Industrial Engineering Journal
ISSN: 0970-2555
Volume : 52, Issue 12, No. 2, December : 2023

OPTIMIZATION USING DEFORM-3D SOFTWARE AND EXPERIMENTAL STUDY ON THE INFLUENCE OF MAGNETIZED COOLANT ON TOOL WEAR IN TURNING OPERATION

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Abstract: DEFORM-3D is a FEM-based simulation software designed to analyze the three-dimensional (3D) flow of complex metal forming processes using the Lagrangian method. It is a practical and efficient tool to predict the material flow in industrial forming operations without the cost and delay of shop trials. While machining highly hard materials the friction developed in the machining area will generate more heat which reduces the tool life. Magnetization of Coolant is one of the methods which increases the effective viscosity value which reduces the friction by decreasing the rate of coolant flow between the tool-chip interface. In this present work DEFORM 3D software has been used to simulate and to get the optimal process parameters for minimum Tool wear in turning of AISI D3 high carbon steel material with tungsten carbide insert with the help of Taguchi L9 Orthogonal array-based design of experiments. Further, the process variables (speed, feed, and depth of cut) were optimized using the statistical techniques ANOVA and Regression analysis. On lathe machine experimental work has been carried out by using both the Magnetized and Non-Magnetized coolants with the optimal machining process parameters obtained from the software. The tool wear mechanism has been observed through SEM (Scanning Electron Microscope) analysis. It's a shred of clear evidence that the use of magnetized coolant reduces the tool wear progression when compared with the use of non-magnetized coolant.

Keywords: DEFORM 3D, Optimization, L9 Orthogonal array, Tool wear, Magnetisation, Effective viscosity, SEM analysis.

Introduction: Production operations often demand extended periods of heavy cutting, which can generate excessive heat that cannot be dissipated through normal coolant alone. To mitigate this issue, magnetized liquid coolant is used to swiftly remove heat and prevent production from being halted due to overheating. In addition, magnetized coolant can enhance cutting speeds, while simultaneously reducing friction and wear on the tool. This is possible because cutting fluids serve as lubricants, facilitating the cutting processes by reducing the resistance between the chip and the tool's cutting edge. By effectively controlling the temperature and reducing friction, the use of magnetized coolant significantly improves the efficiency of production processes and enhances the Tool life. Umidjon Mardonov, et, al. [1] They conducted research and summarized the findings of their investigation into the effects of a magnetic field on a variety of flowing and non-flowing fluids. They also claimed that the magnetic field causes the moving fluid's viscosity coefficient to decrease. The influence of a magnetic field on a liquid's property can be used in a variety of mechanical engineering applications, including lubricating coolants in the cutting process. Yong Yang, et, al. [2] They evaluated the magnetization treatment technique and the law of its influence on cutting performance using a newly designed triethanolamine borate water-based cutting fluid as the research object. They discovered the magnetic field strength, as well as parameters for friction coefficient, roughness, and workpiece surface shape, by assessing findings and parameters. Xuhong Guo, et, al. [4] discussed the effect of a magnetic field on the cutting performance of micro-textured tools when lubricated with Fe_3O_4 Nanofluid. They also mentioned that cutting 316 L stainless steel with micro-textured tools was done in a magnetic field, and the influence of different magnetic field parameters on the machining characteristics of micro-textured tools (TT) under Fe3O4 Nanofluid (MNF) lubrication conditions was studied. P. Bagchi, et, al. [5] looked into the theoretical analysis and experimental results, which both point to the possibility of improving cutting tool wear characteristics under the influence of a magnetic field. Friction is assumed to be the primary cause of wear in the theoretical study. M. K. Muju, et, al. [6] discovered the impact of magnetic fields on cutting tool diffusive wear. Diffusivity has a direct effect on the mass of a wear particle, and applying an external magnetic field to a deforming junction has a significant impact. A. Bouchoucha, et,al. [7] investigated the effect of a magnetic field on the wear of a cutting tool constructed of metallic carbide during a turning operation. Observations using a scanning electron microscope (SEM) and an optical microscope revealed three forms of wear: flank wear, crater wear, and wear caused by plastic deformation. Furthermore, they found that increasing the magnetic field changes the form and morphology of chips while also raising the contact temperature. N. Ab Wahab et, al. [8] created a portable magnetic clamping chuck for lathe machines. The chuck is composed of mild steel and features a few brass intercepts. This project demonstrates how to make magnetic clamping and how to determine its functionality. A Finite Element Method (FEM) based software DEFORM 3D is a process simulation system used by Production engineering industries to analyze machining processes in computers. The main purpose of using this software is to reduce the shop floor trials and redesigning of tools also the improved tool and die designs minimize the overall cost of manufacturing. This simulation software also shortens the lead time in bringing a customer's desired product to market [9]. Taguchi L9 orthogonal array-based design of experiments is a statistical technique that provides process optimization and this is a powerful tool providing an efficient manufacturing environment for producing high-quality products [10-12].

1. Material: AISI (American Iron and Steel Institute) D3 steel is one of the alloys of steel. This steel istreated with heat to get a hardness in the range of 58 – 64 HRC. After heat treatment, this steel gets properties like high absorption/wear resistance, good dimensional stability, and high compression strength. It allows corrosion resistance when it is polished. This steel belongs to the 'D' group based on the AISI classification system. AISI D3 steel shows high wear resistance when it contains 12% of chromium tool steel, Table 1 shows the chemical composition with % of the mass contribution. D3 steel offers better surface conditions under oil hardening. Mostly used for Cold die punches, Ejector pins, Die drawings, Power metal tooling, Blanking dies for paper, and Shear blades.

Table 1 Chemical Composition of AISI D3

C	Si	Mn	Cr	W
2.5	0.60	0.60	12	1

2. DEFORM 3D Simulation: Speed, feed & depth of cuts have been taken as process parameters (Table 2) and Simulation has been done up to 1200 steps for turning up to 25mm length by considering those three process parameters with three levels. Taguchi's L9 orthogonal array-based design of experiments has been used to run the simulation (Table 3). Figure 1 shows the process setup in which machining parameters speed, feed, and depth of cut values have been entered. Figure 2 shows the selection of the material in the software, and finally, Figure 3 shows the simulation run.

Table 2 Process variables and levels

Process Parameter	Level-1	Level-2	Level-3
Speed (RPM)	635	975	1500
Feed (mm/rev)	0.285	0.347	0.499
Depth of cut (mm)	0.5	1.0	1.5

Table 3 Design of Experiments (L9 Orthogonal array)

Simulation run	Speed (RPM)	Feed (mm/rev)	Depth of Cut (mm)
1	635	0.285	0.5
2	635	0.47	1.0
3	635	0.499	1.5
4	975	0.285	1.0
5	975	0.347	1.5
6	975	0.499	0.5
7	1500	0.285	1.5
8	1500	0.347	0.5
9	1500	0.199	1.0

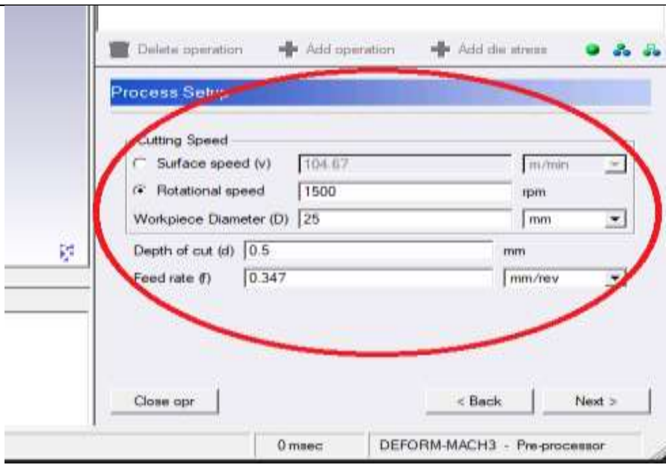

Fig 1: Process setup in Software

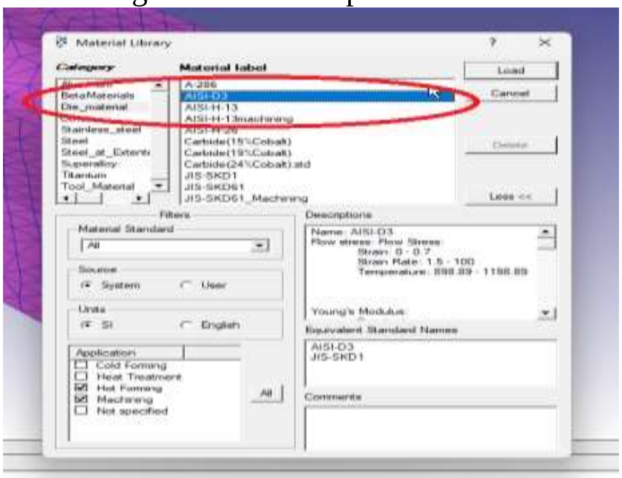

Fig 2: Selection of material in software

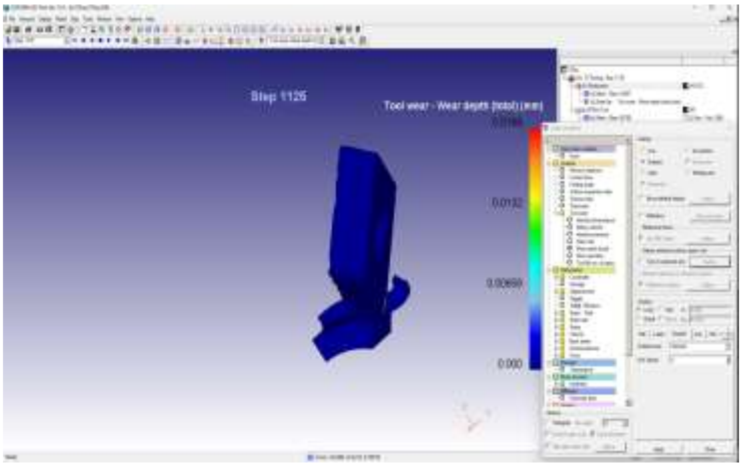

Fig 3: Simulation Run

2.1 Simulation Results and Discussion: The tool wear-wear depth (mm) results were obtained from the simulation (Figure 4)) of the nine experiments in DEFORM-3D software have been taken. Table 4 shows the nine experimental runs with process parameters and tool wear values. Now, the obtained wear depth values were further analyzed for optimization using MINITAB software. From Taguchi's statistical technique of design of experiments (DOE), using the smaller-is-the-better formula of the S/N ratio, the combined S/N ratio values were determined which is shown in Table 4.

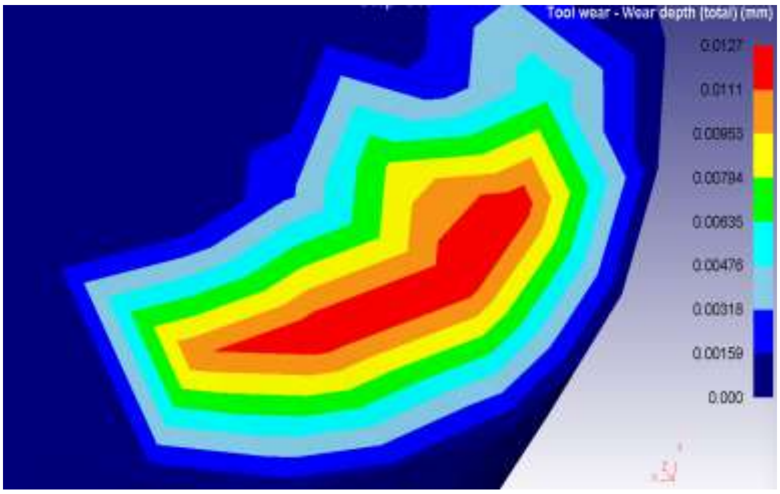

Fig 4: Tool Wear-Wear depth in software

2.2 ANOVA and Regression Analysis: ANOVA is a Statistical objective-based decision-making tool that is used for analyzing the effect of machining factors and their percentage contribution towards the output. From Table 7 Analysis of Variance for S/N ratios, Speed has the highest percentage of contribution with 62.08%, and it is the most significant factor for tool wear. The other machining factors Depth of cut and Feed have percentage contributions of 16.11%, and 12.83% respectively. Error with 8.96% contribution which is under acceptable limit (<10%).

Table 4 Wear-depth and S/N ratio values

Exp. No	Speed (RPM)	Feed (mm/rev)	Depth of cut (mm)	Tool wear-wear depth (mm)	S/N Ratio values
1	635	0.285	0.5	0.022	33.1515
2	635	0.347	1	0.0207	33.6806

3	635	0.499	1.5	0.0228	32.8413
4	975	0.285	1	0.0201	33.9361
5	975	0.347	1.5	0.0192	34.334
6	975	0.499	0.5	0.0176	35.0897
7	1500	0.285	1.5	0.0161	35.8635
8	1500	0.347	0.5	0.0127	37.9239
9	1500	0.499	1	0.0191	34.3793

Table 5 Response Table for Signal to Noise Ratios

Level	Speed	Feed	Depth of cut
1	33.22	34.32	35.39
2	34.45	35.31	34.00
3	36.06	34.10	34.35
Delta	2.83	1.21	1.39
Rank	1	3	2

From Table 5 Response Table for Signal to Noise Ratios and from Figure 5 main effects plot for S/N Ratios, the larger S/N ratio is considered for minimizing the output. The minimum tool wear-wear depth of 0.0127mm was obtained at Level 3 of Speed (1500 rpm), Level 2 of Feed (0.347 mm/rev), and Level 1 of Depth of cut (0.5mm) which were considered as optimum factor levels. From the Table 6 Response Table for Means from the Figure 6 Main Effects plot for Means, the smaller mean value is considered for minimizing the output, which gives us the same optimum levels as above.

Table 6 Response Table for Means

Level	Speed	Feed	Depth of cut
1	0.02183	0.01940	0.01743
2	0.01897	0.01753	0.01997
3	0.01597	0.01983	0.01937
Delta	0.00587	0.00230	0.00253
Rank	1	3	2

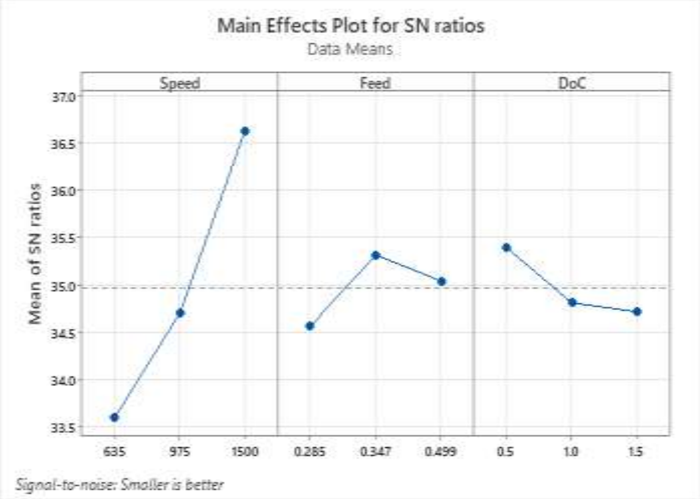

Fig 5: Main Effects plot for S/N Ratios

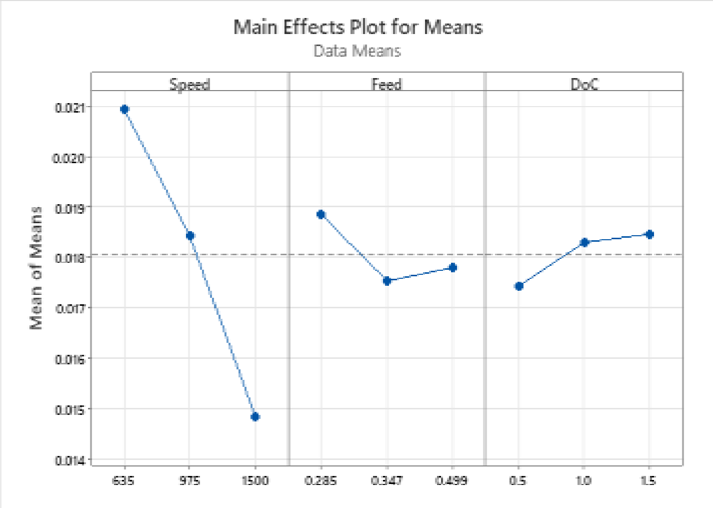

Fig 6: Main Effects plot for Means

Table 7 Analysis of Variance for S/N Ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Speed	**2**	**12.092**	**12.092**	**6.0462**	**6.92**	**0.126**	**62.08**
Feed	2	2.500	2.500	1.2499	1.43	0.411	12.83
Depth of cut	2	3.138	3.138	1.5691	1.80	0.358	16.11
Residual Error	2	1.746	1.746	0.8732			8.96
Total	8	19.477					

Regression Equation

Tool wear = 0.02223 - 0.000007 Speed + 0.00449 Feed + 0.00193 Depth of cut

Table 8 Analysis of Variance for Regression

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	0.000058	0.000019	4.96	0.058
Speed	**1**	**0.000051**	**0.000051**	**13.08**	**0.015**
Feed	1	0.000001	0.000001	0.38	0.567
Depth of cut	1	0.000006	0.000006	1.44	0.284
Error	5	0.000020	0.000004		
Total	8	0.000078			

The regression analysis has been used to predict the correlation between the factors and responses. The developed regression model is based on regression analysis for the responses given in the above equation with respect to Tool wear. From Table 8 Analysis of Variance for Regression, Speed has a P (Probability) value lesser than 0.05 which indicates a significant impact on tool wear followed by depth of cut and feed. The Error percentage among simulation and predicted values were found to be within the permissible limit.

3 Experimental work : To avoid the high machining cost, and machining time and to reduce the number of trials for knowing the best input parameters while machining, Computer-based simulation

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 52, Issue 12, No. 2, December : 2023
has been adopted for knowing the optimal process parameters. On the lathe machine, the turning operation has been carried out by using the optimal process parameters which were found in DEFORM 3D simulation software. Speed-1500 RPM, Feed-0.347 mm/rev, and Depth of cut-0.5mm were used in turning AISI D3 steel. Low-grade Soluble oil has been used as a coolant. First, the machining has been carried out by supplying non-magnetized coolant, after that magnetized coolant was supplied while machining. In both cases, the tool wear progression was analyzed with the help of results obtained from SEM analysis.

3.1 Magnetization of coolant: Magnetization of the coolant is to impose a magnetic field by which the net effect of increasing the effective viscosity. The rate of fluid transport is slowed by the increased magnetic viscosity, resulting in a thickening of the momentum boundary layer. The main purpose of magnetization is to set up the disordered molecules in an ordered manner to absorb more friction or heat while machining. For magnetizing the cutting fluid, we have to prepare the setup for generating the magnetic flux. Copper winding is prepared for the south and north pole by rotating the copper wire in a clockwise and anti-clockwise direction to produce magnetic flux the copper winding rounds up to 3000 turns (10 layers, each layer with 300 turns) copper winding is taken, and by the transformer (Figure 7), the voltage step down is taken for up to 100 volts and then the magnetic flux of nearly 2000 Gauss is generated in the copper winding and it is measured by the gauss meter. Figure 8 shows an Ostwald Viscometer, by using that viscometer the viscosity values of both Non-magnetized and magnetized coolants were calibrated. Table 9 shows the viscosity values of coolant before and after magnetization.


Fig 7 Magnetization of coolant

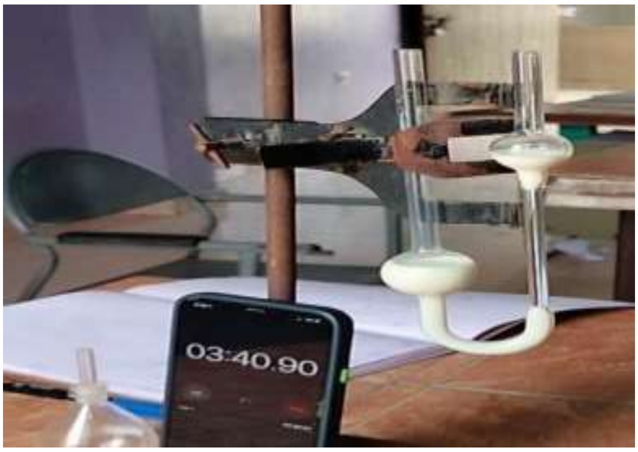

Fig 8: Ostwald Viscormeter

Table 9 Coolant density & viscosity values

Physical Property	Before Magnetization	After Magnetization
density (g/cm3)	1.02	1.15
Viscosity (Milli poise)	10.41	13.08

3.2 SEM Analysis: Tool wear is a major concern in many industries, particularly in manufacturing and machining, where wear and damage to cutting tools can impact the quality and efficiency of the production process. SEM analysis can help identify the wear mechanisms and modes of tool failure, such as adhesive wear, abrasive wear, or fatigue wear. To better understand the wear mechanisms and functionality of materials and tools, SEM imaging can offer extensive information about surface properties, such as surface roughness, wear patterns, and tool marks.

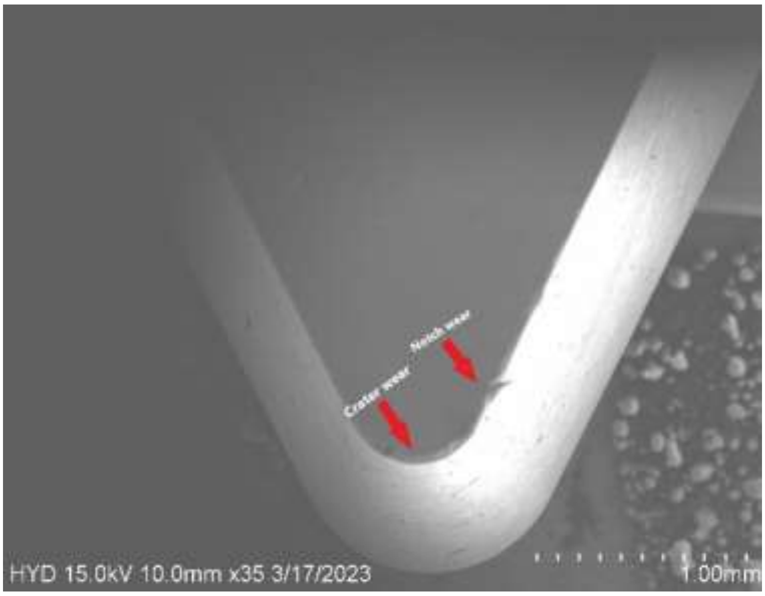

Fig 9: Tool insert SEM analysis for tool wear (Using Magnetized coolant)

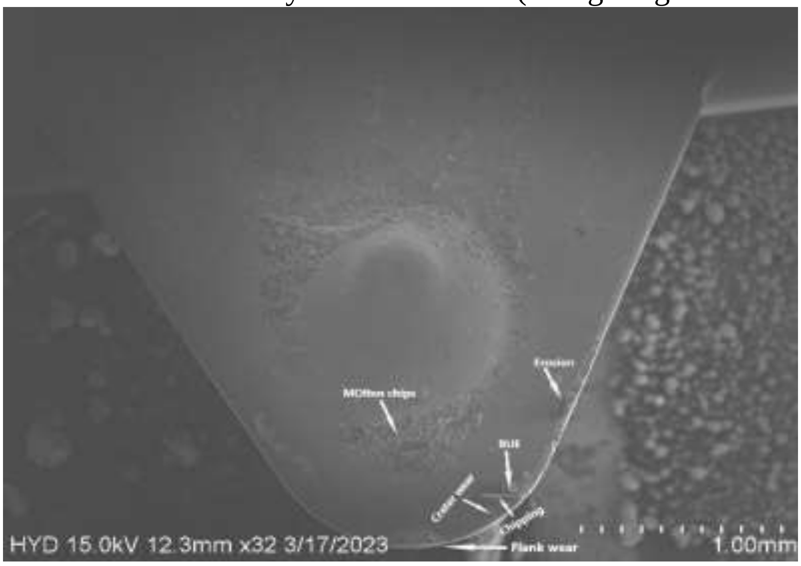

Fig 10: Tool insert SEM analysis for tool wear (Using Non-Magnetized coolant)

The wear spots and wear progression are more when the machining has been carried out by using non-magnetized coolant. Figure 10 gives a clear picture of the wear mechanism with Crater wear, Flank wear, built-up edge formation, Erosion of edges, and some of the molten chips adhered to the face of the insert. Whereas tool wear is minimum when machining has done with magnetized coolant. Figure 9 shows the wear mechanism for magnetized coolant.

4. Conclusions

In this research article, DEFORM 3D software and Taguchi optimization were used to predict the optimal parameters for lower tool wear in the machining of AISI D3 high-carbon steel. ANOVA and Regression analysis were used to study the influence of process parameters. The following results are observed: The minimum wear depth of 0.0127mm has been observed at a speed of 1500 rpm, feed 0.347 mm/rev, and depth of cut 0.5mm. Speed is the most influential factor with 62.08 percent of the contribution. As the cutting speed increases tool wear increases.

Turning off AISI D3 high carbon steel with magnetized coolant reduces tool wear. From the SEM results, wear progression is minimum when compared with the turning of non-magnetized coolant.

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