2014	AISI D2 Steel	Coated Carbide Inserts	Not Defined	Cutting speed: 135,215,325 (m/min) Feed Rate: 0.050,0.102,0.159 (mm/rev) Depth of Cut :0.2,0.4,0.6 (mm)
24	Meddour et al.	2014	AISI 52100	Ceramic Tool	RSM ANOVA	Cutting speed: 100,150,200 (m/min) Feed Rate: 0.08,0.11,0.14 (mm/rev) Depth of Cut :0.05,0.15,0.25 (mm) Nose raidus :0.8,1.2,1.6
25	Das et al.	2015	AISI 4140	Coated Ceramic Inserts	RSM ANOVA	Cutting speed: 100,170,240 (m/min) Feed Rate: 0.05,0.10,0.15 (mm/rev)

26	Ferreira et al.	2016	AISI H13	Ceramic Cutting Tool	ANOVA	Depth of Cut :0.1,0.20.3 (mm) Cutting speed: 80,160,240 (m/min) Feed Rate: 0.05,0.10,0.25, (mm/rev) Cutting Length: 25 (mm)
27	Celik et al.	2016	Titanium alloy Grade 5	PVD & CVD Coated Tool	Not Defined	Cutting speed: 30,60,90 (m/min) Feed Rate: 0.052,0.104,0.162, (mm/rev) Depth of cut: 1,1.5,2 mm Cutting Length: 40,80,120 (mm)
28	Addona and Raykar	2016	OHNS Steel	WNMG 06 04 08 MT, WNMG 06 04 12 MT (Conventional Inserts) and WNMG 06 04 08 WT, WNMG 06 04 12 WT (Wiper Geometry)	Taguchi Method	Cutting speed: 96,01,50,01,800 (rpm) Feed Rate: 0.08,0.15,0.2 (mm/rev) Depth of Cut :0.1,0.3,1.5 (mm) Nose radius :0.8,1.2 (mm)
29	Zhao et al.	2017	AISI52100 Steel	CBN Tool With nominal edges (20,30,40)	Not defined	Cutting speed: 12,01,60,200 (m/min) Feed Rate: 0.08 (mm/rev) Depth of Cut :0.1 (mm) Edge radius :20,30, 40 (µ m)
30	Maity and Pardhan	2018	Ti-6Al-4V	MT-CVD	Taguchi L27	Cutting speed: 43,73,124 (m/min) Feed Rate: 0.04,0.08,0.16

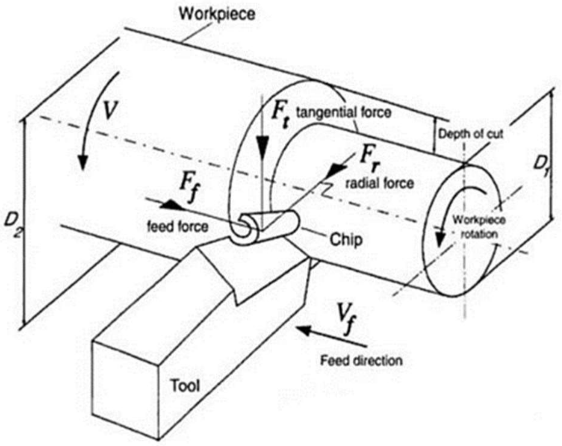
(mm/rev)
Depth of Cut :0.4,0.8,1.6
(mm)

Prasad et al. [16] found with the increase in the feed, the value of surface roughness is increasing. The depth of cut does not have significant influence but the values of surface roughness are varying non -linearly with the increase in the variation of feed rate. It was also observed that among all the process parameters a strong interaction was there. Kaewkuekool et al. [17] concluded that the surface increase with the increase in feed rate. Feed rate is the most significant factor that influences the surface roughness. Depth of cut is the least significant factor and it has not been considered in the equations. Chavoshi and Tajdari [18] conducted experiments for the surface roughness modelling during hard turning. It concluded that there is a significant effect of hardness on surface roughness. The surface roughness decreases with increase in hardness. Asilturk and Akkus [19] determined the effect of cutting parameters on surface roughness in the hard turning. The effects of cutting speed,feed rate and depth of cut were examined and it was concluded that there is negligible effect of speed and depth of cut on the surface roughness and depth of cut plays a vital role at the 95% reliability level . Saini et al. [20] studied the influence of cutting parameters on the surface roughness. It concluded that the depth of cut has less significant influence on the surface roughness. Surface roughness is mostly influenced by the feed rate which is followed by the cutting speed and the tool nose radius. It was stated that the better surface finish the feed rate should be at the low level of the experimental range and the speed and nose radius at the higher level. Hessainia et al. [21] concluded that the cutting speed has the maximum influence on the surface roughness of the material. Feed rate also contributes to the surface roughness significantly. Rao et al. [22] reported the significance of machining parameters on the surface roughness. It investigated that the depth of cut has less significant effect on the evolution of the surface roughness and also there is no significant effect of the interaction of either of the parameters on the surface roughnessSrithar et al. [23] carried out experimental analysis for the investigation of surface roughness and concluded that the surface roughness decreases with the increase in the cutting speed. When the depth of cut and the feed rate are gradually increased, the surface roughness also increases. The result comes out that the feed rate is the most controlled parameter to influence the surface roughness. Meddour et al. [24] reported that at small feed rate and high nose radius, the best surface roughness is obtained and also its inverse stands true. Das et al. [25] investigated that the surface roughness is primarily effected by the feed rate and the trend is followed by the cutting speed. Depth of cut has a negligible effect and the cutting speed has a negative effect on the surface roughness. Ferreira et al. [26] stated that if the multi radii geometry is used, it leads to a better surface finish and the cutting speed was found to be the least effecting factors of all. When the experimental and predicted results were compared, then the feed rate was found go of most consideration for the existing difference. Celik et al. [27] performed an investigation of cutting parameters effect on the surface roughness and reported that surface roughness resulted at the low range of the cutting parameters was better than that at the high range. Addona and Raykar [28] used wiper insert geometry to analyse the surface roughness. Feed is the most significant factor for the surface roughness. After this the depth of cut and the type of insert are found to be statistically significant. Zhao et al. [29] showed that the actual values of the cutting edge radius and the nominal radius have a noticeable difference. When the edge radius is increased, the variation of the edge radius becomes smaller and the edge radius distribution is closer to that of the nominal values. Maity and Pradhan [30] carried out the experiment in which the cutting parameters speed, feed and depth of cut are varied with the three levels. The most influencing cutting variable to affect the surface roughness is the cutting speed.

2.2 CUTTING FORCES

The cutting forces in turning can be resolved into the following three components as shown by the figure below:

1. Feed force
2. Tangential force
3. Thrust force



Feed force, which is also known as axial force acts in the direction of feed.

Tangential force is the force which acts in the direction of the cutting velocity vector. Power consumption in this is more as compared to the feed force.

Radial force pushes the tool away from the work piece and acts in the radial direction.

The cutting forces need to be minimized during the hard turning and hence various approaches are made by different researchers.

Effects of machining parameters on cutting forces

I. Lazoglu et.al [31] to investigate the mechanical and thermal loads during turning of 51CrV4 with hardness of 68 HRC by a CBN tool. The shear flow stress, shear and friction angles are determined from the orthogonal cutting tests. The result shows that cutting force coefficients are obtained from the orthogonal to oblique transformations. Qian and Hossan [32] studied the effects of cutting parameters on cutting forces during the hard turning of various hardened materials. It reported that the cutting forces show an increasing trend with the increase in the speed, feed, tool nose radius, negative rake angle and the workpiece hardness. Lalwani et al. [10] conducted an experiment to investigate the effects of cutting speed, depth of cut and feed rate on cutting forces. It is concluded that the feed force is mostly influenced by the depth of cut and the thrust force and the cutting force are influenced most by the feed rate and the depth of cut. Interaction between the fed and the depth of cut is the secondary factor to contribute to the cutting forces. Sharma et al. [11] used the neural network to investigate the effects feed, depth of cut, speed and approaching angle on cutting forces. It was investigated that with the increase in depth of cut, feed and approaching angle the cutting forces tend to increase. The passive angle increase with increase in the depth of cut, speed and feed while decreases with the increase in the approaching angle. Feed force is highly influenced by the depth of cut and also shows an increasing trend for all the parameters used.

Table: Cutting Force

S.NO	AUTHOR	YEAR	MATERIA L	CUTTING TOOL	MOD. TECH	PARAMETERS
31	Lazoglu et al.	2006	Hardened steel	CBN	Finite eleme nt Metho ds	Cutting speed 90-140 m/min, Radial Depths of cut 60-120 µm, Feed Rate 0.01-0.08 mm/rev
32	Qian et al.	2007	AISI 52100, D2, H13, AISI 4340	CBN	Not Define d	Cutting speed: 140,180,240 (m/min) Feed Rate: 0.15,0.3,0.45,0.6

						(mm/rev) Depth of Cut :0.2 (mm) Edge Radius : 0.02,0.06,0.1,0.2 (mm)
10	Lalwani et al.	2008	MDN250 steel	Coated Ceramic tool.	RSM	Cutting speed: 55,74,93 (m/min) Feed Rate: 0.04,0.08,0.12 (mm/rev) Depth of Cut :0.1,1.5,0.2 (mm)
11	Sharma et al.	2008	Adamite	Coated Carbide Inserts	Neural Network	Cutting speed: 36.6,51.5,81.7,126.6,196 (m/min) Feed Rate: 0.1,0.17,0.27,0.13,0.21 (mm/rev) Depth of Cut :0.3,0.6,0.9,1.5 (mm) Approaching Angle: 45,60,75,90
33	Fnides et al.	2008	AISI H11	Mixed Ceramic	Not defined	Cutting speed: 125, 250(m/min) Depth of cut: 0.15, 0.30(mm) Feed rate: 0.08, 0.16(mm/rev)
34	Stanimir et al.	2008	RUL1V Steel	Mixed Ceramic Inserts	Not defined	Rake angle: -6…-50^{o} Flank wear: 0, 0.1, 0.2, 0.3, 0.4(mm) Cutting speed: 40, 80, 120(m/min)
35	Souza et al.	2009	Grey cast Iron	Ceramic Tool (Silicon Nitride)	Not Defined	Cutting speed: 180,240,300,360,420 (m/min) Feed Rate: 0.12,0.23,0.33,0.33,0.40,0.50 (mm/rev) Depth of Cut :1.0

						(mm)
36	Bouchelaghem et al.	2010	AISI D3	CBN Inserts	Not Defined	Cutting speed: 85-310 (m/min) Feed Rate: 0.08-0.16 (mm/rev) Depth of Cut :0.5 (mm)
37	Fnides et al.	2011	AISI H11	Mixed Ceramic tool	RSM	Cutting Speed: 90, 120, 180 (m/min) Feed rate: 0.08, 0.12, 0.16 (mm/rev) Depth of cut: 0.15, 0.30, 0.45(mm)
38	Bermingham et al.	2011	Titanium Grade 5		Not Defined	Cutting speed: 125 (m/min) Feed Rate: 0.15,0.20,0.36 (mm/rev) Depth of Cut :1.1,2.0,2.7 (mm) M.R.R : 48.61,48.53,48.69 (^{cm3}/min)
39	Aouici et al.	2012	AISI H11	CBN	RSM	Cutting speed: 12,01,80,240 (m/min) Feed Rate: 0.08,0.12,0.16 (mm/rev) Depth of Cut :0.15,0.30,0.45 (mm) Work piece Hardness : 40,45,50 (HRC)
40	Bartarya and Choudhury	2012	EN31 Steel	CBN	ANOVA	Cutting speed: 16,72,04,261

						(m/min) Feed Rate: 0.075, 0.113, 0.15 (mm/rev) Depth of Cut :0.1,0.15,0.2 (mm)
41	RAO at el.	2013	AISI 1050 Steel	Ceramic Cutting Tool	Taguchi Method	Cutting speed: 50,75,95 (m/min) Feed Rate: 0.05,0.10,0.15 (mm/rev) Depth of Cut :0.25,0.50,0.75 (mm)
42	Meddour et al.	2014	AISI 52100	Ceramic Tool	RSM ANOVA	Cutting speed: 10,01,50,200 (m/min) Feed Rate: 0.08,0.11,0.14 (mm/rev) Depth of Cut :0.05,0.15,0.25 (mm) Nose radius :0.8,1.2,1.6
43	Basavarajappa et al.	2014	AISI 4340	Coated Carbide Tool	Not Define d	Cutting speed: 80,110,200,260 (m/min) Feed Rate: 0.06,0.10,0.14,0.18 and 0.26 (mm/rev) Depth of Cut :0.3,0.6,0.81.0 and 1.2 (mm)
44	Chinchanikar and Choudhury	2015	AISI4340	Coated Carbide Tool	RSM	Cutting speed: 100,142,200,265,30 (m/min) Feed Rate: 0.1,0.15,0.2,0.25,00.3 (mm/rev) Depth of Cut :0.5,1,1.5,2,2.5

						(mm)
45	X.M. Anthony	2015	AISI D2	Multi coated carbide, Cermets and ceramic inserts	ANO VA, Taguc hi	Cutting Speed: 100,140,180 (m/min) Feed rate: 0.1, 0.15, 0.2 (mm/rev) Depth of cut: 0.2, 0.3, 0.4(mm)
46	Zahia et al.	2015	AISI 4140	Ceramic Inserts	RSM ANO VA	Cutting speed: 90,120,180 (m/min) Feed Rate: 0.08,0.12,0.16 (mm/rev) Depth of Cut :0.15,0.30,0.45 (mm)
47	Sankar and Rao	2016	AISI 52100	CBN TOOL	L27 Orthog onal array ANO VA	Cutting speed: 400,650,900 (m/min) Feed Rate: 0.04,0.06,0.08 (mm/rev) Depth of Cut :0.4,0.6,0.8 (mm) Nose radius : 0.4,0.8,1.2 (mm)
48	Korkmaz and Gunay	2018	AISI 420 Martensitic Stainless Steel	Coated Carbide Inserts	Finite Eleme nt Model ling	Cutting speed: 12,01,70,200 (m/min) Feed Rate: 0.12,0.16,0.2 (mm/rev) Depth of Cut :0.3,0.45,0.6 (mm)

Fnides et al. [33] conducted an experiment using mixed ceramic tool to investigate the effects of cutting parameters on cutting forces. It concluded that the tangential force is mostly influenced by the variation in depth of cut. Flank wear also has considerable effect on the cutting forces. It also stated that the surface roughness is sensitive to the feed rate variation and the flank wear Stanimir et al. [34] concluded that the low value of flank wear and negative rake angles are justified by the increase in the forces. The solution for decreasing the cutting forces is the tilt in the worn turning tool so that the flank wear is increased. Souza et al. [35] investigated the machining effects of cutting forces and concluded that after a certain speed the cutting forces tend to decrease. The cutting force is the highest among all and is always greater than the thrust force. At the higher feed rate all the three forces increase with the increase in the feed rate. Bouchelaghem et al. [36] concluded that when the flank

wear of the CBN tool increases, it leads to the increase in the cutting forces. Radial force is the most dominating force component which is followed by the axial force and the tangential force is the least dominating and less sensitive to the tool wear evolution. Depth of cut tend to increase the cutting forces. Fnides et al. [37] determined a cutting force model during hard turning of material. It concluded that the cutting forces are highly influenced by the variation of depth of cut. Feed rate is the second most prominent factor affecting the cutting forces. Bermingham et al. [38] made observations on the cutting force in the cryogenic machining and found that cutting forces were reduced by applying the cryogenic coolant due to the presence of the flank nozzle which provided lubrication on flank face. When the cryogenic coolant was applied it was noted that the values of the thrust were always the highest. No significant change was seen in the feed force during the cryogenic cooling. Aouici et al. [39] experimentally investigated the effects of the cutting speed, feed rate and the depth of cut on the cutting forces during the hard turning. The investigation showed that the depth of cut influenced the feed force and the cutting force strongly and the cutting speed had
very small influence. The predicted results had good agreement with the experimental results. Bartarya and Choudhury [40] developed a force prediction model during hard turning. Results show that the cutting forces fairly depend on the machining parameters. Depth of cut is the most influential parameter which affects all the three forces. After this the feed follows and the speed is the parameter which influences the least. The response surface analysis were a bit contrary and showed that with the increase in the speed the forces first decrease and then increase. Rao et al.
[41] investigated the influence of cutting speed, feed rate and depth of cut on the cutting forces and concluded that depth of cut has significant influence on the cutting forces and the interaction of all the three parameters also influences the evolution of the cutting forces. Meddour et al.
[42] concluded that the cutting force components are most significantly influenced by the depth of cut and feed rate contributes small. Tool nose radius effects thrust force only. The interaction of cutting speed and depth of cut is significant for the feed force. Basavarajappa et al. [43] analysed the cutting forces using the multi-layered cutting tools. The results show that the major force is the thrust force which is followed by the cutting force and the feed force. With the increase in the feed rate and the depth of cut the cutting force increases but decreases with the increase of the cutting speed. The most prominent parameter to effect the cutting force is the feed rate followed by the depth of cut. To minimize the cutting forces the combination of low feed rate and low depth of cut with high speed is recommended. Chinchanikar and Choudhury [44] considered the tool wear effect for cutting force modelling during the turning of the hardened material using the multi-layer coated carbide tools. The results showed that the forces induced by the flank wear only are affected by the amount of wear and cutting conditions like depth of cut.

X.M. Anthony [45] analysed the cutting forces and chip formation morphology during hard turning. It concluded that cutting forces are considerably effected by the depth of cut and then the cutting speed follows. Nose radius and cutting angles also contribute to the cutting force generation. Zahia et al. [46] proposed the RSM technique to predict and optimise the cutting forces based on cutting speed, depth of cut and feed rate. Findings report that the forces increase with the increasing hardness of the material. Linear increase is there in the cutting forces as the depth of cut and the feed rate increase. The factors that have the highest influence on the cutting forces are the feed rate and the depth of cut. Shankar and Rao [47] concluded that the forces increase linearly with the increase in all the parameters but the rate of increment varies for individual parameter. Most of the contribution in turning is as in the sequence, tool nose radius, depth of cut, speed and feed rate. Nose radius is the most controlled parameter. Korkmaz and Gunay [48] did the finite element simulation of cutting forces in turning. Johnson Cook material model was used for the simulation of the forces. Results show that the cutting speed has less significant effect on the cutting forces. Depth of cut has the major influence and the feed rate follows. The minimum forces can be obtained by optimising the parameters.

2.3 RESIDUAL STRESSES

After machining processes, the work piece material releases the thermo mechanical load on its top because of the machining, but all of the energy cannot be retrieved. Some energy is used in the plastic deformation, which causes the material to show some stresses, particularly at its free ends of the surface. These stresses which reside in the material after the removal of loading are known as residual stresses. Residual stresses which are in the machined surface layers are influenced by the cutting tool, work material, cutting parameters (cutting speed, feed and depth of cut) and contact conditions of the tool/chip and tool/ work piece interfaces. Tool geometry has substantial effects on the cutting process and the residual stresses, as it influences cutting forces, residual stresses, and the surface integrity. The method implemented to calculate the near surface residual stresses and strains induced by high speed machining consists of replicating the residual stress and strain generation mechanisms in metal milling by simulating the both distinctly [53]. In hard turning, the difference of surface and in-depth residual stresses significantly rises, up to 3.8 times, with a higher depth of cut and the usage of several passes; but, this trend is less important for surface grinding. When residual stresses are exist in a component, they can have positive or negative impact on the behaviour of the components in service as the principal of superposition is applied to any stress developed by external loads. Cracking or twisting of the component after quenching, dimensional variation during machining, and grain boundary attack from corrosion are some of the negative impacts of residual stresses. It is a general consent among researchers that moderate grinding conditions usually develop compressive residual stresses, while aggressive grinding conditions lead to the generation in tensile residual stresses. To guarantee the elimination of any damaged layers due to thermal effects and residual stresses, every specimen is etched and measured for residual stresses using the method of X-ray diffraction [54]. It has been observed that the surface machined with the curved inserts has better surface finish than that machined with the quadrilateral inserts, while the residual stress produced with the curved inserts is more compressive than that produced with the quadrilateral inserts [63]. The tool wear affects the cutting zone temperature and residual stresses generated on the machined surface [13]. More cutting forces and high temperatures may intensely affect the integrity of surface, often causing the development of high tensile residual stresses in the machined surface [14].

Effect of machining parameters on residual stress

M'Saoubia et al.[49]investigated that if the cutting speed is increased it leads to a greater variation in the surface residual stress but the increasing feed rate has negligible effect on residual stress. It is also found that the thickness of tensile layer decreases with cutting speed but increases with feed rate. Rech and Moisan [50] investigated that the external residual stresses increase with the economical cutting conditions. Feed rate did not affect the residual stresses significantly in the deep sub surfaces. Compressive residual stresses were induced when machining was done at low cutting speed and low feed rate. B.B. BARTHA et.al [51] to study the wear performance of AISI 52100 bearing steel the microstructure, surface roughness, residual-stress field, and loading conditions from each wear test were used to develop the process-performance model. The result shows that the applied normal loads affected the surface roughness, residual stresses, and, in turn, the wear performance of the material.

Table: Residual Stress

S.NO	AUTHOR	YEAR	MATERIAL	CUTTING TOOL	MOD. TECH	PARAMETERS
49	M'Saoubia et. Al	1999	AISI 316L	Coated and Uncoated Tungsten carbide tool.	X-Ray Diffraction	Cutting Speed : 75- 200 (m/min) Feed Rate :0.1-0.3 (mm/rev) Width of Cut : 4-6 (mm)
50	Reach and Moisin	2002	Case-hardened 27MnCr5 Steel	CBN	Not Defined	Cutting Speed: 50-250 (m/min) Feed Rates: 0.05-0.2 (mm/rev) Depth of Cut: 0.15 (mm)
51	Bartha et al.	2004	AISI 52100	CBN	Not Defined	Cutting Speed : 150 (m/min)

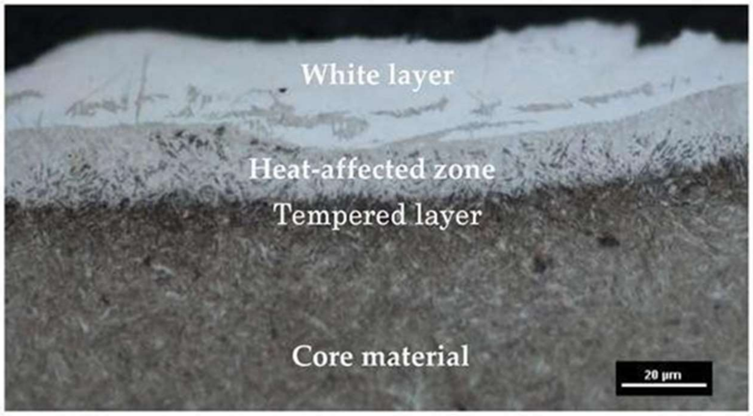
			Steel	Ceramic		Feed Rate : 0.05-0.2 (mm/rev) Normal Loads 50- 200 (N)
52	Ding et. al	2011	AISI H13 Steel	PCBN	Single Factor experiment method	Cutting speed : 80-240 (m/min): Feed rate : 0.05-0.25 (mm/tooth) Radial Depth of Cut: 0.6–3.0 (mm) Axial depth of cut : (mm) 0.8-4.0
53	Wu and Li	2014	Alimimnum alloy 7075	CBN	X-ray Differation FEM	Depth of Cut (mm) : 0.5-2 Width of Cut(mm) : 10 Rotation speed(r/min) 10000-20000, Feed Rate(m/min) 4-25
54	Martell et. al	2014	AISI 1053 steel	CBN	Not defined	Feed Rate : 0.004 (in/rev) Surface Velocity : 400 ft/min Rake Angle : -5^0

T. C. Ding et.al [52] to investigate the effects of cutting parameters (cutting speed, feed, radial depth of cut, and axial depth of cut) on surface roughness and residual stress during end-milling AISI H13 steel with the different geometrical inserts, i.e., the parallelogram inserts and the round inserts. The result shows that the surface milled with the round inserts has far more superior surface finish than that milled with the parallelogram inserts. Wu and Li [53] to study the effects of machined surface quality and cutting parameters on residual stress distribution. The cutting residual stress of 7075 aluminum alloy is experimentally and numerically investigated by an X- ray diffraction technique and an elastic–visco plastic FEM formulation. The results show that cutting residual stresses increase with machined surface roughness. Joseph J et.al [54] conducted an experimental work on the surface and in-depth residual stresses in hardened AISI 1053 steels machined using hard turning and surface grinding processes. Cubic boron nitride (CBN) cutting tools and X- ray diffraction measurement of residual stress were used in this process. In this process compared with hard turning, surface grinding produces higher magnitudes of average compressive residual stresses, it also generates up to 14 times higher scattering of residual stresses. The result is show that the highly compressive average residual stress will be offset by highly scattered.

2.4 WHITE LAYERS

Griffiths described a white layer as a hard surface layer formed in a variety of ferrous materials under a variation of conditions, and this layer resists etching compared to the bulk material [12, 13].

This surface layer was found to be of high hardness compared to the bulk and featureless when detected under a low power microscope. Thickness values of white layer produced in all the experiments, with carbide and CBN tools, when VBmax reaches 200 mm, varied from 0.4 mm to1 mm. It is very fascinating to note at this time that during turning the interrupted and fully interrupted surfaces under all the situations with both the tools no white layer was found on the surface of the machined workpiece. The first reason being that with interrupted turning, the tool workpiece contact surface is not continuous; thus the heat propagation through the work piece surface is delayed by interruptions. The second reason is that the rotation of interrupted/fully interrupted surface work piece produces an air flux through the spaces on the surface, which helps in keeping the work piece and tool at lower temperature.



With increase in cutting speed by both the tools, the thickness of the white layer generated increases. Hard machining has some technical limitations comprising inadequate surface finish and dimensional accuracy and generating white layer (WL) which is categorized as a damage of the machined components. Consequently, in many cases exceptional abrasive operations such as belt grinding, finishing grinding or super finishing are applied to increase surface finish and remove WL created by hard turning (HT).

Effect of machining parameters on white layer

Aramcharoen et.al [55] to investigation the effect of CrTiAlN and CrTiAlN+ MoST and high cutting speeds on white layer formation in machining for tool steel H13 (57 HRC) was examined after turning at a conventional and high cutting speed. Coated tools resulted in lower work piece and tool temperatures. The coated tools resulted in reduced and also more homogeneous

hardening effects compared to the uncoated tool. GUO et.al [56] to investigate the effect of white layer on frictional and wear performance on AISI 52100 steel using worn cutting tool or grinding wheel. Dry and lubricated sliding contact tests for white layer surfaces by turning and grinding were carried out at different load levels on a ball-on-disk tribometer with real-time monitoring of the wear process using an acoustic emission sensor. The results show that the existence of a turned white layer slightly decreases the coefficient of friction (COF), while a ground white layer significantly increases COF at dry conditions.

Table: White Layer

S.NO	AUTHOR	YEAR	MATERIAL	CUTTING TOOL	MOD. TECH	PARAMETERS
55	Aramcharoen et. al	2007	Hardened H13 Tool Steel	Coated Carbide Tool	Not defined	Cutting speed : 200-800 (m/min) Depth of Cut : 0.1 (mm) Feed Rate : 0.3

						(mm/rev)
56	Guo and Waikar	2009	AISI 52100 Steel	Worm Cutting Tool Grinding Wheel	Taylor Hobson Talysurf CLI 2000 3D surface profiling system	Sliding speed : 30 (mm/s) Normal Load :10-50 (N) Test time : 2h Dry test : 3 Lubricated test : 3
57	Dogra et. al	2011	AISI H11 Steel	CBN Uncoated Carbide	Not Defined	Cutting Speed : 97-180 (m/min) Feed Rate : 0.6-0.11 (mm/rev) Depth of Cut : 0.15 (mm)
58	Dogra et. al	2012	AISI 8620 Steel	CBN Coated carbide	Not Defined	Cutting Speed: 90-190 (m/min) Feed Rate : 0.08 (mm/rev) Depth of Cut : 0.15 (mm)
59	Zhang et. Al	2011	AISI H 13 Steel	Coated Carbide	Single-Factor Experimental Design	Cutting speed : 80-240 (m/min): Feed rate : 0.05-0.25 (mm/tooth) Radial Depth of Cut: 0.6–3.0 (mm) Axial depth of cut : (mm) 0.8-4.0

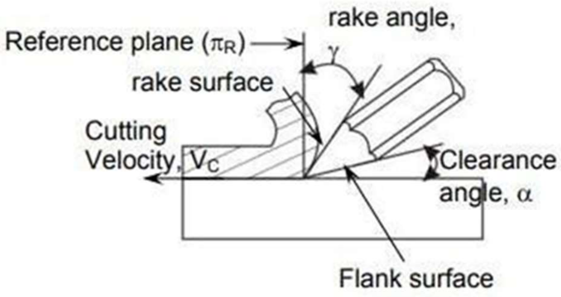
Dogra et.al [57] to investigate the compression between cubic boron nitride (CBN) and coated carbide and cryogenically treated coated/uncoated carbide inserts in terms of flank wear, surface roughness, white layer formation, and micro hardness variation under dry cutting conditions for finish turning of hardened AISI H11 steel (48–49 HRC). Results showed that tool life of carbide inserts decreased at higher cutting speeds. The surface roughness achieved under all cutting conditions for coated-carbide treated / untreated inserts was comparable with that achieved with CBN inserts and was below 1.6 µm. Dogra et.al [58] to investigate the surface integrity and tool life of CBN and Carbide tools are used in the AISI 8620 steel with hardness of 49–50 HRC. The results indicated that the longest tool life was achieved with CBN tool as comparison to coated carbide tool. Zhang et.al [59] to investigate the white layer formation and its mechanical and physical properties generated in high-speed machining of hardened steel in terms of surface integrity. The results will be indicate a useful guide to control or minimize the white layer formation and, more significantly, to promote the application of hard milling technique in die and mold industry.

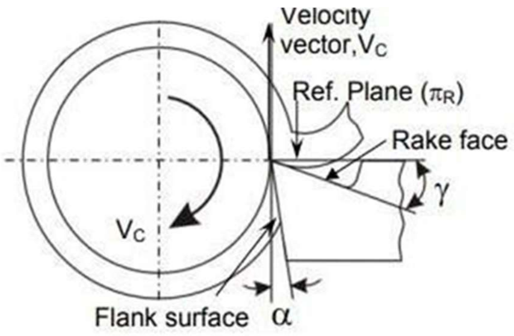
2.5 TOOL GEOMETRY

The designation of the cutting part shape of the tool is usually termed as the tool geometry. The widely used designation systems for tool geometry are as described

1. American Standards Association system (ASA) or American National Standards Institute (ANSI)
2. Orthogonal Rake system (ORS)

Material and geometry of the cutting tools mutually play very significant role on their performances in attaining efficiency, effectiveness and overall economy of process of machining. The tem tool geometry is mainly refers to some definite angles or slope of the prominent faces and edges of the tools at the cutting point. The most significant angles for the cutting tools are rake angle and clearance angle [NPTEL]. Rake angle and the clearance angle for the turning operation are as shown in Fig. below.





Rake angle (γ): It is the angle of inclination of rake surface from the reference plane.

Clearance angle (α): It is the angle of inclination of clearance or flank surface from the machined surface. Rake angle is provided so that the chips can flow easily and overall machining can be done with ease. Rake angle exists in positive, or negative or even zero form.

Clearance angle is basically provided for avoiding the rubbing of the tool flank with the surface being machined which leads to the loss of energy and damage to both surface of job and tool. Therefore, clearance angle is a necessity and must be positive.

Effect of machining on tool geometry

Singh and Rao [60] to study the effect of the tool geometry (effective rake angle and nose radius) and cutting conditions (cutting speed and feed) on the surface finish during the hard turning of the bearing steel. The result shows that the variation of the surface roughness with respects the parameters variables. Thamizhmanii et.al [61] to study the surface roughness produced by turning process on hard martensitic stainless steel by Cubic Boron Nitride cutting tool. The work piece material was hard AISI 440C martensitic stainless steel. The result show that surface roughness increases with increasing feed rate and a large tool nose radius. C.

Richard Liu [62] to investigate the effect of the cutting speed, feed rate and rake angle on chip morphology transition, a thermo mechanical coupled orthogonal (2-D) finite element (FE) model and to determine the effects of tool nose radius and lead angle on hard turning process. The results suggest that chip morphology transits from continuous to saw-tooth chip with increasing feed rate and cutting speed, and changing a tool's positive rake angle to negative rake angle.

Table : Tool Geometry

S.NO	AUTHOR	YEAR	MATERIAL	CUTTING TOOL	MOD. TECH	PARAMETERS
60	Singh and Rao	2007	AISI 52100 Steel	CBN Ceramic	RSM	Cutting Speed : 100-200 (m/min) Feed Rate : 0.10-0.32 (mm/rev) Nose Radius : 0.4-1.2 (mm) Effective Negative Rake Angle : 6-26 (deg)
61	Thamizhmanii et. al	2008	AISI 440C Martensitic Stainless Steel	CBN	Not Defined	Nose Radius : 0.40 (mm) , Cutting Speed : 125-225 (m/min) Feed Rate : 0.125 (mm/rev) Depth of

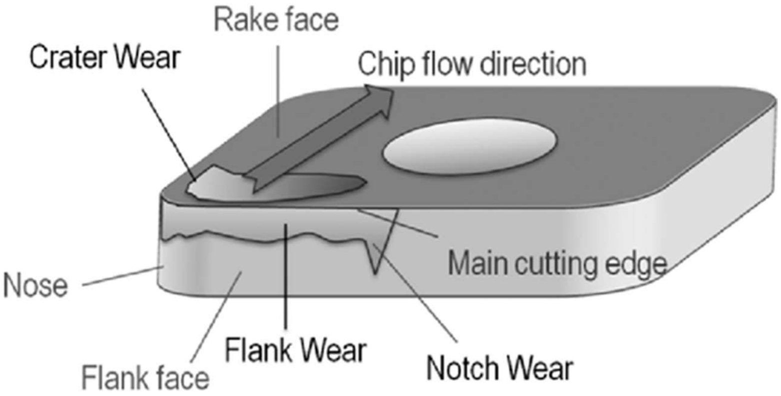
62	C. Richard Liu	2011	AISI 52100 Steel	PCBN	FEM	Cut : 0.50 (mm) Cutting Speed : 1.0-3.0 (m/s) Feed Rate : 0.035-0.25 (mm/rev), Rake Angle : –(5-30) (deg)
63	Ding et. al	2011	AISI H13 Steel	PCBN	Single Factor Experiment Method	Cutting speed v(m/min) 80-240, Feed (mm/tooth) 0.05-0.25, Radial depth of cut (mm) 0.6-3.0, Axial depth of cut (mm) 0.8-4.0
64	Raja Kountanya	2011	AISI 52100	PCBN	CAD	Cutting Speed : 120 (m/min) Feed Rate : 0.152-0.203 (mm/rev) Depth of Cut 0.152-0.203 (mm) Corner Radius 0.8 (mm)
65	Batish et.al	2014	EN31, SAE8620 and EN9 tool steels	CBN	Genetic algorithm and artificial neural network (ANN)	Cutting speed 75-150 (m/min) Feed Rate : 0.03-0.1mm/rev, Machining force 6.321- 94.012N
66	Bougharriou et. al	2014	AISI 1042 and UNS S32760	Carbide Tool	Not Defined	Cutting Speed : 450 (rev/min) Feed rate : 0.08 (mm/rev) Depth of Cut : 0.5 (mm) Corner Angle 45-135 (deg)
67	Zhi Chen et.	2014	High Carbon	Wire	Taguchi	Major axis (μm) 39.5- 86.1 Minor axis (μm) 15.8-34.4

al	And High Chromium Alloy Steel	Electrode	Method	$x0$ (μm) 18.8 0 −27.8 Wire lag δ (μm) 30.4 - 30.9 Error (μm) 26.5 - 8.6

Ding et.al [63] to investigate the effects of cutting parameters (cutting speed, feed, radial depth of cut, and axial depth of cut) on surface roughness and residual stress during end-milling AISI H13 steel with the different geometrical inserts, i.e., the parallelogram inserts and the round inserts. The result shows that the surface milled with the round inserts has far more superior surface finish than that milled with the parallelogram inserts. Raja Kountanya [64] to study the surface of the cutting tool was constructed using one angular scalar specifying location on the corner radius and leading/trailing edges and another non-dimensional scalar for specifying location on the relief, edge-hone, chamfer and tool-top. Results indicate that no difference between conventional 2D and the new 3D modelling was found. Batish et.al [65] to study to the effect of different process parameters on machining forces, surface roughness, dimensional deviation and material removal rate during hard turning of EN31, SAE8620 and EN9 tool steels. Feed rate followed by hardness, cutting speed and nose radius-depth of cut significantly affected machining forces whereas feed rate had the largest effect on surface roughness. Bougharriou et.al [66] to investigate the analytical modelling was performed to predict the surface profile obtained by turning and burnishing after turning operation. The AISI 1042 and UNS S32760
material and carbide tool are used in this study. The result shows that the surface profile depends on several parameters such as cutting parameters, tool geometry, work piece and tool materials, and vibration parameters. Zhi Chen et.al [67] to investigate the effect and influence trends of control factors on corner error. To analyze and reduce the geometrical inaccuracy of rough corner cutting; the major causes of corner inaccuracy (45◦, 90◦ , and 135◦ angle) are analyzed in detail, an elliptic fitting method is proposed to describe the trajectory of wire electrode centre, and the feasibility of model is confirmed by measuring the corner edge of work piece. The result is show that the confirmatory experiments, more than 50 % decrease of corner error has been achieved at 5 mm/min cutting feed rate by the optimized control factors combination in rough corner cutting.

2.6 TOOL WEAR

The variation of shape of the tool from its original form, throughout cutting, resulting from the steady loss of tool material is termed as tool wear. In any machining operation the tool is exposed to three different factors which are force, temperature and sliding action caused by relative motion between tool and the work piece. The situation is worsened due to the presence of extreme stress and temperature immediate to the surface of the tool. However, wear occurs during the cutting action, and it will ultimately result in the cutting tool failure. Once the tool wear reached a definite amount, the tool or active edge needs to be replaced to assure the preferred cutting action. This will consequence in loss of production because of the machine down-time, in addition to the loss of replacing or mending the tool .Thus study of tool wear is very important from the stand point if performance and economics. The major types of tool wear are flank wear, crater wear, nosewear and notch wear as shown in Fig.



Flank wear

Flank wear is caused due to the rough action of discontinuities such as remains from built up edges etc. It damages out the side and end flank of the tool. It occurs at the interface of the tool work-piece. This wear prevails at the lower speeds. Flank wear can be checked in production by inspecting the tool or by following the change in size of the tool or machined part. Flank wear is calculated by the width of the wear land, VB. If the value of VB goes beyond some critical value (VB > 0.5~0.6 mm), the tool failure may be caused by excessive forces.

The following may be the reasons for flank wear

- The friction is present at the tool work interface.
- The rough action of the powdered particles present at the tool workpiece interface.
- The diffusion wears, reason being the atomic attraction between workpiece and the tool the tool material atoms will be diffused and deposited over the workpiece which is called as diffusion wear.

Crater wear:

Crater wear usually occurs in machining of ductile material due to the abrasion and diffusion of metal at the tool face. It is occurs at face at a shorter distance from cutting edge. This wear dominates at the higher speeds.

Crater wear disturbs the mechanics of the operation by increasing the original rake angle of the tool and resulting in, making cutting easier.

The following are the reasons of crater wear

- The friction is present at the tool chip interface,
- The abrasive actions of microchips existing at the chip-tool interface.
- The abrasive action of the fragments of the built up edges formed at the chip-tool interface.

Effects of machining parameters on tool wear

Endres and Kountanya [68] studied the tool wear effects of unhoned and honed tools. The results for the up sharp tools showed that the effect of corner radius on wear is clearly seen which reduce the tool wear at the lead edge and the tip. It is also shown that the wear has less sensitivity to the feed when compared to the corner radii. In case of honed tools small honed tools showed the similar results as in case with the up sharp tools and the large honed tools appeared to have a minimising corner radius in the wear which later shifts to the higher levels of wear. Liu et al. [69] determined the effect of the workpiece hardness on the tool wear characteristics. It concluded that at the critical hardness and highest speeds, the PCBN gets worn out which indicate that it is not suitable for use near the critical hardness. Chou and song [70] investigated that the tool wear is developed with time. Flank wear shows a linearly increasing behavior. The tool nose radius in the range of 0.8-0.24 mm does not have significant effect on the tool wear. J. M. Zhou et.al [71] To study the flank wear of a CBN tool is monitored by feature parameters extracted from the measured passive force, by the use of a force dynamometer. The feature parameters include the passive force level, the frequency energy and the accumulated cutting time. An ANN model was used to integrate these feature parameters in order to obtain more reliable and robust flank wear monitoring. The result shows that good correlation was also found between the cutting force and the tool wear, the passive force exhibits a higher sensitivity to the tool wear among the three force components, which suggests the feasibility of tool wear monitoring by monitoring the passive force. Huang and Liang [72] proposed a CBN tool crater wear model for hard turning and summarised the main mechanisms for wear as abrasion, adhesion and diffusion. The information required for the prediction of the tool crater wear are tool geometry, cutting condition and tool/workpiece material properties. The main mechanism of the wear is reported as the adhesion over the different ranges of cutting conditions. Poulachon et al. [73] investigated the tool wear mechanism of the CBN tool for various hardened materials. The parameter which influences the tool wear the most is the presence of the carbides in steel microstructure. Tool wear rate is influenced by the increasing cutting speed.

Table : Tool Wear

S.NO	AUTHOR	YEAR	MATERIAL	CUTTING TOOL	MOD. TECH	PARAMETERS
68	Endres and Kountanya	2002	AISI 1040 steel bar	Uncoated Carbide	Not Defined	Cutting speed: 183 (m/min) Feed Rate: 0.022,0.037,0.083 (mm/rev) Depth of Cut :2.5 (mm)
69	Liu et al.	2002	GCr15 Bearing steel	CBN Tool	Not Defined	Cutting speed: 75,110,160,200 (m/min) Feed Rate: 0.08,0.15,0.24 (mm/rev) Depth of Cut :0.25,0.50,0.80 (mm)
70	Chou and Song	2003	AISI 52100	Alumina titanium carbide composite	Not Defined	Cutting speed: 2-3 (m/min) Feed Rate: 0.05-0.6 (mm/rev) Depth of Cut :0.2 (mm)
71	Zhou	2003	100Cr6, 60–62 HRC	DCMW 11T308 (CBN)	Artificial Neural Network	Cutting speed 160 (m/min) Depth of cut 0.05 (mm) Feed rate 0.05 (mm/rev)
72	Huang and Liang	2004	AISI 52100 steel	CBN Inserts	Not defined	Cutting speed: 1.52,2.29 (m/sec) Depth of cut: 0.203,0.102 (mm) Feed rate: 0.076,0.168 (mm/rev)
73	Poulachon et al.	2004	AISI 52100 AISI D2 AISI H11	CBN Tool	Not defined	Cutting speed: 180-230 (m/min) Feed Rate: 0.08, 0.12 (mm/rev) Depth of Cut :0.2 (mm)

74	Tamizharasan et al.	2005	Different Workpiece hardness values over 45 HRC	CBN	Not Defined	Cutting speed: 100,150,200 (m/min) Feed Rate: 0.06,0.10,0.14 (mm/rev) Depth of Cut :0.2,0.3,0.4 (mm)
75	Dhar et al.	2005	AISI 4340 Steel	Uncoated Carbide Inserts	Not Defined	Cutting speed: 110 (m/min) Feed Rate: 0.16 (mm/rev) Depth of Cut :1.5 (mm)
76	Coelho et al.	2006	AISI H13 & AISI D2	Coated Carbide	Not Defined	Cutting speed:1.5-12 m/min Feed speed: 69.5-556.8 mm/min,
77	Costes et al.	2007	Inconel 718	CBN Inserts	Not Defined	Cutting Speed: 50-500 m/mm Feed Rate: 0.2 mm/rev Dpth Of Cut: 0.3 mm
78	Quiza et al.	2008	AISI Steel D2 (HRC 60)	Ceramic Cutting Tools	Taguchi Method	Cutting speed 80-150 m/min Feed 0.05-0.15 mm/rev Time 5-15 min Tool Wear 0.032-333
79	Venugopa et al.	2007	Titanium Grade 5	Uncoated Carbide Inserts	Not Defined	Cutting speed: 70,85,100 (m/min) Feed Rate: 0.2 (mm/rev) Depth of Cut :2.0 (mm) Dry, Wet (soluble oil) and Cryogenic Cooling in
80	Dhara and Kamruzzaman	2007	Aisi 4037	Coated Carbide inserts	Not Defined	Cutting speed: 165, 194, 239 and 264 (m/min) Feed Rate: 0.10, 0.13, 0.16 and 0.20 (mm/rev) Depth of Cut : 1.55 (mm) Dry, wet and

						cryogenic cooling by liquid nitrogen
81	Ghani et al.	2007	AISI H13	CBN TOOL		Cutting speed: 144.26 (m/min) Feed Rate: 0.172 (mm/rev) Depth of Cut : 0.2 (mm) Cutting Length: 85, 170, 255,340 (mm)
82	Grzesik and Zalisz	2008	AISI 5140 (DIN 41Cr4)	Mixed Ceramic tool	Not defined	Cutting speed: 100 (m/min) Feed Rate: 0.04-0.8 (mm/rev) Depth of Cut :0.2 (mm)
83	Saini et al.	2012	AISI H11 Tool Steel	Ceramic Tool	RSM	Cutting speed: 10,01,30,160 (m/min) Feed Rate: 0.05,0.13,0.2 (mm/rev) Depth of Cut :0.1,0.3,1.5 (mm) Nose raidus : 0.4,0.8,1.2
84	Das et al.	2015	AISI 4140	Coated Ceramic Inserts	RSM ANOVA	Cutting speed: 10,01,70,240 (m/min) Feed Rate: 0.05,0.10,0.15 (mm/rev) Depth of Cut :0.1,0.20.3 (mm)
85	Celik et al. (printed 4)	2016	Titanium alloy Grade 5	PVD & CVD Coated Tool	Not Defined	Cutting speed: 30,60,90 (m/min) Feed Rate: 0.052,0.104,0.162,

						(mm/rev) Depth of cut: 1,1.5,2 mm Cutting Length: 40,80,120 (mm)
86	Maity and Pardhan	2018	Ti-6Al-4V	MT-CVD	Taguchi L27	Cutting speed: 43,73,124 (m/min) Feed Rate: 0.04,0.08,0.16 (mm/rev) Depth of Cut :0.4,0.8,1.6 (mm)

Tamizharasan et al.[74] concluded that the flank wear of the tool is negligibly affected by the depth of cut. Mainly the interactions of the transferred layers on wear land and the microstructure between the tools decide the tool performance. Dhar et al. [75] concluded that a reduced tool wear is obtained by using the MQL machining. The reduction in tool wear either improves the tool life or enhances the productivity by allowing the higher feed rate and cutting velocities. Reginaldo Teixeira Coelho [76] to investigate the some aspects of wear and performance when solid carbide coated taps M10 ×1.5 cut hardened AISI H13 and AISI D2. The results indicate the threads on hardened AISI H13 were possible with reasonably low tool wear. Cutting surface presented some indication of small flaws due to the adhered material on the taps. Costes et al.

[77] described the modes of the degradation of the tool. Under the high stress and the temperatures, the workpiece during the machining superficially plasticise itself and the area between the insert and the rake and flank faces get filled with the alloy. No effects of the grain size are shown on tool life. Ramon Quiza et.al [78] conducted an experimental work using ceramic cutting tools, composed approximately of Al2O3 (70%) and Tic (30%), on cold work tool steel D2 (AISI) The models were adjusted to predict tool wear for different values of cutting speed, feed and time, one of them based on statistical regression, and the other based on a multilayer perception neural network. The result is show that in comparing the obtained neural network model with the statistical multiple regressions, the neural network allows more accurate prediction for the tool wear. Dhar and Kamaruzzaman [79] investigated the tool wear under the cryogenic conditions and concluded that the dry machining provided more tool wear and the cryogenic cooling with the liquid nitrogen caused lesser tool wear. Ghani et al. [80] conducted an experiment and also finite element modelling to investigate the tool life and the tool wear behaviour in hard turning. Cutting temperature is the prominent factor in the tool wear. At different cutting speed the tool wear was caused due to the chipping. Tool experience a crater wear at high speeds due the shifting of the maximum temperature and the maximum stress locations near to the cutting edge. Grzesik and Zalisz [81] investigated the wear phenomenon of the mixed ceramic tips during hard turning operations. It was observed that the wear mechanism

for the tool involved the abrasion, fracture, adhesive tacking, plastic flow and the material transfer. Tribochemical effects were also generated in the machining tests. Dogra et al. [82] concluded that the wear resistance of the tool is higher at the smaller grain size. Cryogenic cooling leads to increase the tool life due to the cooling and the lubrication at the cutting zone. Tool life can be increased to some value by increasing the chamfer angle. Saini et al. [83] studied the influence of cutting parameters on the tool wear. It concluded that the cutting speed and nose radius are the parameters which influence the tool wear the most. Due to high pressure and temperature, the flank wear takes place during the hard turning. To get the minimum tool wear the cutting speed should be taken at the low level of experiment range. Das et al. [84] concluded that the flank wear is mostly effected by the cutting speed

and the interaction of the feed rate and depth of cut. Depth of alone does not affect much on the flank wear. Celik et al.
[85] stated that the increase in the cutting parameters such as seep, feed, depth of cut and cutting length lead to increase in the tool wear. At the highest cutting parameter ranges, the tool wear was the highest. Maity and Pradhan [86] experimentally investigated the effects of cutting parameters in which the cutting parameters speed, feed and depth of cut are varied with the three levels. The most influencing cutting variable that effected the tool is the cutting speed.

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