International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Analysis of Cutting Velocity Impact on Machining Parameters of CNC Turning operation for Tool Steel D2: An DOE based study

***Poojashree Soni*[1], *Prashant Kumar*[2*]**

[1], *MTech Research Scholar, Mechanical Engineering Department, JEC, Kukas (Jaipur)*
[2], *Assistant Professor, Mechanical Engineering Department, JEC, Kukas (Jaipur)*

A B S T R A C T

The present research aims to study the effect of cutting velocity on high strength alloy steels (tool steel D2) in terms of chip formation and surface roughness. The cutting velocity was varied from 150 to 400 meters per minute, along with variable feed rate and depth of cut. The selected alloy steels have properties such as high strength, high hardness, and low corrosiveness. The surface response technique was used to analyze the surface roughness. The investigation also included an analysis of the shape of chip formation and its impact on quality. The research was conducted using the Taguchi method of design of experiment and the results were analyzed using signal to noise ratio analysis.

Keywords:Tool Steel D2, Machining, Taguchi method, chip formation, surface roughness, signal to noise ratio, analysis of variance (ANOVA)

1. Introduction

The impact of cutting velocity on the turning of cylindrical objects on a CNC (Computer Numerical Control) machine is an important factor to consider in manufacturing processes. Cutting velocity refers to the speed at which the cutting tool moves along the surface of the material being machined. In CNC turning, the cutting tool is rotated at a high speed and fed into the workpiece, removing material to create the desired shape.The cutting velocity has a significant effect on the quality and efficiency of the machining process. A higher cutting velocity can lead to a faster machining time, but it can also result in increased wear on the cutting tool and potentially lower surface quality. On the other hand, a lower cutting velocity may result in a longer machining time but may produce a better surface finish and extend the life of the cutting tool.

The selection of an appropriate cutting velocity is influenced by several factors, including the material properties of the workpiece, the type and condition of the cutting tool, and the desired surface finish. Harder materials typically require lower cutting velocities to prevent tool wear, while softer materials can withstand higher cutting velocities. The type of cutting tool also plays a role, with some tools being more suitable for high cutting velocities and others being more suitable for low cutting velocities. The desired surface finish is another important factor, as a higher cutting velocity may produce a rougher finish, while a lower cutting velocity may produce a smoother finish.In addition to these factors, the cutting velocity also affects the temperature at the cutting zone, which can have a significant impact on the machining process. A higher cutting velocity can generate higher temperatures, which can cause the workpiece material to deform and affect the accuracy of the machined part. On the other hand, a lower cutting velocity may result in lower temperatures and a more stable machining process.

To optimize the cutting velocity in CNC turning, it is important to carefully consider the various factors that can impact the machining process. This may involve adjusting the cutting velocity for different materials or using different cutting tools for different machining conditions. By carefully controlling the cutting velocity, it is possible to achieve the desired surface finish and improve the efficiency and quality of the machining process. In present study the D2 tool steel was selected as machining object and then different cutting velocities were selected to find the impact on the final product.

2. Literature Review

In a study by Balaji et al. (2022), the response surface approach was used to determine the optimal machining parameters for turning super duplex stainless steel (SDSS) with uncoated carbide tools. The machining was conducted in a cooled gas atmosphere and the responses evaluated were surface roughness, tool wear, cutting force, and cutting temperature. The surface roughness was measured using a surface roughness tester and the cutting temperature was monitored with a thermocouple. Analysis of the readings was then performed and surface and contour plots were generated for the cutting temperature.

In a study by Rashid et al. (2013), the surface defect machining (SDM) method for high-throughput processing was examined. This method combines the benefits of porosity machining and pulsed laser pre-treatment to improve the controllability of the process and enhance the quality of the machined surface. The SDM technique was analyzed through the use of the finite element method (FEM) and molecular dynamics (MD) modeling.

Cotterell and Byrne analyzed the chip formation during the machining of titanium alloy. During orthogonal cutting, saw-tooth chips were formed through a two-stage process: first, material in front of the tool expands due to plastic deformation, and second, a shear band is created when the critical strain level is reached, resulting in concentrated high strain and catastrophic breakdown.

Halim et al. investigated the impact of tool wear on chip morphology during the milling of a nickel alloy with a coated carbide tool. They found that at an early stage of wear, a single element chip is produced, while in the steady wear stage, a twin element chip is formed due to the action of the worn tool geometry at the cutting edge. In some cases, the chips fused with the worn regions of the tool face as they passed over it. When localized flank wear occurred, the twin element chips transformed into segmental chips with a sawtooth-like shape. In a cryogenic environment, the segmented chip was produced in the steady wear stage, while in dry machining conditions, it was produced in the later stage of tool wear.

In a study by Nandhakumar et al., the chip formation and wear mechanisms of silicon nitride based ceramic and silicon carbide whiskers reinforced alumina round inserts were examined during the turning of solution-annealed Inconel 718 with a 10% concentration cutting fluid. The cutting speed was 250 meters per minute in the first set of tests and 300 meters per minute in the second set. The results showed that the SiAlON turning inserts produced the best results in terms of tool flank wear, total tool life, and workpiece surface polish at a cutting speed of 300 meters per minute. At cutting rates above 250 meters per minute, the Inconel 718 chip morphology indicated significant shear band localization in the major shear zone of the chip/tool interface, resulting in the segmentation of chips.

In a study by Al-Ajmi et al., experiments were conducted to investigate the effects of cutting speed and feed rate on the surface roughness and machinability of Inconel 718 when turning with coated carbide tools. The results showed that an increase in cutting speed led to a decrease in surface roughness, while an increase in feed rate led to an increase in surface roughness. The results also indicated that the machinability of Inconel 718 improved with an increase in cutting speed and a decrease in feed rate.

3. Objective and Methodology

In this study, the effect of cutting velocity on high strength alloy steels was investigated. The cutting velocity was varied from 20 to 100 meters per minute, along with changes in the feed rate and depth of cut. Three different types of alloy steels belonging to the AISI D2 Tool Steel family were selected for the test samples due to their high strength, hardness, and low corrosion properties. The focus of the study was on chip formation and surface roughness, which were analyzed using the surface response technique. The research process involved selecting the scope of the study, developing a research plan, conducting experiments on the work components, and analyzing the results. The data was recorded using the Mini-Tab program and the conclusion of the study was drawn. The research flow diagram is shown in Figure 1.

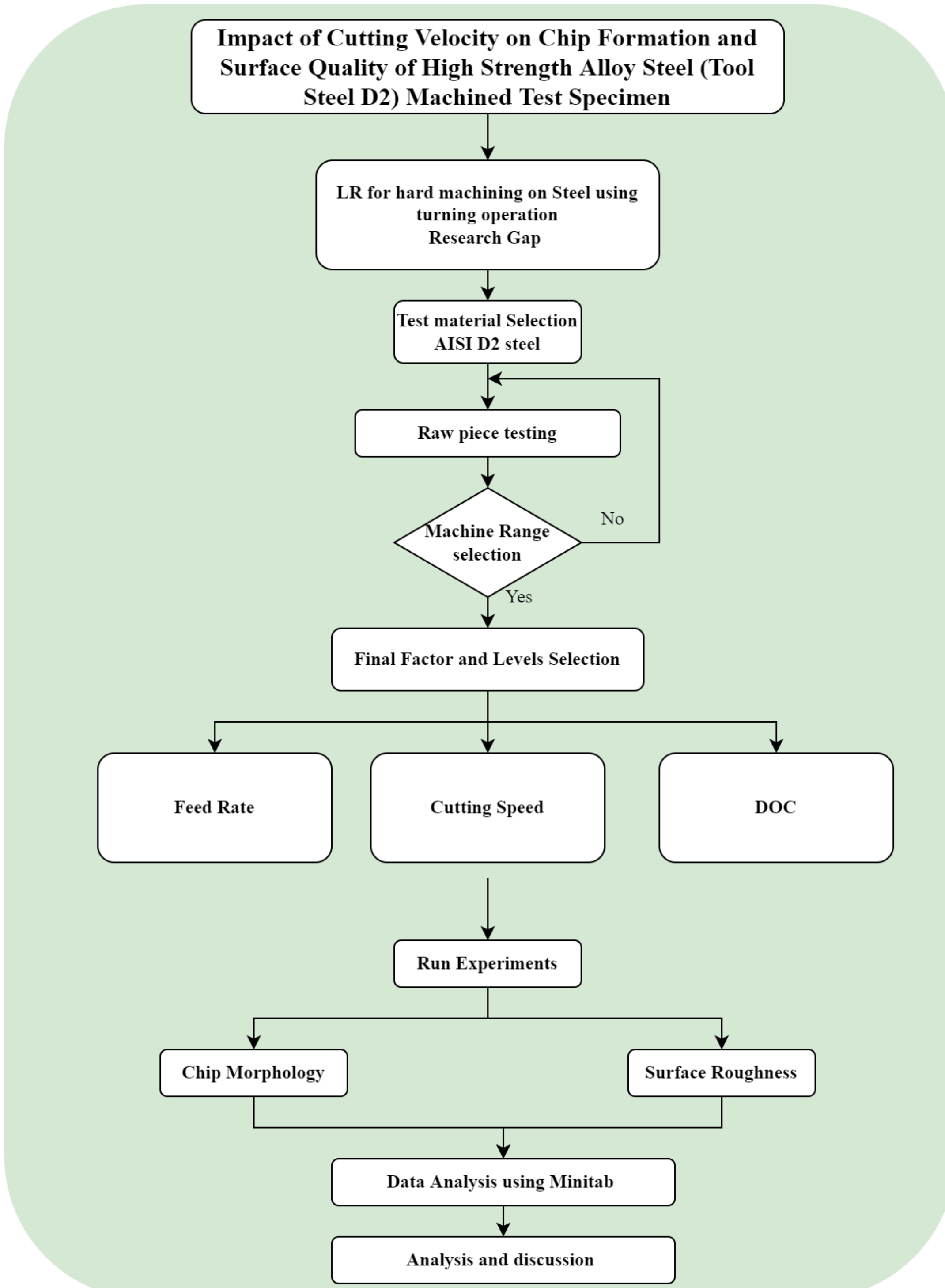

Fig.1.Research Flow Diagram for Present Study

4. Material and Methods

AISI D2 tool steel was used as the test material to determine its machinability. The test specimens were cylindrical rods with a diameter of 50 millimeters and a length of 70 millimeters, manufactured from bar stock. Smaller diameter rods are preferred for their ability to bear stress and higher tensile strength and elongation, and have the advantages of lower cost and ease of storage and handling. Tables 1 and 2 show the characteristics of the D2 steel used in the experiment.

Table 1

Chemical composition of Tool Steel “D2” [36]

Steel	C	Mn	Si	Cr	Mo	V	Fe
D2	1.52	0.34	0.31	12.05	0.76	0.92	Bal

Table 2

Mechanical Properties of Tool Steel “D2” [36]

Steel	Modulus of Elasticity	Yield Strength	UTS	Displacement at Fracture
	GPa	MPa	MPa	mm
D2	203	350	758	0.61

The experiments were conducted in a wet environment using a TM-1 model tool room lathe and a HAAS vertical lathe center, as shown in Figure 2. The HAAS vertical computer numerical control machining center has x, y, and z motions of 30 inches, 12 inches, and 16 inches, respectively, and can accommodate larger workpieces (762 mm x 305 mm x 406 mm). The capabilities of the HAAS vertical machining center used for the experiments are listed below.

Fig.2.Lathe Turning Machine

5. Pilot Experiments for Present Study

Pilot experiments are important in present machining research studies because they allow researchers to test and optimize their experimental setup and methodology before conducting the main study. This can help ensure that the main study is conducted efficiently and effectively, and can also help identify any potential issues that may arise during the main study. Pilot experiments can be used to test different machining parameters, such as cutting speed, feed rate, and depth of cut, to determine their impact on the machining process and the final machined component. They can also be used to test different tool materials and geometries to identify the most suitable option for the main study. Pilot experiments can also be used to test and validate measurement techniques, such as surface roughness measurement or tool wear assessment, to ensure that they are reliable and accurate. In addition, pilot experiments can be used to assess the repeatability and reproducibility of the machining process, which is important for ensuring the reliability of the main study's results. Overall, pilot experiments play a crucial role in machining research studies by helping researchers to optimize their experimental setup, identify the most suitable machining parameters and tools, and validate measurement techniques. This can ultimately lead to more reliable and accurate results in the main study.The final range selection for the present investigation using pilot study was present in table 3.

Table 3

Pilot Experiments for present research work

Sr No	Factor	Range after Pilot Ex
1	Feed Rate (mm/rev)	0.2 to 1
2	Speed (RPM)	1000 to 2000
3	Depth of Cut (mm)	0.3 to 1

This range is verified by using pilot experiment on the machine. These trial results are validated when full final completed product was made by the machining process. The final product should looks like shown in figure 3.

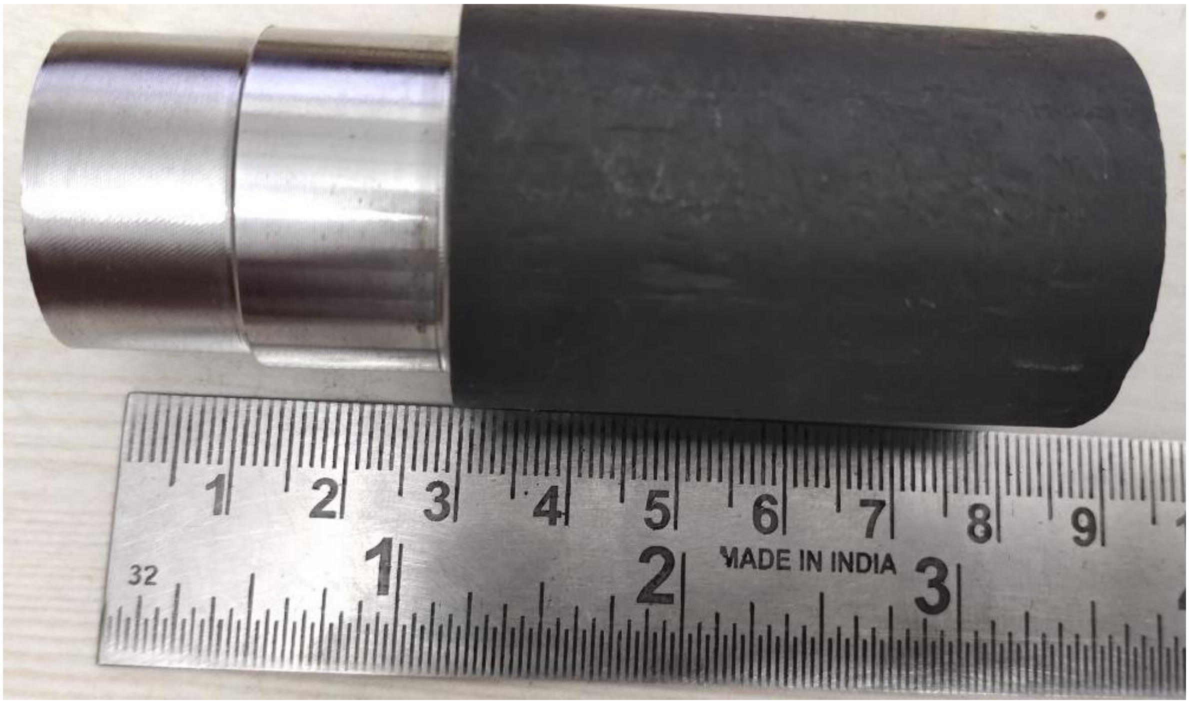

Fig. 3 Product made for pilot experiment (Stepped Turning)

The CAD model of the product with dimension was shown in figure 4, all dimensions are in mm.

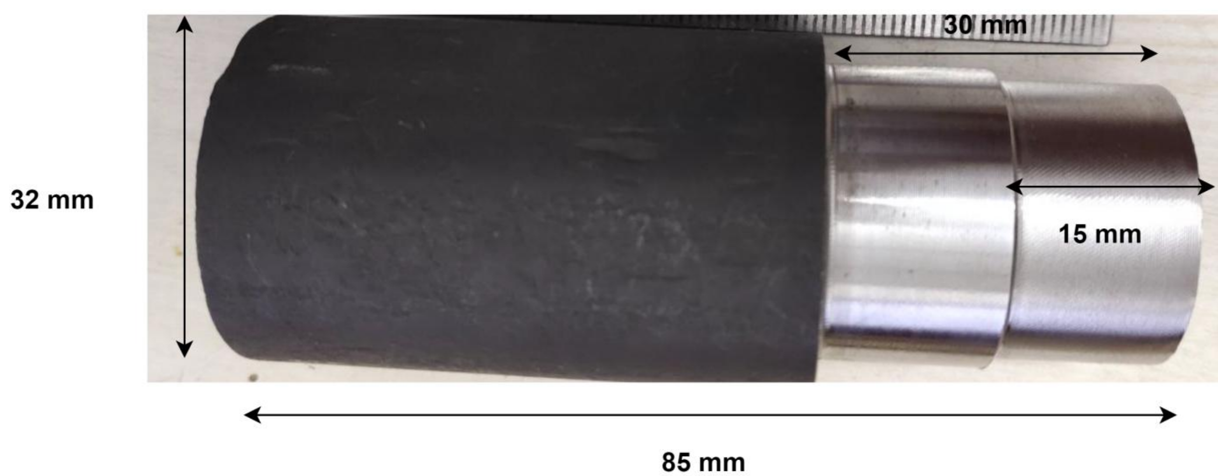

Fig.4 Dimensions of the final Product

6. Taguchi Method

The Taguchi method, also known as the Taguchi loss function or Taguchi design of experiments, is a statistical method for optimizing the quality of a product or process. It was developed by Genichi Taguchi, a Japanese engineer and statistician, in the 1950s.

The Taguchi method is based on the idea that a product or process should be designed to minimize the loss or cost associated with its performance, rather than simply trying to maximize performance. To do this, the Taguchi method uses experimental designs and statistical analysis to identify the factors that have the greatest impact on the loss function and to determine the optimal levels of these factors for minimizing loss.

One key tool used in the Taguchi method is the orthogonal array, which is a matrix that is used to organize and analyze the results of experiments.

Orthogonal arrays are designed so that the effects of different factors can be separated and identified, making it easier to identify the most important factors and to optimize the product or process. Overall, the Taguchi method is a useful tool for improving the quality and performance of products and processes, and has been widely adopted in a variety of industries.

TABLE 4

Factors and levels for hard turning

Factors/Levels	Speed	Feed Rate	DOC
	m/min	mm/min	mm
I	140	0.5	0.2
II	190	0.6	0.3
III	240	0.7	0.4
IV	290	0.8	0.5

These factors and levels are required to select the experiment table for present investigation. The selection of experiment runs are done by using Taguchi method and the final orthogonal array was present in table 5.

TABLE 5

Orthogonal array developed for present experiment work

Run	Speed	Feed Rate	DOC
1	140	0.5	0.2
2	140	0.6	0.3
3	140	0.7	0.4
4	140	0.8	0.5
5	190	0.5	0.3
6	190	0.6	0.2
7	190	0.7	0.5
8	190	0.8	0.4
9	240	0.5	0.4
10	240	0.6	0.5
11	240	0.7	0.2
12	240	0.8	0.3
13	290	0.5	0.5
14	290	0.6	0.4
15	290	0.7	0.3
16	290	0.8	0.2

7. Result and Discussion

The final table in which both response parameters are presented was list out in table 5. As saw in table 6, the first response parameter was roughness of the object which was measured after performing the turning operation as per experiment table.

TABLE 6

Experiment results for l16 orthogonal array

Run	Speed	Feed Rate	DOC	Roughness
1	140	0.5	0.2	2.98
2	140	0.6	0.3	3.15
3	140	0.7	0.4	3.29

Run	Speed	Feed Rate	DOC	Roughness
4	140	0.8	0.5	3.42
5	190	0.5	0.3	3.12
6	190	0.6	0.2	3.09
7	190	0.7	0.5	3.19
8	190	0.8	0.4	3.51
9	240	0.5	0.4	3.23
10	240	0.6	0.5	3.19
11	240	0.7	0.2	3.31
12	240	0.8	0.3	3.49
13	290	0.5	0.5	3.33
14	290	0.6	0.4	3.45
15	290	0.7	0.3	3.39
16	290	0.8	0.2	3.63

The formula required for the signal to noise ratio analysis was present in table 7.

TABLE 7

SIGNAL TO NOISE RATIO FORMULATION FOR RESPONSES

Response Parameter	S/N ratio Option	Formula
Tensile Strength	Larger is better	$S/N = -10\log\frac{1}{n}\left(\sum y^2\right)$
Drilling Time	Smaller is better	$S/N = -10\log\frac{1}{n}\left(\sum\frac{1}{y^2}\right)$

8. S/N Ratio-Surface Roughness

In the Taguchi method, the signal-to-noise (S/N) ratio is used to measure the performance of a product or process. The S/N ratio is a measure of the strength of the signal (i.e., the desired output or response) relative to the noise (i.e., the undesired variation or error). The S/N ratio is calculated by dividing the mean of the signal by the standard deviation of the noise. A higher S/N ratio indicates that the signal is stronger and the noise is weaker, resulting in better performance. A lower S/N ratio indicates that the signal is weaker and the noise is stronger, resulting in poorer performance. In the Taguchi method, the S/N ratio is used to determine the optimal levels of the factors that affect the performance of a product or process. By changing the levels of these factors and measuring the resulting S/N ratio, it is possible to identify the optimal combination of factor levels that results in the highest S/N ratio and the best performance. The S/N ratio is an important concept in the Taguchi method and is widely used in quality control and engineering to measure and improve the performance of products and processes.

Using equation from table 7, the individual S/N ratio for the present response surface roughness was computed. Based on these individual S/N ratios, the average S/N ratio table was created to compute the delta variable using equation from table to determine the relationship between factors and response parameters. Table 8 displays the average S/N ratio and delta for the surface roughness response parameter. Figure 5 depicts the Mean surface roughness map for orthogonal array L16.

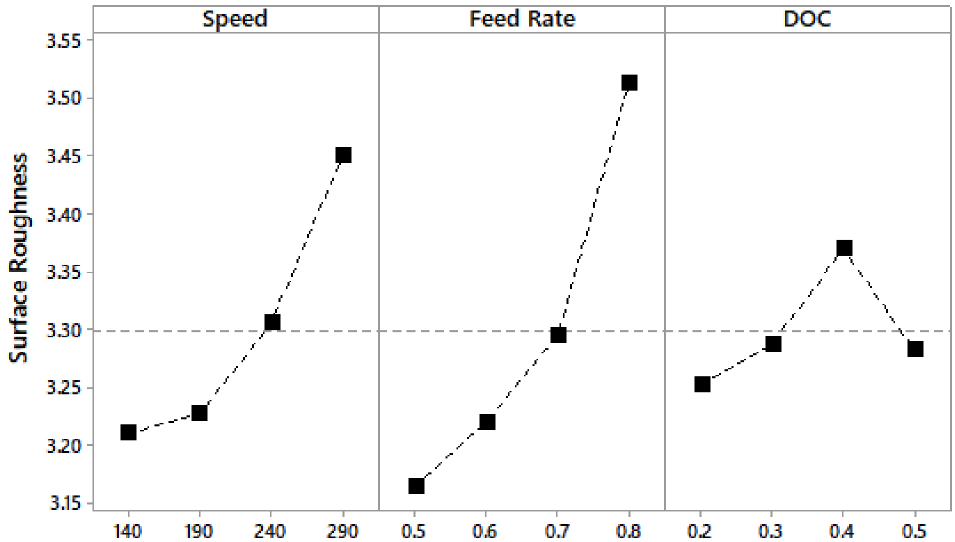

Fig. 5 Mean Surface Roughness plots for input parameters

As seen in figure 5, the average roughness of the orthogonal array trials L16 was present for all three variables Speed, feed rate, and depth of cut. As shown in the figure for speed, the surface roughness increased as the speed levels rose. The same increase was displayed for the machine's feed rate. In contrast, in DOC, the first three levels indicate an increase in surface roughness, while the final level indicates a decrease. This is due to the influence of two additional elements and the heating of the item, which can alter the surface roughness of the final product.

TABLE 8

Rank identification for surface roughness of d2 tool steel

Level	Speed	Feed Rate	DOC
1	-10.12	-10	-10.22
2	-10.17	-10.15	-10.33
3	-10.38	-10.36	-10.55
4	-10.75	-10.91	-10.32
Delta	0.63	0.91	0.33
Rank	2	1	3

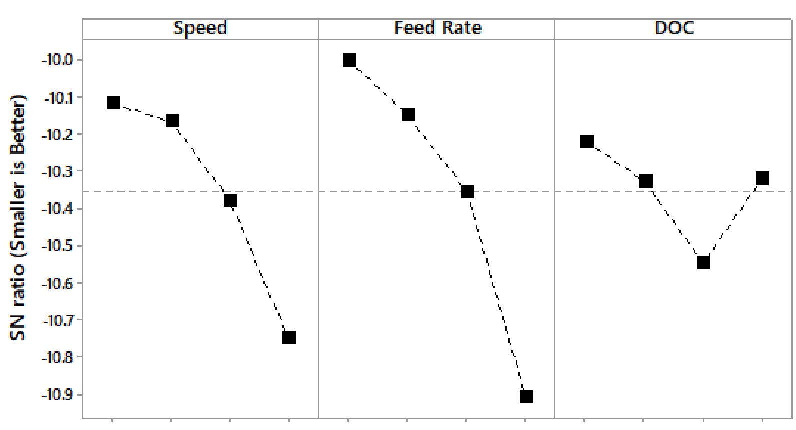

Fig. 6 S/N Ratio of Surface Roughness plots for input parameters

The rank identification and S/N ratio (lower is better) were displayed in table 8 and figure 6, respectively. As shown in table 8, the most important element for controlling the surface roughness of the item is feed rate, followed by the speed of the operation and the depth of cut (DOC).

Regression modeling is developing the statistical relation among independent and dependent factors and the validated with using Analysis of variance (ANOVA) test. In present section the linear regression modeling equations was developed for Surface roughness. After developed equation was tested by ANOVA test in which percentage contribution of each factors was presented. The Pareto chart and AVOVA table was shown in figure 7 and table 9 respectively.

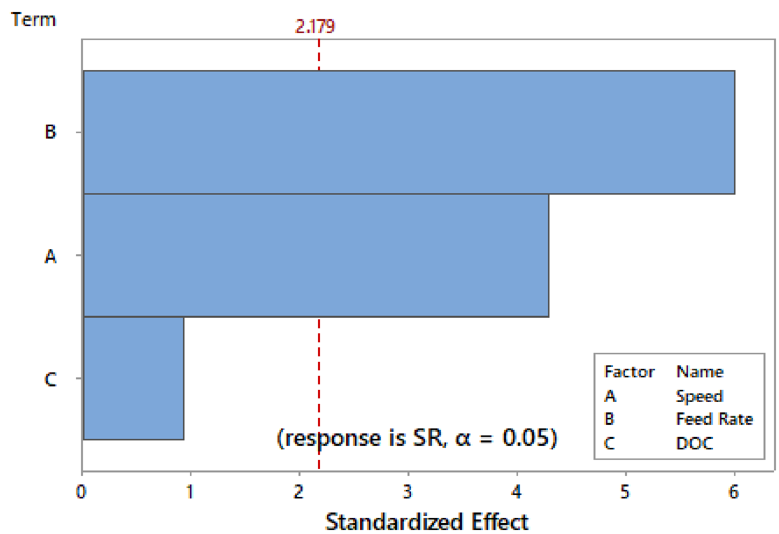

Fig. 7 Pareto Plot for Response Surface Roughness for Linear Regression

TABLE 9

ANOVA testing for regression of surface roughness

Source	DF	SS	Contribution	MS	F-Value	P-Value
Model	3	0.382914	82.23%	0.127638	18.51	0
Linear	3	0.382914	82.23%	0.127638	18.51	0
Speed	1	0.127201	27.32%	0.127201	18.45	0.001
Feed Rate	1	0.249761	53.64%	0.249761	36.23	0
DOC	1	0.005951	1.28%	0.005951	0.86	0.371
Error	12	0.08273	17.77%	0.006894		
Total	15	0.465644	100.00%			
R2			82.23%			

As seen in table 9 ,the highest contribution of among all factors was for Feed rate which was equal to 54% whereas the least percentage contribution was for DOC and the present factor was not significant for the liner regression model equation of the Surface Roughness. The normal probability plot for the residuals of the surface roughness was shown in figure 8.

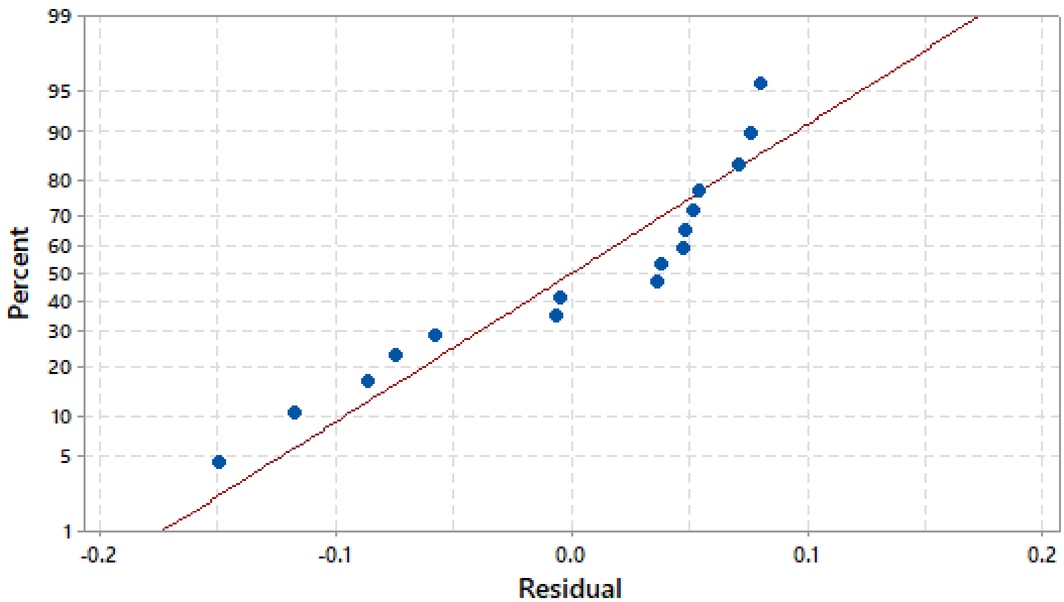

Fig. 8 Normal Probability plot for Regression of Surface Roughness

The final linear regression model equation developed for surface roughness was shown in equation

$$\text{Surface Roughness} = (0.0015 * \text{Speed}) + (1.118 * \text{Feed Rate}) + (0.173 * \text{DOC}) + 2.168$$

9. Conclusion

The signal to noise ratio (smaller is better) analysis for surface roughness response parameter provide the some important conclusion which are following: the best ranked parameter was feed rate, second ranked parameter was speed and least ranked parameter was DOC. The Optimal solution for the surface roughness was at (Speed140 FeedRate0.5 DOC0.2) found. It was also found that by increasing the speed, the surface roughness of the object was also increased. By increasing the feed rate, the surface roughness of the object was also increased but for DOC the Surface roughness was first increased then decreased.

References

[01] Brinksmeier, E., Walter, A., Janssen, R., & Diersen, P. (1999). Aspects of cooling lubrication reduction in machining advanced materials. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 213(8), 769-778.

[02] Lal GK, and Choudhury (2005) Fundamentals of Manufacturing Processes. Narosa Publication House Pvt Ltd. India

[03] Weinert, K., Inasaki, I., Sutherland, J. W., & Wakabayashi, T. (2004). Dry machining and minimum quantity lubrication. CIRP annals, 53(2), 511-537.

[04] Sreejith, P. S., & Ngoi, B. K. A. (2000). Dry machining: machining of the future. Journal of materials processing technology, 101(1-3), 287-291.

[05] Ho, Hoa & Haasis, Hans. (2017). Improving Value Chain Through Efficient Port Logistics. Management Studies. 5. 10.17265/2328-2185/2017.04.007.

[06] Yoon, H. -S., Lee, J. –Y., Kim, H. -S., Kim, M. -S., Kim, E. –S., Shin, Y. –J., Chu, W. -S., & Ahn, S. -H., (2014). A Comparison of Energy Consumption in Bulk Forming, Subtractive, and Additive Processes: Review and Case Study. International Journal of Precision Engineering and Manufacturing Green Technology, 1, 261 – 279.

[07] Javidrad, Hamidreza & Ahadi, Erfan & Larky, Mostafa & Riahi, Mohammad. (2018). Investigation in environmental and safety aspects of additive manufacturing (AM).

[08] Balaji, S. & Selvakumar, C. & Sukanya, G. & Muruganandham, V.R. & Devan, P.D.. (2022). Investigation and optimization of turning process parameters in super duplex stainless steel. Materials Today: Proceedings. 10.1016/j.matpr.2022.01.450.

[09] Girsang, Irving & Dhupia, Jaspreet. (2015). Machine Tools for Machining. 10.1007/978-1-4471-4670-4_4.

[10] Chegdani, Faissal & EL Mansori, Mohamed. (2017). Friction scale effect in drilling natural fiber composites. Tribology International. 119. 10.1016/j.triboint.2017.12.006.

[11] Rashid, Waleed & Goel, Saurav & Luo, Xichun & Ritchie, James. (2013). The development of a surface defect machining method for hard turning processes. Wear. 302. 1124-1135. 10.1016/j.wear.2013.01.048.

[12] H.K. Tonshoff, C. Arendt, R.B. Amor, Cutting of hardened steel, CIRP ¨ Annals—Manufacturing Technology 49 (2) (2000) 547–566.

[13] W. Grzesik, Mechanics of cutting and chip formation, in: J.P. Davim (Ed.), Machining of Hard Materials, Springer, London, 2011, pp. 87–114.

[14] Suresh, R. & Basavarajappa, Satyappa & Gaitonde, V. & Samuel, G.L. & Davim, J.. (2013). State-of-the-art research in machinability of hardened steels. Proceedings of the Institution of Mechanical Engineers Part B Journal of Engineering Manufacture. 227. 191-209. 10.1177/0954405412464589.

[15] Nakayama K, Arai M and Kanda T. Machining characteristics of hard materials. CIRP Ann: Manuf Techn 1988; 37(1): 89–92.

[16 Shivpuri R. Dies and die materials for hot forging. ASM Handbook, ASM International, USA 2005, pp.47–61.

[17] Lee WS and Su TT. Mechanical properties and microstructural features of AISI 4340 high-strength alloy steel under quenched and tempered conditions. J Mater Process Tech 1999; 87: 198–206.

[18] Lee TH and Mathew P. Experimental and theoretical investigation of AISI D2 hardened steel machining with varying nose radius CBN tools. Int J Mach Mach Mater 2007; 2(2): 254–269.

[19] Poulachon G and Moisan A. Hard turning: chip formation mechanisms and metallurgical aspects. J Manuf Sc E: T ASME 2000; 122(3): 406–412.

[20] Dutta, Samik & Pal, Surjya & Sen, Ranjan. (2014). Digital Image Processing in Machining. 10.1007/978-3-642-45176-8_13.

[21] Davies, Matt & Burns, Timothy. (2001). Thermomechanical oscillations in material flow during high-speed machining. Philosophical Transactions of The Royal Society A Mathematical Physical and Engineering Sciences. 359. 10.1098/rsta.2000.0756.

[22] Ning, Y., Rahman, M., & Wong, Y. S. (2001). Investigation of chip formation in high speed end milling. Journal of materials processing technology, 113(1-3), 360-367

[23] Halim, N. H. A., Haron, C. H. C., Ghani, J. A., & Azhar, M. F. (2019). Tool wear and chip morphology in high-speed milling of hardened Inconel 718 under dry and cryogenic CO2 conditions. Wear, 426, 1683-1690.

[24] Osmond, Luke & Curtis, David & Slatter, Tom. (2021). Chip formation and wear mechanisms of SiAlON and whisker-reinforced ceramics when turning Inconel 718. Wear. 486-487. 204128. 10.1016/j.wear.2021.204128.

[25] Zhao, Yanzhe; Li, Jianfeng; Guo, Kai; Sivalingam, Vinothkumar; Sun, Jie (2020). Study on chip formation characteristics in turning NiTi shape memory alloys. Journal of Manufacturing Processes, 58(), 787–795. doi:10.1016/j.jmapro.2020.08.072

[26] Hasbrouck, Christie & Hankey, Austin & Abrahams, Rachel & Lynch, Paul. (2020). Sub-Surface Microstructural Evolution and Chip Formation During Turning of AF 9628 Steel. Procedia Manufacturing. 48. 559-569. 10.1016/j.promfg.2020.05.083.

[27] Patel, Vallabh D.; Gandhi, Anish H. (2019). Analysis and modeling of surface roughness based on cutting parameters and tool nose radius in turning of AISI D2 steel using CBN tool. Measurement, (), S0263224119300806–. doi:10.1016/j.measurement.2019.01.077

[28] Tang, Linhu; Sun, Yongji; Li, Baodong; Shen, Jiancheng; Meng, Guoliang (2018). Wear performance and mechanisms of PCBN tool in dry hard turning of AISI D2 hardened steel. Tribology International, (), S0301679X18306054–. doi:10.1016/j.triboint.2018.12.026

[29] Mallick, Rajashree; Kumar, Ramanuj; Panda, Amlana; Sahoo, Ashok Kumar (2020). Performance characteristics of hardened AISI D2 steel turning: A review. Materials Today: Proceedings, (), S2214785320313201–. doi:10.1016/j.matpr.2020.02.565

[30] R. Kumar, A.K. Sahoo, P.C. Mishra, R.K. Das, Comparative investigation towardsmachinability improvement in hard turning using coated and uncoatedcarbide inserts: part I experimental investigation, Adv. Manuf. 6 (1) (2018)52–70.

[31] R. Kumar, A.K. Sahoo, P.C. Mishra, R.K. Das, Performance assessment of airwater and TiO2 nanofluid mist spray cooling during turning hardened AISI D2steel, Ind. J. Eng. Mater. Sci. 26 (2019) 235–253.

[32] F. Kara, M. Karabatak, M. Ayyıldız, E. Nasc, Effect of machinability,microstructure and hardness of deep cryogenic treatment in hard turning ofAISI D2 steel with ceramic cutting, J. Mater. Res. Technol. (2019), https://doi.org/10.1016/j.jmrt.2019.11.037.

[33] A. Srithar, K. Palanikumar, B. Durgaprasad, Experimental investigation andsurface roughness analysis on hard turning of AISI D2 steel usingpolycrystalline cubic, Boron Nitride (PCBN) Mater. Today: Proc. 16 (2019)1061–1066.

[34] S.S. Sarnobat, H.K. Raval, Experimental investigation and analysis of theinfluence of tool edge geometry and work piece hardness on surface residualstresses, surface roughness and work-hardening in hard turning of AISI D2steel, Measurement 1312 (2019) 35–260.

[35] M.A. Xavior, P. Jeyapandiarajan, Multi-objective optimization during hardturning of AISI D2 steel using grey relational analysis, Mater. Today:. Proc. 5 (5)(2018) 13620–13627

[36] Algarni, Mohammed. (2019). Mechanical Properties and Microstructure Characterization of AISI “D2” and “O1” Cold Work Tool Steels. Metals. 9. 1169. 10.3390/met9111169.