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Investigations of Hard Turning Parameters through Experiments for Case Hardening Steels

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ABSTRACT

India's mechanical sector is expanding in the international marketplace. Suppliers of vehicle parts and accessories, a specialized industrial sector, form the backbone of the industry. On the other side, it is also having some difficulties. Raw material costs, gasoline costs, overhead costs, etc. are all rising daily. Hard turning is a process of removing the metal from the surface of a cylindrical object which is having hardness more than 45 HRC. Modern mechanical industries face an increasing demand for high productivity, and all manufacturers are constantly looking for ways to produce their products more quickly, more cheaply, and with higher quality while reducing non-value-added operations. In this study, an effort is made to enhance the hard turning process in terms of key performance measures. For hard turning, the EN 353 material is chosen, and it is hardened using the carburizing process. To get the most out of the hard turning process and to maximize performance, the process parameters are thoroughly examined and analyzed. Taguchi and orthogonal array designs were used to carry out the experiments. The goal of the current study is to critically evaluate research on cutting forces, tool wear, surface finish, and material removal rate when machining hardened steel. The ANOVA is used to determine which process parameter has a significant impact on performance measurements. The GRA method is then used to identify the optimal combination of parameters, relationships, and influence on each parameter.

Keywords : Hard turning, EN 353 material, Carburizing process, Taguchi designs, ANOVA

I. INTRODUCTION

With increased machining operations, the issue of machining process efficiency. There are many ways by which we can increase the efficiency, out of which selection of optimal machining factor to achieving this condition. In metal cutting operation, the manufacturer to set the process controllable variables at their optimal conditions noise variables on the levels and variability in the outputs. To design an effective process control for metal cutting operation by parameter optimization, a manufacturer seeks to balance between quality and cost at each stage of operation resulting in improved of a product under consideration. Out of many types of machining operations, boring, turning, milling, broaching, grinding, honing and lapping are the key value-adding metal cutting process required to produce assembly components and final products.

Need of Optimization in Machining Operations

Process parameter optimization in these machining operations is required to be undertaken in two stages first of modeling input-output and in process parameter relationship. And Secondly, Determination of optimal or near-optimal cutting conditions. Modeling of input-output and in-process parameter relationship is considered as an abstract representation of a process that causes and effects of process inputs into outputs. An optimization technique provides optimal solutions to the overall optimization problem formulated, and subsequently implemented in actual metal cutting process.

Turning Process: Turning is machining procedure in which a single point cutting tool removes unnecessary material from the surface of a revolving cylindrical work piece. The cutting tool is fed linearly in a path parallel to the axis of revolution. Turning is carried on a CNC lathe or normal lathe that gives the power to turn the work piece at a given revolving speed and to feed to the cutting tool at particular rate and depth of cut. Therefore, three cutting parameters that are cutting speed, feed and depth of cut need to be demisable in a turning operation. The reason of turning process is to construct low surface roughness of the parts.

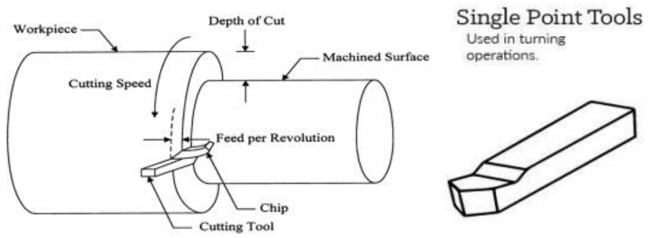


Fig.1: Turning Process

The cutting tool is fed either linearly in the parallel to the axis of rotation or at right angles to the axis of rotation of the work piece or along a particular path to construct complex shapes. The most important motion of cutting in turning action is the rotary motion of the work piece, and the minor movement is the feed movement.

Cutting Parameters

Feed: It is used to explain the distance the tool moves per rotation of the work piece. The feed depends on the finish desired and the strength and rigidity of the part and the machine.

Cutting speed: It is defined as the speed at which a point on the exterior of the work passes the cutting or point of the tool and is takes in meters/min. Cutting speed is measured by

$$V = \frac{\pi D N}{100}$$

Where,

D = Diameter of work piece,

N = Speed in rpm

V = Cutting speed in meter/min

Cutting speed depends primarily on work piece hardness and tool material.

Depth of cut: This is the quantity of how wide and deep the tool cuts into the work piece. A large radial depth of cut will require a low feed rate and reduce the tool life. To minimize the number of cuts required, the depth of cut should be as great as is consistent with the strength of the part, the power of the machine tool, the strength and size of any cutting tool. As the depth of cut is increased, the cutting force becomes larger.

Nose Radius: Nose radius makes the cut smoother and finer as it can overlap the previous cuts and eliminates the peaks and valleys that a pointed tool produces.

Output parameters

Production Time: Production time refers to the time taken for the machining operation to complete. It is mostly expressed in seconds (s). Production time varies as per the input parameters such as material to be machined, machining speed, feed, depth of cut, cooling conditions, cutting tool material etc.

Tool Life: Tool life can be considered as number of work pieces are machined by the single tool. To determine the optimum feed and speed for maximum tool life, because tool life is many times more sensitive to changes in cutting speed than to any other single factor.

Surface Roughness: The surface finish produced in a machining operation usually as the tool wears. This is true for a tool worn by chipping.

II. LITERATURE REVIEW

The literature is divided in to various groups as per below.

Francisco J. G. Silva (2021) reviewed the paper which provides improving the quality of machined surfaces, and enhancing process sustainability and distributed as a result of the demand for increased machining productivity and longer tool life.

Rajamurthy, G., et al. (2018) review to the focus on choosing the best parameters that are maintaining the required product quality at the lowest possible cost and shortest lead time. Taguchi's L_9 orthogonal array was employed in the trials, used to CNC machine the EN 31 alloy steel. For the lowest surface roughness and maximum MRR, the optical parameters were discovered independently by use of Taguchi's method, and the findings were compared with those of the Grey relation analysis.

Dillip K. Mohanta et al. (2021) In this paper two main factors used to evaluate a tool's performance are the cutting forces present at the chip tool interface and the surface quality of the machined surfaces. Aside from that, this research also addressed the difficulty in calculating the pressures for high precision machining of components with complex shapes and challenging materials.

Shilpa B. Saharea et al. (2016) In this research work, Al2024 material are sought for surface roughness, metal removal rate, and cutting pressures by varying cutting parameters such as cutting speed, feed per tooth, and depth of cut under various cutting situations. The three independent variables of cutting speed, feed rate, and depth of cut will be used to determine the surface roughness, cutting forces, and metal removal rate mathematically.

Sudhansu Ranjan Das et al. (2015) review of effects and optimization of machining parameters in hard turning process. The primary goals of this study are to investigate and assess how various machining factors affect tool wear, tool life, surface roughness, power consumption, cutting forces, cutting temperature, MRR and chip morphology during turning of various hardened steels.

Amardeep Kumara et al. (2017) studied the turning of hard components using wiper tool inserts. According to research, this kind of machining eliminates the need for grinding, saving money and energy while enabling production that is both affordable and environmentally benign.

Ch. Sateesh K. et al. (2018) reviewed the Present work and future prospects of the Application of surface modification techniques during hard turning. In this paper, surface modification methods used in hard turning applications to enhance cutting tool machining performance.

Samarjit Swain et al. (2019) In this paper emphasizes the investigation of the link between input machining parameters and vibration signal on machining characteristics. According to studies, vibration amplitude increases along with cutting speed. However, the vibration's amplitude reduced as the DOC increased.

Suha Karim Shihab et al. (2014) In this research on hard turning that has been conducted utilizing hard turning tools including carbide, cubic boron nitride, ceramics etc. and the impact of process parameters on heat generation during cutting, cutting forces, surface quality and surface integrity, and tool wear have been reviewed.

R. Sood et al. (2000) In this paper a study of the face turning procedure for milling hardened bearing steel utilizing CBN cutting tools is presented. In hard turning, there is an apparent size effect where the specific energy rises with decreasing values of the un deformed chip thickness.

Bernhard K, et al. (2013) worked on Influence of tool edge preparation on performance of ceramic tool inserts. Speed feed and tool type are the variables they examined. To determine the performance of the output characteristics, namely, surface finish, cutting force and tool wear, the High Alloyed Steel - X123CrMoV12 was employed.

J. Guddata et al. (2011) In this work, the cutting forces and surface roughness were assessed and studied. For a variety of cutting parameters, they developed a model based on the statistical design of trials to forecast cutting forces and surface roughness.

R. Suresh et al. (2012) In studied hard turning of AISI 4340 steel using multilayer coated carbide tool. They varied the feed, speed, and cut depth while maintaining the same hardness. Cutting tool wear and machining power increases practically linearly as cutting speed and feed rate increases. A combination of a low feed rate and a rapid cutting speed is necessary to reduce surface roughness.

N. Jouini et al. (2013) studied The ability of precision hard turning to increase rolling contact fatigue life. They investigated and examined the impacts of speed, feed, depth of cut, and material hardness on surface polish and fatigue life. For investigation, a hollow shaft made of AISI 52100 steel was used.

R. Suresh et al. (2012) utilizing coated carbide inserts for study on hardened AISI 4340 steel
machinability. This experiment employed speed, feed, and depth of cut as input elements and
surface roughness, machining forces, and tool wear as output responses. AISI 4340 steel that was hardened and tempered and had dimensions of 100 mm dia. and 400 mm length was utilized for the experiment.

Z. Hessainia et al. (2013) using cutting parameters and tool vibrations. The testing was conducted using 42CrMo4 steel, which had been hardened and tempered. The input variables were depth of cut, speed, feed, and hardness.

A. Kr. Sahoo et al. (2013) worked that the factors that have the major impact on surface roughness are feed, cutting speed, and depth of cut. It is shown that the interaction between the depth of cut and feed is more significant. Tool wear found at lower values all the settings are put to low values.

K. Bouacha et al. (2010) worked on a response surface methodology-based statistical study of surface roughness and cutting forces in hard turning AISI 52100 bearing steel with a CBN tool. Input variables for this experiment were depth of cut, speed, feed, and hardness, with hardness kept constant.

S. Ranjan Dasa et al. (2018) In this work, the cutting circumstances and tool geometry affected the surface roughness of bearing steel in its final, hard form (AISI 52100). The experiment was conducted using an extremely accurate lathe. The cutting implements were mixed ceramic inserts consisting of titanium carbo nitride and aluminum oxide. This study shows that the feed, cutting speed, and nose radius are the primary variables affecting the surface finish.

N. Gupta et al. (2019) study was done on a Taguchi-based analysis of cutting force in a hard-turning of EN 31 material with an insert covered with locally manufactured carbon nanotubes.

V. Pradeep Allua et al. (2019) In this study, tool nose radius, cutting speed, feed rate, and depth of cut affected the surface roughness of AISI 52100 steel during dry hard turning [90].

B. Ravi Sankar et al. (2017) investigated the Taguchi Method for the study of Forces during Hard Turning of AISI 52100 Steel. The current study tried to investigate how turning parameters affected the forces produced during severe turning of AISI 52100 bearing steel.

Hamdi Aouici et al. (2012) In this study, experimental investigation was done into the relationships between surface roughness and cutting forces in hard turning as a function of cutting speed, work piece hardness, feed rate and depth of cut. Surface roughness significantly influenced by feed rate and work piece hardness.

Mohamed Walid Azizi et al. (2012) surface roughness and cutting force modeling were highlighted in order to improve the machining parameters for AISI 52100 steel finish hard turning.

C. J. Raoa et al. (2014) focused on determining the best process parameters to analyse tool life during turning operations. In this work, the work material is aluminum and the tool material is tungsten carbide. Under different conditions, it was possible to estimate the tool life, surface quality, cutting force, and other features by adjusting various elements, such as depth of cut, speed, and feed.

Sarmad Ali Khan et al. (2018) the experimental tests on the edge preparation, work piece hardness, and operating parameters of wiper inserts were conducted using AISI D2 steel. The purpose of the work addressed here is to assess how wiper insert micro shape affects the material's critical hardness condition.

2.5 Optimization Techniques

Equbal et al. (2012) have used the Taguchi approach and the finite element method to optimize the geometry of connecting rods..

J. Antony et al. (2001) In this paper describes the Taguchi method as a very effective problem-solving approach for improving process performance, yield, and productivity. Due to unexpected procedures, it reduces production costs, rework expenses, and scrap rates.

Uday A. Dabade et al. (2013) To improve surface integrity on turned surfaces of Al/SiCp Metal Matrix Composites, it was examined how to employ Grey Relational Analysis in multi-objective process optimization.

J.B. Saedon et al. (2014) explored the WEDM grey relational analysis and orthogonal array for the multi-objective optimization of titanium alloy. The impact of process factors is investigated using graphs of the (S/N) ratio.

Anand S. Shivade et al. (2014) used the combined Taguchi technique and the Grey relational analysis approach to work on multi-objective optimization in WEDM of D3 tool steel. During machining of D3 tool steel, the impact of pulse-on time, pulse-off time, peak current, and wire speed on MRR, dimensional variation, gap current, and machining time is explored.

III. METHODOLOGY

Process parameters: The process parameters affecting hard turning viz.; material, tool material, tool geometry, cutting parameters etc. are discusses below.

Work Material: Mechanical qualities like hardness, strength, and toughness are improved via heat treatment of components like gears, axles, clutch plates, etc. The steel components expand as a result of heating and cooling after the heat treatment procedure. The chemical composition of EN 353 steel is shown in table no. 3.1.

Table No.1: EN 353 Chemical composition

Element	C	Mn	Si	S	Cr	Mo	Ni
Percentage	0.15	0.75	0.23	0.04	1	0.12	1.25

Input variables: The input variables and output measures are selected by referring literature. Five input parameters cutting speed, feed, depth of cut, material hardness and tool nose radius are selected.

Table No.2: Input parameters and their levels

Sr. No.	Parameters	Unit	Level 1	Level 2	Level 3
1	Speed	m/mm	60	120	180
2	Feed	mm/rev	0.06	0.15	0.24
3	Depth of cut	Mm	0.2	0.5	0.8
4	Hardness	HRC	58	60	62
5	Tool Nose radius	Mm	0.4	0.8	1.2

Output Measures

Cutting Forces: The primary benefit of measuring cutting forces in turning operations is the analysis of plastic-mechanical behavior during the cutting Process.

The material removal rate: It can be estimated using the volume of material removed. It serves as a measure of the machining rate's speed.

Tool wear: The chip and workpiece are in metal-to-metal contact while being exposed to high temperatures and stresses. Tool wear effects can include increased cutting force, increased cutting temperature, decreased tool life, the accuracy of parts etc.

Material Selection and Hardening Process: For this study, the material EN 353 was chosen. Soft cylindrical bars with a diameter of 28 mm and a length of 120 mm have been used. Carburizing was employed to increase their hardness above 45 HRC. These soft bars are then carburized, which increases their hardness.

Fig.2: Raw material

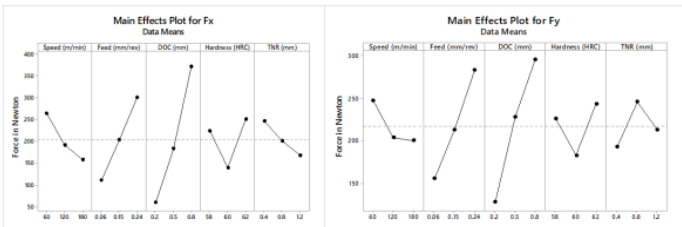
Fig. 3: Experimental setup on CNC machine

Parameters setting on CNC machine: After fixing the tool, the machine's speed, feed rate, and depth of cut were carefully set, and a trial run was carried out.

IV. Results and Discussion

Effect of output measures with input variables

All three cutting forces found linearly vary with the cutting speed, feed, and depth of cut. As speed increases the cutting force decreases. Increased speed can reduce the friction and the material becomes plastic, hence turning becomes easy and forces get reduced. As the feed and DOC increase the forces also increase, in both cases, direct pressure on the tooltip is increased and it results in increasing the cutting forces.



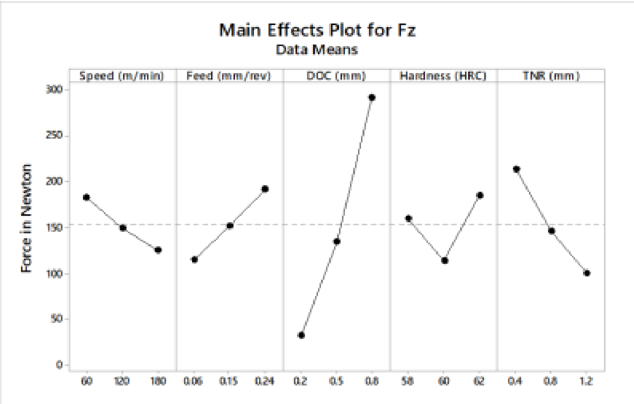


Fig. 4: Main effect plot for Cutting Force

From fig.4, we can see that the nature of force variation with hardness. The forces first decrease at 60 HRC but again increase with an increase in hardness at 62 HRC. The material properties like toughness and brittleness get changed with the change in hardness, so this type of variation has occurred. The forces F_x and F_z decrease with an increase in tool nose radius whereas F_y gets increased first and then gets decreased.

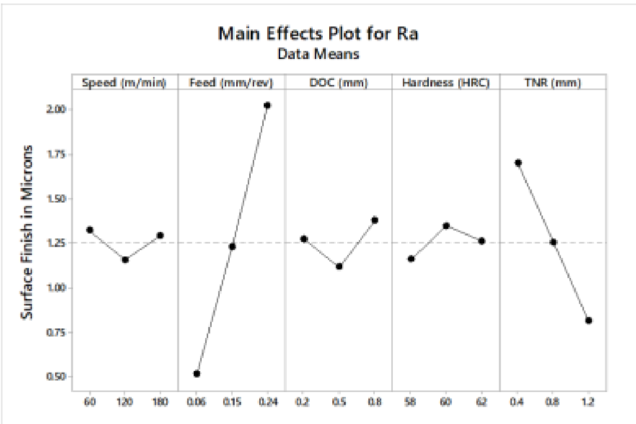


Fig. 5: Main effect plot for Surface roughness

From fig.5, we can observe that, the surface roughness varies linearly with feed and TNR. It decreases as feed increases and increases as TNR increases. Surface roughness was found minimum at 0.06 mm/rev feed. It gets increases initially with speed and DOC while again decreasing slightly with it. Its variation with hardness, it is minimum for 60 HRC and quite more at 58 and 62 HRC hardness. As feed increases, the power requires to remove the same amount of material increases. It will exert more force on the specimen, so the surface finish is poor with more feed. As TNR is more, surface contact is also more and results in a good surface finish.

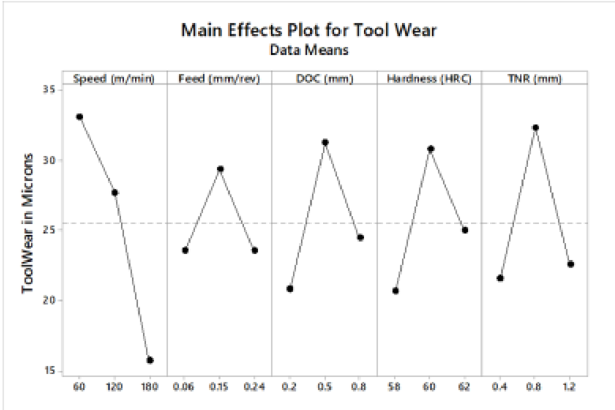


Fig. 6: Main effect plot for tool wear

The main effects plot for tool wear is shown in fig.6. As seen from the above graph, tool wear linearly varies with cutting speed and decreases as cutting speed increases. This can be attributed to less contact with the tool when cutting speed increases. Tool wear varies non- linearly with the feed, DOC, hardness, and TNR. Tool wear is less for minimum and maximum levels of the feed, DOC, hardness, and TNR, whereas it was found to be more at intermediate values. Tool wear was found minimum at the 180 m/min speed.

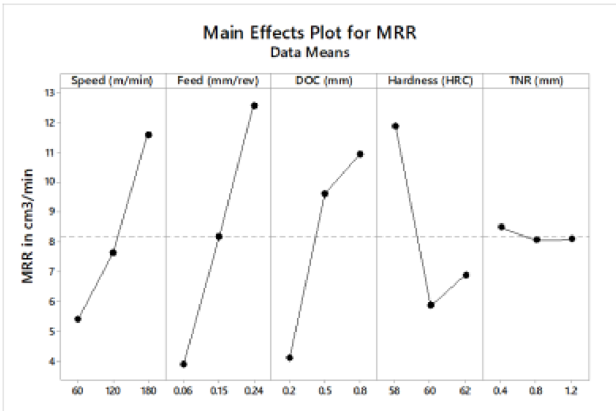


Fig. 7: Main effect plot for Material Removal Rate

From the main effects plot for MRR in fig.7, it can be observed that, the material removal rate increase with an increase in speed, feed, and DOC, it varies linearly with these input parameters. MRR is lowest at 60 HRC hardness while maximum at 58 HRC hardness.

The MRR is more at 0.4 mm TNR while it is quite the same for 0.8 and 1.2 mm TNR. Speed, Feed, and DOC affect directly the MRR. In case of Hardness, it decreases first at 60 HRC but again increases at 62 HRC. As Hardness increases the material becomes brittle, hence the MRR is more at 62 HRC than 60 HRC.

V. Conclusions & Future Scope

Conclusion: This contribution looks at how cutting forces, surface roughness, tool wear, and material removal rate relate to speed, feed, depth of cut, material hardness, and tool nose radius when hard turning EN 353 steel. The following findings have been drawn from research.

- From the experimental analysis and optimization, it was seen that the input process parameters viz. cutting speed, feed, and depth of cut, hardness and tool nose radius greatly influence the output measures and plays a vital role in deciding surface roughness, cutting forces, tool wear and material removal rate.
- The measurement of cutting force can be effectively used in the range of 58 to 62 HRC hardness range to decide the machining parameters and to set tooling parameters to get better machining performance.
- The input process parameter feed was the most significant factor in deciding the surface roughness of hard turning process. At 95% confidence level, feed found to be affecting the surface roughness with a percentage contribution of 69.47%, followed by tool nose radius with 20.81%.
- Cutting speed, one of the process variables, was shown to be the most important factor for tool wear at a 95% confidence level, contributing 36.24% of the total. Tool nose radius also a major role, contributing 22.47% of the total.
- The input parameter Depth of Cut affects material removal rate with 35.53% contribution followed by Tool Nose Radius with 16.01% contribution.
- A Taguchi based GRA is done to get optimum input process parameters for required output measures. As per GRA, the 8th experimentation trial was found to be the best combination of input variables. The levels of parameters are 60 m/min speed, 0.24 mm/rev feed, 08 mm depth of cut, 62 HRC hardness and 0.8 mm tool nose radius. The GRA was also done to get minimum cutting forces.

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