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A Review on Investigating the Effect of Machining Parameters on Surface Roughness, Machining Forces and Tool Wear in Turning of AISI 4340

Jignesh Khara**, Shivang Jani, G.D. Acharya
Department of Mechanical Engineering, Atmiya Institute of Technology and Science,
Rajkot, Gujarat, India

Abstract

Now a day due to the advent of technology, newer materials are coming day by day in the market, due to which it is difficult for an operator to choose the proper cutting parameter for a tool-workpiece combination to get required surface finish and dimensional precision. The main problem associated with turning process is surface roughness and tool wear, which affect the quality of turned part. The main objective of this study is to investigate and evaluate the effect of different cutting parameters (cutting speed, feed rate and depth of cut), cutting conditions (dry, wet, etc.) and interface temperature on surface roughness and tool wear during turning of AISI 4340 alloy steel.

Keywords: *Surface roughness, tool wear, interface temperature, AISI4340, machining forces*

****Author for Correspondence*** E-mail: jignesh_khara@yahoo.com

INTRODUCTION

Turning is a machining process in which cutting tool removes material from rotating workpiece using a machine called as lathe. Figure 1 shows the typical turning process.

In Figure 1:
D1=Diameter of workpiece,
D2=Diameter of machined surface,
L=Length of cut.

Turning process is most widely used in automobile industries (e.g., manufacturing of bearings, gears, heavy duty shafts, axles, spindles, couplings, pins, and cams which require tighter geometric tolerances, longer service life and good surface finish), aerospace sectors and other manufacturing industries where metal cutting of component is required. Present day's quality is the key parameter for customer satisfaction. Quality of turned part is mostly defined by surface finish and dimensional precision of the part in turning process. The quality of turned part is affected by many parameters as shown in Figure 2.

AISI 4340 ALLOY STEEL

Alloy steels are designated by AISI four-digit numbers. According to AISI designation, first two digits '43XX' indicate nickel-chromium-molybdenum steels and last two digits 'XX40' indicate the carbon percentage (.40%). It has high toughness and strength in the heat treated condition. Tables 1 and 2 show the chemical composition and properties of AISI 4340 alloy steel.

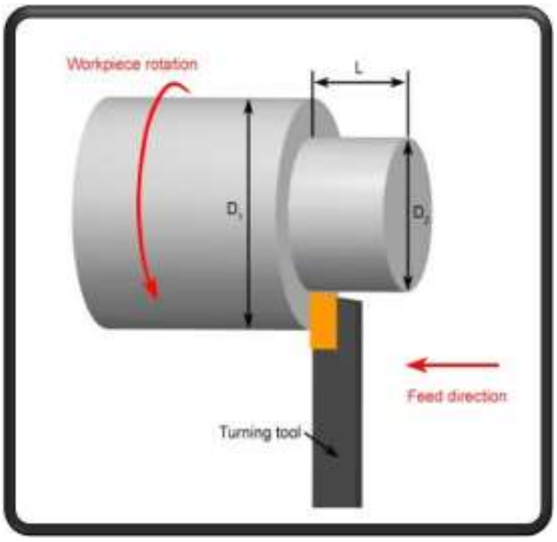

Fig. 1: *Turning Process [1].*

Applications

- In critical components for aerospace engineering (e.g., landing gears), and

- In automotive transmissions (e.g., manufacturing of bearings, gears, heavy duty shafts, axles, spindles, couplings, pins, and cams).

Above applications require stringent geometric tolerances, longer service life and good surface finish [3].

Surface Roughness
Surface roughness is defined as fine irregularities available in the surface texture, usually including those resulting from the inherent action of the production process, like feed marks produced during the machining process. The accuracy or tolerance of a machine component is mainly dependent on the surface roughness. A close tolerance dimension requires a very fine finish or low surface roughness which requires multiple machining operations.

The unit of surface roughness is micrometers or micro inches. It can be measured by using a variety of instruments, including both surface contact and non-contact types. Most widely used technique for measurement of surface roughness in industries is by using a stylus contact-type instrument that provides a numerical value for surface roughness. A stylus contact-type surface measuring instruments can usually provide an indication of surface roughness in terms of the arithmetic average, Ra or root mean square (rms) value Rq [4].

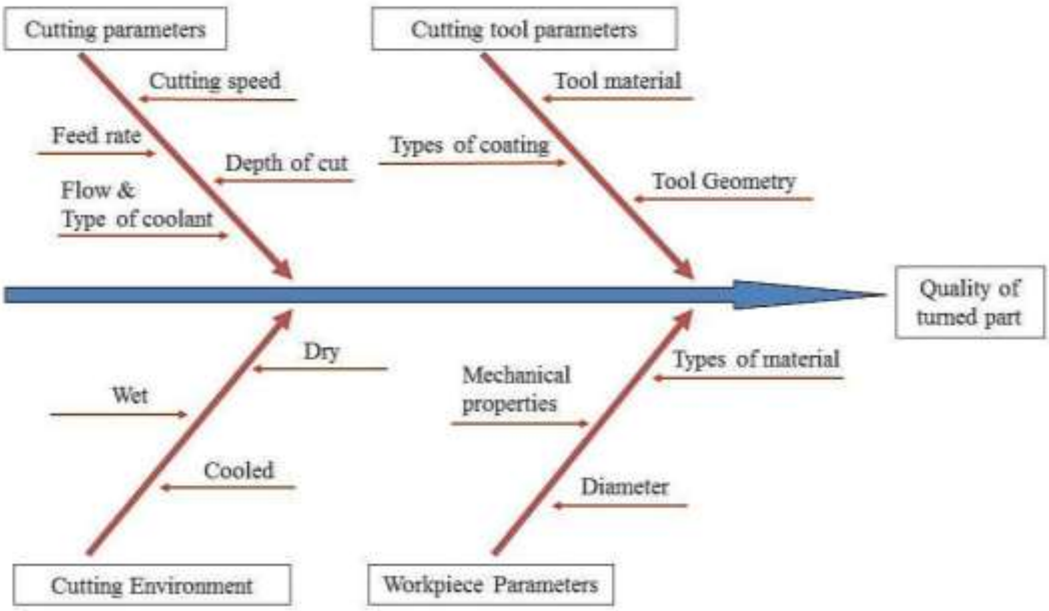

Fig. 2: *Ishikawa Cause-Effect Diagram of a Turning Process [2].*

Table 1: *Chemical Composition of AISI 4340 Alloy Steel [3].*

Alloying Element	Fe	Ni	Cr	Mn	C	Mo	Si	S	P
Content (%)	95.195–96.330	1.65–2.00	0.700–0.900	0.600–0.800	0.370–0.430	0.200–0.300	0.150–0.300	0.0400	0.0350

Table 2: *Properties of AISI 4340 Alloy Steel [3].*

Type of Property	Properties	Metric
Physical Properties	Density	7.85 g/cm^3
	Melting point	1427°C
Mechanical Properties	Tensile strength	745 Mpa
	Hardness (Brinell)	217
	Elongation at break	22%
Thermal Properties	Co-efficient of Thermal expansion (20°C/68°F, specimen oil hardened, 600°C)	12.3 µm/m°C
	Thermal conductivity	44.5 W/mK

Tool Wear

Tool wear is a problem of production management that cannot be controlled during machining in the manufacturing industries. Cutting-tool wear occurs due to normal loads on tool surfaces are high and the cutting chips and workpiece that apply these loads are moving rapidly over the wear surfaces.

The cutting action and friction at these contact surfaces increase the temperature of tool material, which further accelerates the physical and chemical processes associated with tool wear.

In turning process, the unwanted material removes as chips, so for this reason these forces and motions are necessary; therefore cutting tool wear cannot be avoided.

Cutting tool wear occurs along the cutting edge and on adjacent surfaces. Figure 3 shows a view of the cutting process in which the rake and clearance surfaces intersect to define the cutting edge [4].

Interface Temperature

Most effective method of measuring workpiece tool interface temperature is by using thermocouple principle. Figure 4 shows a tool-work thermocouple principle which was used to measure the average cutting zone temperature during turning process. The relationship between the electro-motive force (emf) signal generated during turning and the interface temperature was established by a tool-work calibration setup. As shown in Figure 4, one wire from the rear end of the workpiece (cold junction) through carbon brush and another wire screwed to the cutting insert were connected to multi-meter.

The circuit was completed when the tool came in contact with the workpiece. For each cutting test, thermo-electric emf was measured. Relationship between the emf generated and the corresponding temperature was established by a calibration setup, as shown in Figure 5. A heating coil was used for heating the tool-work thermocouple junction point formed between the coated insert and long continuous chip. Temperature at the junction point was measured by a standard K-type thermocouple wire, which was mounted just near the junction point and connected to temperature indicator. Digital multi-meter was used to record the electromotive force (emf) generated between the hot and cold junctions for the known temperature of the junction point. Both, the workpiece and the tool were insulated properly during turning and calibration process to avoid the generation of secondary emf [5].

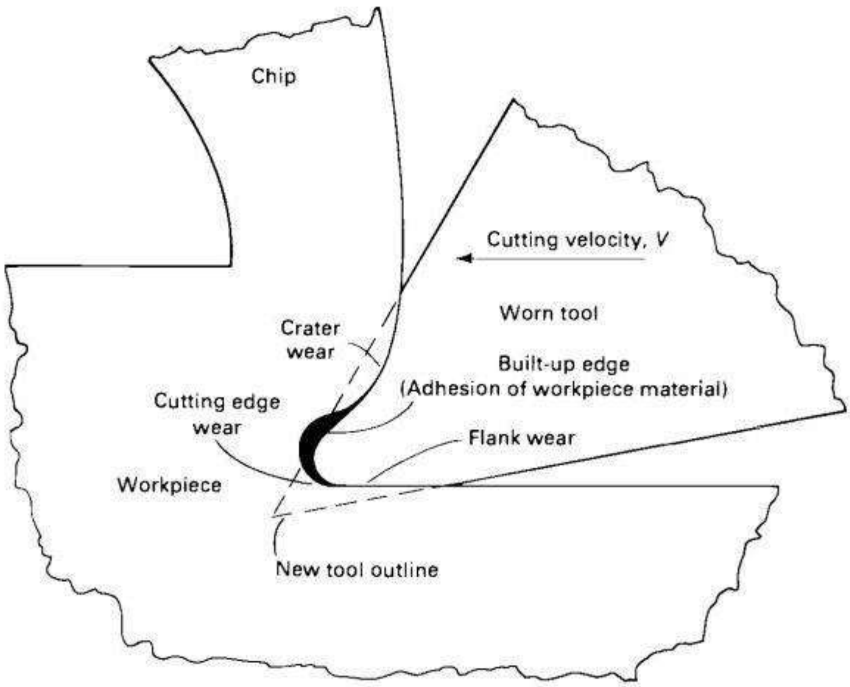

Fig. 3: *Diagram for Tool Wear [4].*

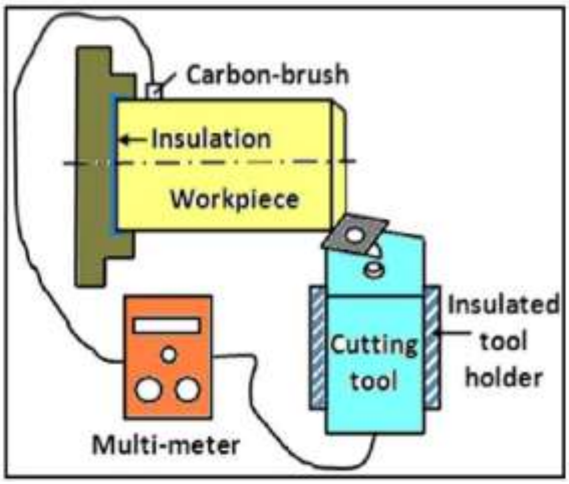

Fig. 4: *Schematic Temperature Measurement Set-Up [5].*

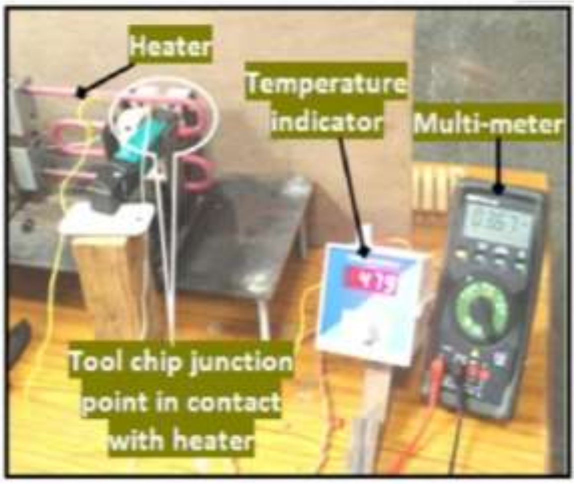

Fig. 5: *Temperature Calibration Set-Up [5].*

LITERATURE REVIEW

The quality of turned workpiece is an area of many researchers. Rashid *et al*. have designed the experiments using the full factorial based Taguchi matrix [6]. After performing the experiments, the variations present in the response data is measured using S/N ratio, and then ANOVA and multiple regression have been carried out on obtained data. They have determined the effect of feed rate (0.02, 0.06, 0.1 and 0.15 mm/rev), linear cutting speed (90, 150, 200 and 250 m/min), and depth of cut (0.1, 0.2, 0.3 and 0.4 mm) on surface roughness. They have obtained the Eq. (1) by applying multiple regression analysis. By putting the data in Eq. (1), the value of surface roughness can be obtained for the given tool-workpiece combination under the stated environmental condition.

$$Ra = -0.11706992 + 8.148467886f + 97.5658*10^{-6}vc - 0.20935731ap$$

Authors have concluded that when feed rate during hard turning approaches very low, it could be most significant parameter [6].

Mandal *et al*. have performed experiment on AISI 4340 material using yttri stabilized zirconia toughened alumina turning insert [7]. They have developed a mathematical model to study the effect of cutting parameters on the surface roughness using the response surface methodology (RSM) for validation of problem. After performing ANOVA (Partial sum squares), it was found that the cutting speed and depth of cut plays a predominate role for the determination of surface roughness of the workpiece. Figures 6–8 shows the effect of cutting parameter on surface roughness [7].

In the work of Mandal *et al.*, a new zirconia toughened alumina (ZTA) inserts was used which was made by powder metallurgy process [8]. Based on standard response surface methodology (RSM) called central composite design, 16 experiments are performed to find the effect of cutting parameters (cutting speed, feed rate and depth of cut) on machining forces (feed force, thrust force and cutting force) in finish hard turning of AISI 4340 steel using developed ZTA (Zirconia Toughened Alumina) insert.

Following are the mathematical equations for forces which are obtained using second order regression analysis:

Feed force (Fx):

$$Fx = 244 + 26.6A + 12.2B + 31.9C - 12.125AB + 16.125AC + 5.625BC - 3A^2 - 12B^2 + 36.5C^2$$

Thrust Force (Fy):

$$Fy = 380.431 + 2.2A + 39.5B + 24C - 4.625AB + 10.375AC + 3.375BC - 4.603A^2 - 21.896B^2 - 7.396C^2$$

Cutting Force (Fz):

$$Fz = 466.1552 + 7.1A + 72.8B + 18.5C - 18.75AB - 15AC + 28.5BC - 8.48A^2 + 2.017B^2 + 10.517C^2$$

Authors have concluded that the central composite design (CCD) is an effective tool for modeling the machining force. They have also shown the interaction effect of variables as shown in Figures 9–11 [8].

Gupta and Sood have performed the experiments on AISI 4340 alloy steel using uncoated tungsten carbide inserts under the varying condition of process parameters (e.g., Cutting speed, feed rate, and different cooling conditions) [9]. They have carried out optimization on the process parameters to minimize the specific cutting force (Ks) and surface roughness Ra. Based on the experiments and optimization performed, authors have concluded that cooling condition is the most significant parameters followed by feed and cutting speed (Table 3).

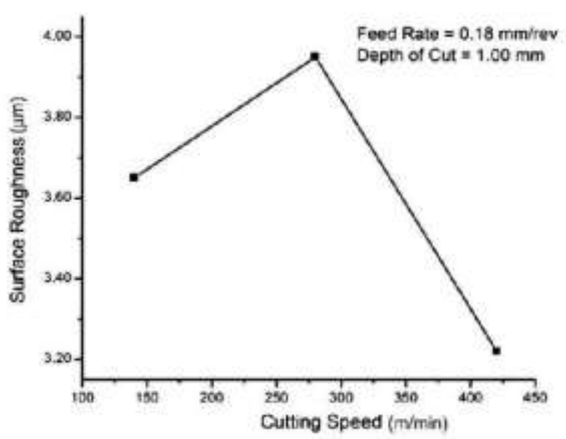

Fig. 6: *Direct Effects of Cutting Speed on Surface Roughness [7].*

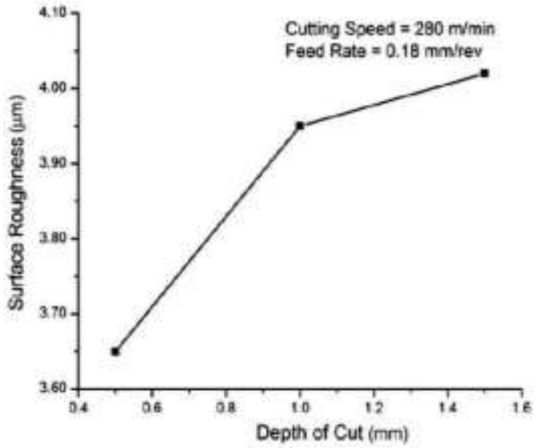

Fig. 7: *Direct Effects of Depth of Cut on Surface Roughness [7].*

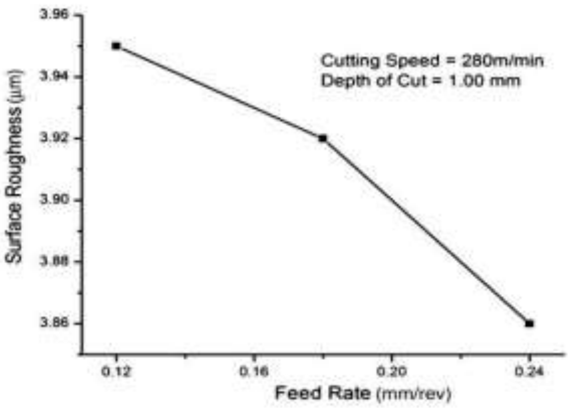

Fig. 8: *Direct Effects of Feed Rate on Surface Roughness [7].*

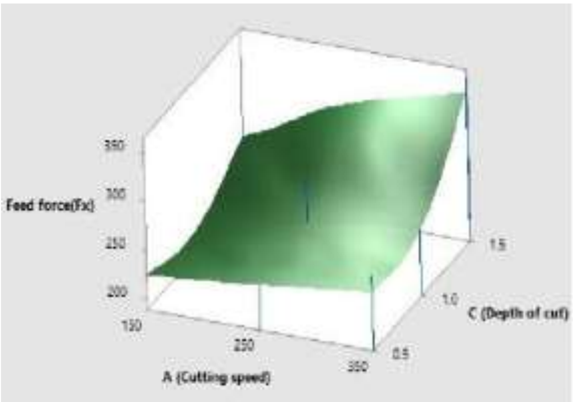

Fig. 9: *Effect of Feed Force with Depth of Cut and Cutting Speed [8].*

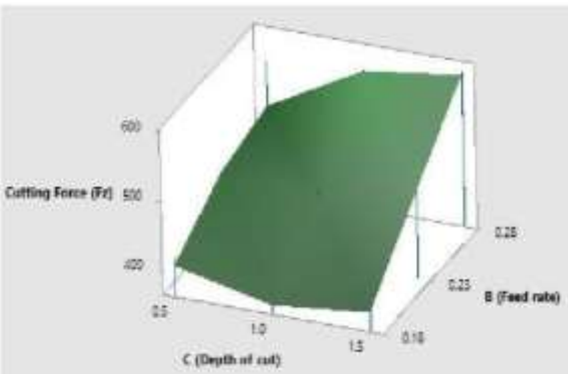

Fig. 10: *Effect of Cutting Force with Feed Rate and Depth of Cut [8].*

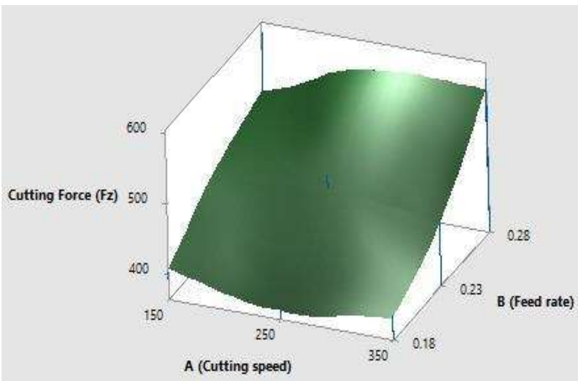

Fig. 11: *Effect of Cutting Force with Feed Rate and Cutting Speed [8].*

Table 3: *Process Parameters and their Levels.*

Parameters	Code	Unit	Levels		
			1	2	3
Cutting speed	V	m/min	51	97	141
Feed rate	F	mm/rev	0.179	0.205	0.248
Cooling condition	Cc	-	Dry	Wet	Cryo

Also using multi-response S/N ratio, authors showed that cryogenic is the optimum cooling condition, cutting speed 57 m/min and feed rate of 0.248 mm/rev [9].

Saini *et al.* presented the influence of approach angle, feed rate, cutting speed and depth of cut on cutting forces and tool tip temperature. They have performed the experiments on AISI 4340 steel workpiece using two different coated carbide inserts (PVD and CVD-coated) under different environmental conditions (dry and MQL machining).

The artificial neural network has been used for error prediction in experimental results. After performing experiments by taking four levels of approach angle, cutting speed, and feed rate (depth of cut is taken as constant), authors have concluded that machining using MQL (Minimum Quantity Lubrication) shows beneficial effects compared to dry machining.
Authors have also concluded that the PVD-coated inserts produced better results compared to CVD coated inserts due to a thin TiAlN layer which provides a fine surface for insert, hence it protects the insert from built-up-edge which reduces tool life [10].

CONCLUSIONS

The surface roughness measurement through a stylus contact type instrument that provides numerical value is found to be an effective method. Feed rate is a most significant parameter for surface roughness. Surface roughness increases as the feed rate increases and it decreases as the cutting speed increases, depth of cut has a negligible effect on surface roughness and tool wear, especially at a low feed rate and cutting speed. The depth of cut is an important parameter for feed force, feed force increases as the increment in the depth of cut and it is less affected by cutting speed and feed rate. Thrust force decreases at higher cutting speed and is less affected by feed rate and depth of cut. Cutting force is mostly influenced by feed rate but at a higher depth of cut and cutting speed, the same force has negligible effect.

The tool-workpiece thermocouple setup as shown in Figure 4, is found to be a most suitable method for measuring average chip-tool interface temperature during the metal cutting process. Tool-wear, especially the flank-wear and surface roughness are directly affected by interface temperature. Cryogenic cooling and minimum quantity lubrication (MQL) can be used to minimize the interface temperature; and by minimizing the interface temperature, the surface roughness can be minimized.

REFERENCES

1. Available from: http://www.custompartnet.com/wu/images/turning/turning-step.png
2. Kumar S, Gupta M, Satsangi PS. Multiple-Response Optimization of Cutting Forces in Turning of UD-GFRP Composite Using Distance-Based Pareto Genetic Algorithm Approach. *ESTIJ*. 2015; 18(4): 680–695p.
3. Available from: http://www.azom.com/article.aspx?ArticleID=6772
4. Davis JR, Lampman SR, Zorc TB, *et al.*, editors. *Metals Handbook*. 9th Edn. *Machining*. ASM International; 1989.
5. Chinchanikar S, Choudhury SK. Cutting Force Modeling Considering Tool Wear Effect during Turning of Hardened AISI 4340 Alloy Steel Using Multi-Layer TiCN/Al2O3/TiN-Coated Carbide Tools. *IJAMT*. 2016; 83(9): 1749–1762p.
6. Rashid WB, Goel S, Davim J, *et al*. Parametric Design Optimization of Hard Turning of AISI 4340 Steel (69 HRC). *IJAMT*. 2016; 82(1): 451–462p.
7. Mandal N, Doloi B, Mondal B. Predictive Modeling of Surface Roughness in High Speed Machining of AISI 4340 Steel Using Yttria Stabilized Zirconia Toughened Alumina Turning Insert. *IJRMH*. 2013; 38: 40–46p.

8. Mandal N, Doloi B, Mondal B. Force Prediction Model of Zirconia Toughened Alumina (ZTA) Inserts in Hard Turning of AISI 4340 Steel Using Response Surface Methodology. *IJPEM.* 2012; 13(9): 1589–1599p.
9. Gupta MK, Sood PK. Optimizing Multi Characteristics in Machining of AISI 4340 Steel Using Taguchi's Approach and Utility Concept. *J Inst Eng India*. 2016; 97(1): 63–69p.
10. Saini A, Dhiman S, Sharma R, *et al*. Experimental Estimation and Optimization of Process Parameters under Minimum Quantity Lubrication and Dry Turning of AISI-4340 with Different Carbide Inserts. *J Mech Sci Tech*. 2014; 28(6): 2307–2318p.

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