

Review on Effects of Process Parameters in Hard Turning of Steels

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Abstract

The hard-turning process is steadily finding its place in modern manufacturing technology and with advance cutting tool materials it can be applied as alternative machining process to grinding providing a more economical way to finish hard surfaces. The main concerns of hard turning are tooling cost and the effect of process on machinability characteristics. The poor selection of process parameters may cause excessive tool wear and increased surface roughness. Hence there is a need to find the right parameters to achieve the right dimensional accuracy, good surface and maximum material removal rate. This paper reviews the effects of various process parameters such as cutting speed, depth of cut and feed rate on the response parameters such as surface roughness, material removal rate and chip reduction coefficient. Through this study main cutting parameters which affect the turning operation are discussed.

Keywords: Chip Reduction coefficient, Grinding, HRC, Hard turning, MRR, Surface roughness

I. INTRODUCTION

In modern machining industries, the main challenge emerging is the achievement of high quality, in terms of work part dimensional accuracy and surface finish, high production rate and cost saving. Traditionally hardened steels have been machined by grinding process, on the other hand grinding process is time consuming and it applicable to limited range of geometries. Hard turning is basically a turning process suitable for machining parts with hardness exceeding 45 HRc which provides similar surface finish and dimensional accuracy to those achieved in grinding.

A. Hard Turning

Hard turning process is defined as machining of metals with hardness greater than 45 HRc. In Hard turning process a single point cutting tool is used either linearly in the direction parallel or perpendicular to the axis of rotation of the workpiece or along a specified path to produce complex rotational shapes. The main advantage of hard turning is that turning operation is carried out on same machine on which soft turning is done before so there is less setup time is required in finish turning. A proper hard turning process gives surface roughness ranging between 0.4-1.0 micro meters. The starting point of hard turning is the material hardness 47 HRC but regularly hard turning is done on the material having hardness 60HRC and higher. The materials required for hard turning are tool steel, case-hardened steel, bearing steel, Inconel, Haste alloy and other exotic materials are also falling in the category of hard turning.

Hard turning is a technology-driven process and therefore depends on machine and work holding technology. Hard turning requires special tool materials, with high wear-resistant and high hardness at elevated temperatures. The most commonly used as tool materials are: silicon nitrides, sintered carbides, cermets, polycrystalline diamonds, oxide and mixed ceramic, cubic boron nitrides (CBN). Polycrystalline cubic boron nitride is characterized by extraordinary hardness at elevated temperatures and compressive strength with good fracture toughness. Hard turning fits perfectly in machining plants with the latest trends for increasing production flexibility. Ideal candidates for hard turning are complex parts where direction, contour, or multiple diameters require form grinding wheels and number of setups for complete grinding of all surfaces. Hardened steel bearings, gears and axle shafts are already being machined using hard turning. Hard turning has already replaced rough grinding operations of bearing races. Nonfunctional zones such as ODs and side faces are quite often hard finish turned. On a daily basis, parts are being hard turned in the following industry segments: automotive, bearing, marine, punch and die, mould, hydraulics and pneumatics, machine tool and aerospace.

B. Hard turning and Grinding

The traditional method of machining the hardened steels includes rough turning, heat treatment and then grinding process. Recently hard machining emerges as an attractive alternative to conventional grinding due to its potential benefits such as short cycle time, process flexibility, higher material removal rate, good surface finish and less environmental problems as there is negligible use of cutting fluid. Hard turning has several advantages over grinding and some of them are:

- The ability to produce complex geometry in one set up;
- Quality of surface finish produced by hard turning is equivalent to that obtained by grinding;
- Machining can be done without coolant and therefore the process is environmentally friendly;
- The cutting process requires less power and
- The cost of hard turning is cheaper;

II. IMPORTANT PARAMETERS IN HARD TURNING

A. Process Parameters

There are basically three main cutting parameters in turning operation which are feed rate, speed and depth of cut. Although there are other factors which are important to a turning process such as material type, hardness, dimension and type of tool being used, but the main three parameters are the ones one can change to improve the process.

1) Cutting speed

Cutting speed is defined as the speed at which the work moves with respect to the tool. It is usually measured in metres per minute (m/min). Cutting speed changes with change in workpiece diameter even through the spindle speed remains the same. Cutting speed must be chosen wisely as if the cutting speed is too low then tool wears out quickly and if value is high then certain vibrations may occur.

$$v = \frac{\pi D n}{1000} \text{ m/min}$$

Here, v is the cutting speed

D is the initial diameters of workpiece in millimetre (mm) and N is the spindle speed in revolution per minute (RPM)

2) Feed

Feed rate is defined as the distance the tool travels one revolution of the part turned. It is expressed in distance per revolution (mm/rev). The selection of feed rate is the decision which affects the whole process. Tool feed rate greatly impacts the surface roughness of workpiece. The low feed rate gives good surface finish but results in low process speed and high feed rates means rapid wear of cutting tool.

3) Depth of cut

Depth of cut can be defined as the amount of material being removed from the material surface in a single pass. It is expressed in millimeters (mm). Depth of cut varies inversely to cutting speed and high depth of cut results in vibrations, chattering and high tool wear.

B. Performance Parameters

1) Surface roughness

In modern manufacturing industry surface finish emerges as most important quality characteristics which influences the performance of manufacturing process and manufactured products. Surface roughness is imperfections on the surface of materials in form of succession of hills and valleys varying both in height and spacing. The surface finish has direct contact with the functioning of machine parts, load carrying capacity, tool life, and fatigue life, bearing corrosion and wearing qualities. Failure due to fatigue always occurs at sharp corners because of stress concentration at that place. Different requirements demand different types of surface so measurement of surface texture quantitatively is essential. Surface irregularities can be classified into four categories gives as follows: -

- 1) First order- This type of irregularities is arising due to inaccuracies in the machine tool itself and the irregularities produced due to deformation of work under the action of cutting forces and the weight of the material.
- 2) Second order- This order of irregularities is caused due to vibration of any kinds such as chatter marks.
- 3) Third order- If the machine is perfect and completely free of vibrations still some irregularities are caused by machining due to characteristics of process such as feed mark of cutting tool.
- 4) Fourth order- This type of irregularities is arise due to rupture of material during the separation of chip.

2) Material removal rate

Material removal rate (MRR) is defined as the material is removed per unit time. In modern manufacturing industries turning is most common method used to metal cutting because of its ability to remove materials at faster rate with good surface quality. Material removal rate has great significance in metal removal process and is influenced by feed rate and depth of cut. The careful selection of cutting parameters improves the material removal rate which improves the overall productivity of manufacturing process. The material removal rate is calculated by using the equation given below

$$Q = \pi D_{\text{avg}} D F N$$

Where, Q is the material removal rate (mm^3/min)

- D_{avg} is the average diameter of work piece (mm)
- D is the depth of cut (mm)
- F is the feed rate (mm/rev)
- N is the cutting speed (RPM)

C. Chip reduction coefficient

Chip reduction coefficient can be defined as the ratio of chip thickness to undeformed chip thickness. It is also called cutting ratio and is expressed as Greek letter zeta ζ . Chip reduction coefficient greatly impacts the machining process as larger the value of chip reduction coefficient means more chip thickness, which means more efforts of forces or energy is required to accomplish the machining work. It is always desirable to reduce the chip reduction coefficient with sacrificing material removal rate. The degree of thickening of the chip is expressed by

$$\zeta = \frac{a_2}{a_1}$$

Where, ζ is the chip reduction coefficient

$a_1 = f \sin k_r$ is the thickness of undeformed chip

$a_2 =$ chip thickness (mm)

$f =$ feed rate (mm/rev)

$k_r =$ principal cutting edge angle

III. LITERATURE REVIEW ON HARD TURNING

- 1) E.D Derakhshan et al. [2009] investigated the surface roughness of AISI 4140 steel by hard turning using two different grades CBN inserts. Five different work pieces with five different hardness level in the range of 45-65 HRc used. Process parameters of feed rate, depth of cut Cutting speed and hardness level were analyzed to find out that minimum surface roughness of ($R_a=0.207$) was obtained through machining 50 HRc cutting speed of 473 m/min ^[1].
- 2) H.Singh et al. [2011] investigated the effect of various cutting parameters on the material removal rate and surface roughness of EN-8 general purpose steel. Taguchi L16 orthogonal array is used to design the experiment and ANOVA was used to analyse the results. They found out that spindle speed and feed rate were the most significant parameters that provide significant amounts of Material removal rate and surface finish ^[2].
- 3) Samir Khamel et al. [2012] investigated the effects of process parameters like cutting speed, feed rate and depth of cut on tool life, surface roughness and cutting forces in hard turning of AISI 52100 of bearing steel of hardness 60 HRc with CBN tools. Taguchi L27 orthogonal array is used for design of experiment and Analysis of variance (ANOVA) provides that cutting speed has 59.14% effect on reduction of tool life; surface roughness is affected by feed rate at 64.09%. Optimized parameters are cutting speed $V_c=168$ m/min, feed rate=0.08 mm/rev, depth of cut=0.22 mm ^[3].
- 4) H.Aouici et al. [2012] investigated the effects of cutting parameters, workpiece hardness on surface roughness and cutting force components in hard turning of AISI H11 steel with CBN 7020 tool. Three different hardness levels of 40, 45, 50 HRc were selected as input parameters. By applying response surface methodology (RSM) and ANOVA they found out that feed force (F_a) and cutting force (F_v) are strongly influenced by depth of cut at 56.77% and 31.50% respectively and cutting speed has a little influence of 0.14 ^[4].
- 5) M.W Azizi et al. [2012] investigated the effects of various cutting parameters on surface roughness and cutting forces in finish hard turning of AISI 52100 steel with Al₂O₃ + TiC mixed ceramic inserts. They found out that at different hardness level surface roughness increases with increase in feed rate decrease with increase in work piece hardness. Optimum machining conditions of cutting speed=170 m/min, feed rate= 0.08 mm/rev and depth of cut= 0.1 mm was achieved at workpiece hardness of 56.51 HRc ^[5].
- 6) Gaurav Bartarya et al. [2012] developed a force prediction model during hard turning of AISI 52100 steel hardened to 60 HRc using CBN tool. By analysing cutting parameters ant cutting parameters is was found that depth of cut was most influential parameter affecting cutting forces followed by feed rate. From Response surface methodology (RSM) it was observed cutting forces first decreases then increases with increases in cutting speed ^[6].
- 7) R.Suresh et al. [2012] analyse the influence of cutting parameters and machining time on surface roughness, cutting forces and tool wear in hard turning of AISI 4340 steel with coated carbide insert. By using Response surface methodology they found that machining forces deace with increases in speed and with further increase in feed rate the forces increases and surface roughness is sensitive to variation in feed rate at lower values of cutting speed. Better surface quality is observed at higher cutting speed with lower feed rate ^[7].
- 8) K.Nabil et al. [2012] carried out a statistical analysis by Response surface methodology (RSM) to find out the machining response that is surface roughness in hard turning of 40CO4 steel of hardness 54 HRc with mixed ceramic cc650 insert. They concluded that Response surface methodology combined with factorial design of experiments is a useful technique for surface roughness evaluation and feed rate has highest influence on surface quality ^[8].
- 9) D.V Lohar et al. [2013] carried out the experiment to compare the performance of CBN tool in machining of AISI 4340 steel in dry, wet and minimum quantity lubrication (MQL) by varying the speed, feed rate and depth of cut. They use the

- commercially available cutting fluid in minimum quantity (5-20 ml/min). By Taguchi experimentation it was observed that there is 40% decrease in cutting forces and 36% decrease in cutting temperature during minimum quantity lubrication^[9].
- 10) S.B Salvi et al. [2013] carried out the experiment to analyse the optimum cutting conditions to get the lowest surface roughness in turning of 20MnCr5 case hardening steel of hardness 46 HRC and use the ceramic based inserts. By applying Taguchi and ANOVA they concluded that surface roughness Ra improved when the cutting speed and feed is increased^[10].
 - 11) T.T.M Kannan et al. [2014] performed the experiment on AISI 316 Austenite stainless steel to investigate the heat partition, tool wear and tool life. In their investigation, they found that CBN cutting inserts has been damaged in moderate cutting velocity and produce good machinability and higher cutting temperature decreases the yield strength of produced white layer^[11].
 - 12) R.Suresh et al. [2014] studied the effect of various cutting parameters in hard turning of AISI H13 steel at 55 HRC with Poly vapour deposit (PVD) coated TiCN ceramic tool under dry cutting conditions. They used Central composition design concept of Response surface methodology for design of experiments and concluded that abrasion was the principal wear mechanism observed at higher cutting speed and feed rate was the most influential parameter. Developed Response surface methodology model has 95% confidence value and can be used to tool wear and surface roughness^[12].
 - 13) Martin Takacs et al. [2014] investigated the effects of varying speed and feed rate on AISI D2 steel at 62 HRC and to determine the resultant forces. They use Finite element simulation (FEM) to investigate the chip removal theoretically and then compare the results with practical results. It can be stated that the passive force is the most dominant force component and theoretical cutting force values are 45-120% higher than the measured one^[13].
 - 14) D.K Das et al. [2014] investigate the surface roughness during hard turning of EN24 of 50 HRC hardness with coated carbide insert. By using grey based Taguchi and regression analysis it was concluded that surface roughness of 0.42 micron is obtained at cutting speed of 130 m/min, depth of cut 0.4 mm/rev and feed rate was found to be most dominant parameters for output response^[14].
 - 15) A.K Sahoo et al. [2014] studied the performance of multilayer carbide insert in the machining of AISI D2 steel at 53 HRC using Taguchi L27 orthogonal array to predict surface roughness also S/N ratio and optimum parametric condition were analysed. He found that feed is most influencing parameter for surface roughness followed by cutting speed whereas depth of cut has least significance on surface response^[15].
 - 16) H.Zahia et al. [2015] studied the use of Response surface methodology (RSM) to determine optimum cutting conditions leading to minimum surface roughness and cutting force components. AISI 4140 hardened alloy steel at 56 HRC is used and machined with PVD coated ceramic insert. They concluded that higher the work material hardness the higher is the machining force. It is found out that for turning of AISI 4140 steel optimal cutting parameters are cutting speed of 180 m/min, feed rate of 0.08 mm/rev, cut of depth of 0.15 mm and gives surface roughness of Ra= 0.23 micron^[16].
 - 17) S.Chinchanikar et al. [2015] investigated the effect of minimum quantity lubrication (MQL) on hard turning of AISI 4340 steel at 55 HRC using TiSiN-AiAlN coated carbide tool. By multi objection optimization of parameter in dry and MQL cutting conditions it is observed that hard turning under MQL produce a significant improvement in tool life by almost 30% I comparison to dry cutting and lowering cutting forces and surface roughness. Optimum cutting conditions of cutting speed= 136 m/min, feed rate= 0.088 mm/rev, depth of cut= 0.3 mm was observed^[17].
 - 18) P.Netake et al. [2015] developed a statistical model to predict the cutting force and surface roughness during hard turning of AISI 52100 alloy steel at 62 HRC under minimum quantity lubrication using PVD coated nanocrystalline TiSiN-AiAlN coated carbide tool. It was found that correlation coefficient close to 0.9 gives the impression that developed model is reliable. Decrease in surface roughness was observed with increase in cutting speed and depth of cut has most significant effect on cutting forces^[18].
 - 19) A.Agrawal et al. [2015] studied the effect of cutting parameters in influencing the surface roughness of AISI 4340 steel hardened to 69 HRC with CBN insert. They attempted modelling with three regression models that are multiple regression, Random forest and Quintile regression. They observed that surface roughness of Ra- 0.502 micron was obtained at feed rate= 0.08 mm/rev, depth of cut= 0.1 mm and cutting speed= 1608 RPM. They conclude that Random forest regression model is superior choice over other regression models^[19].
 - 20) D.M Naigade et al. [2015] investigates the effects of cutting environment on chip formation in hard turning of hardened alloy AISI 4340 at 45 HRC with CBN insert. It is observed that chip thickness is less in Minimum quality lubrication (MQL) then wet and dry turning. MQL gives higher cutting ratio and also tightly coiled chips are formed in MQL which can be easily handled^[20].
 - 21) I.Daniel Lawrence et al. [2015] predicted the effects of machining parameters such as feed rate, cutting speed, depth of cut on surface roughness and material removal rate in hard turning of EN36 steel. They use Taguchi L9 orthogonal array for the design of experiments and used Grey relational analysis and response surface methodology to study the effects of parameters. They found that feed rate is the most influencing factor followed by cutting speed^[21].
 - 22) D.M D'Addona et al. [2016] studied the use of wiper geometry for hard turning of OHNS steel at 55 HRC and its comparison with conventional single nose radius insert. They concluded that wiper geometry inserts (Ra=0.197µm) gives

superior surface finish as compared to conventional inserts ($R_a=0.652\mu\text{m}$) and is can give comparable surface finish with grinding operation and feed is found most significant parameter for surface roughness [22].

- 23) H.Aouici et al. [2016] studied the comparison of surface roughness between ceramics and CBN inserts in hard turning of AISI H11 hot work steel at 50 HRC. It is observed that feed rate is most influential in case of hard turning with ceramic insert then CBN insert also CBN inserts has better performance as compared with ceramic inserts. Surface roughness ratios of ceramic insert $R_a= 1.8\mu\text{m}$ and CBN INSERT $R_a= 1.28\mu\text{m}$ has been observed [23].
- 24) Pardeep Kumar et al. [2016] investigated the machining parameters of AISI D13 die tool steel with CBN tool. They studied the influence of machining parameters such as tool nose radius and work piece hardness on cutting forces and surface roughness of material during hard turning. Central composite design has been used for design of experiments and Analysis of variance is used for statistical analysis. They concluded that higher the workpiece hardness higher will be surface finish [24].
- 25) Singla et al. [2016] investigates the effects of various machining parameters on the surface roughness and material removal rate in hard turning of vanadium steel. They used Taguchi L9 orthogonal array for design of experiments and Signal to noise ratio, Analysis of variance is used to study the outcomes. They found that cutting speed at 43.24 % is most influential factor to surface roughness besides depth of cut at 34.70%. The optimized parameters for better surface finish are cutting speed=1000 m/min, feed=0.2 mm/rev and depth of cut= 0.6 mm [25].

IV. CONCLUSION

The present study has overviewed the hard turning of various hardened steels that are used by different manufacturing industries. Hard turning offers a number of potential benefits over grinding including lower setup times, lower equipment cost, flexibility in process and geometry and elimination of high usage of cutting fluid. Surface roughness and material removal rate are performance parameters and are significantly affected by cutting parameters, workpiece hardness, tool materials and tool vibrations. From this study, it is found that feed rate is most significant factor followed by depth of cut in case of surface roughness and cutting speed is most significant factor for tool wear. Feed and depth of cut are significant for increasing material removal rate. By carefully selecting feed rate, depth of cut and cutting speed hard turning can greatly enhance the profitability of a closed tolerance products. Taguchi method, Response surface methodology and analysis of variance are efficient tools for designing, controlling and optimization of parameters.

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