EXPERIMENTAL STUDIES OF TEMPERATURE, SURFACE ROUGHNESS AND FEM ANALYSIS ON OPTIMIZATION OF PROCESSING PARAMETERS ON ORTHOGONAL MACHINING AISI 4340

Mohammad KHOSRAVI[1] and Hossein JAMSHIDI[2] and Ramin ZAREI[3]
[1]*Department of Mechanical Engineering, Birjand University of Technology, Birjand, Iran,*
E-mail: mkhosravi@birjandut.ac.ir
[2] *Department of Mechanical Engineering, Birjand University of Technology, Birjand, Iran,*
E-mail: h.jamshidi@birjandut.ac.ir
[3]*Department of Mechanical Engineering, Birjand University of Technology, Birjand, Iran,*
E-mail: r.zarei@birjandut.ac.ir

ABSTRACT*: AISI 4340 steel is one of the most widely used materials in many industries, including modelling, automotive connecting rods, crankshafts, and gear shafts. In machined parts, surface quality is one of the most important output parameters that are of interest to the applicant. In this regard, in the chipping process, approximately 98% of the force applied to the workpiece is converted to heat in order to deform the material. Therefore, controlling the variations of temperature on the machined surface and its significant impact on the surface quality can improve the service life and performance of the part. Therefore, post-machining surface health is a crucial issue. Consequently, one of the most important methods by which the temperature in the shear zone is reduced, and the surface quality is improved is the optimization of machining parameters. In this research, using the parameters of cutting speed, feed rate, cutting depth, and tool radius in AISI 4340 steel orthogonal turning, temperature, and surface roughness were investigated. The results of experimental temperature tests were simulated by finite element software. Finally, the simulation results were in good agreement with the experimental results. Since the machining temperature and surface roughness have an effect on the machining performance, a composite function of temperature and surface roughness with the same effect is considered as the function. A quadratic model best describes the function changes with the most significant impact on the feed rate and then the tool radius. The proposed function models are considered in the range of shear parameters. The relative error of the optimal value and the mean value is 2.5%.*

KEYWORDS*: Machining, Surface Roughness, Temperature, Optimization*

1 INTRODUCTION

AISI 4340 steel with the standard number DIN 1.6582 and the approximate amount of typical elements of carbon, silicon, manganese and nickel are extensively used in various industries in manufacturing components that require high strength, toughness and fracture resistance. Among the most important applications of this steel are automotive rods, crankshafts, gear shafts and high-speed railway[1, 2]. By machining this steel, surface roughness and temperature in cutting zone can be achieved. Machining is a manufacturing process in which a sharp tool penetrates into a resilient material because of the relative movement of the tool and workpiece, and the shear force is applied to the tool-workpiece contact area. Penetration causes workpiece deformation to remove material from the surface in the form of chips. During chip formation, mechanical energy is converted to thermal energy. In soft materials, heat is generated in three distinct areas, namely the initial deformation zone, the tool-chip interface, and the workpiece-tool interface with tools affecting the quality of the finished product surface[3]. The decrease in tool temperature during the machining process affects some of the process parameters such as dynamic stability, tool wear, workpiece surface integrity and geometric dimensions. In tool temperature modelling, due to the selection of machine tool strength during machining, tool wear monitoring and surface roughness prediction are necessary[4, 5]. Surface roughness is a property of the material surface texture characterized by rough topography compared to an ideal flat surface. In assembled parts, surface roughness is one of the main parameters considered in determining the product quality. The machining parameters affecting surface roughness and shear force include cutting speed, cutting depth and feed rate. The correct selection of these parameters can reduce the amount of surface quality and machining force[6-13]. Some researchers have utilized the Taguchi method to optimize shear parameters to minimize surface roughness during machining[14]. In machining surface analysis, increasing shear force results in increased shear parameters during the turning operation. These parameters have a significant impact on machining operations[15, 16]. Figure 1 shows the impact of the cutting force on the shear parameters.

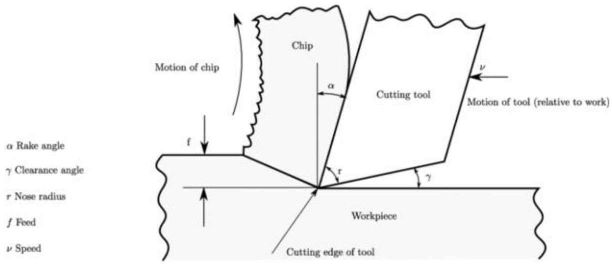

Fig. 1 Impact of cutting force on cutting tool and fracture plane[17]

In a study, the impact of cutting speed and feed rate on shear force and surface quality of EN24 alloy steel was investigated[18]. Surface quality plays an essential role in machined parts; therefore, optimizing and changing the shear parameters when machining alloy steel is done better for a final surface. During machining, increased friction between the tool and workpiece, and between the tool and chip results in high temperatures in the machining area. A shear fluid is used to reduce the high temperature in the machining area. Shear fluids improve the surface quality and tool life and machining process[19-21]. Due to the tool tip-workpiece friction, workpiece plastic deformation, tool-final surface lateral wear, the friction between the tool chip surface and deformed chip, and heat increase the temperature value in the shear zone[22, 23]. The temperature obtained from chipping is one of the limitations of machining operations. This has adverse effects on the workpiece surface quality, dimensional accuracy, tool wear, and prime cost. In addition, the use of shear fluid causes problems for human health and environmental pollution. These limitations have led researchers to perform dry machining operations at low temperatures. Taylor published his first paper on the role of heat in metal shear (cutting) in 1907[24]. In their research, Matsumoto et al. [25]concluded that the workpiece material and hardness affect the machined surface quality and integrity. In another study, Nalbant et al. [26] investigated the impact of feed rate, tool tip radius, and cutting depth on surface roughness in AISI 1030 steel turning. They reported that the feed rate and the tool tip had a more significant effect on surface roughness, whereas cutting depth had almost no effect on surface roughness. Additionally, Yang et al. [27] investigated the impact of tool tip radius, feed rate, and cutting depth on diamond-mediated facing on surface roughness obtained through simulation and experimental results. According to the results, the tool tip radius has the most significant impact and the cutting depth has the least effect on surface roughness. Some researchers have done their research to predict shear temperature using experiments. Many researchers agree that shear (cutting) temperature has a significant impact on machining performance; however, measuring and predicting it is not an easy task. Hence, they presented several techniques for measuring the shear temperature of the shear interface. Among other approaches, Shaw [24] and Stephen [28] have proposed the tool-work thermocouple method as a rational approach. However, given the difficulty of performing the experiments required to measure the shear temperature, many researchers have focused their attention on analytical and numerical problem-solving methods for evaluating the shear temperature. The published work [29] points out that the finite element method can predict the shear temperature in a steady-state machining mode.

Today, due to the importance and widespread use of AISI 4340 steel, the production of high-quality and long-lasting products is of great importance. This steel is one of the materials widely used in various industrial fields. So far, there has been limited research on the quality of machining surfaces and the temperature produced during the chipping process. Due to the frequent use of this material and the impact it generates on temperature, the machining process plays an essential role in surface quality, lathe quality, and overall manufacturing performance. This illustrates the importance of the present study. The results of the temperature test were simulated and compared with ABAQUS and DEFORM finite element software.

2 DESIGN OF EXPERIMENT

In this study, Design-Expert V11 software based on response surface methodology (RSM) was used to design the experiment. In analysing engineering problems, especially in performing experimental tests where the response to the problem is influenced by different input variables, the use of statistical methods of experiments helps design, model, analyse and optimize these processes. One of the best statistical methods is RSM. Experiment design is one of the most appropriate methods for researchers to improve, modify, save time and cost of tests and detect their accuracy and defects. The method can model the relation between the inputs and outputs of a test and present it as a mathematical quadratic equation. Given the effective variables and interactions, the general form of the equation is as Eq. 1.

$$y = \beta 0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i} \sum_{j} \beta_{ij} x_i x_j + \varepsilon \quad (1)$$

In this quadratic equation y is described as the output response in terms of the test inputs. In this equation β constants are the coefficients of the regression equation, xi is the main input factors of the test, is the square of the input factors of the test, and $xixj$ is the second-order interaction effect of the input factors of the test. If accurate, the proposed model can predict the output behaviour in terms of input parameters throughout the test and provide optimal points. Many tests must be performed to control the process. Therefore, one of the primary purposes of the Experiment design is to select the best possible modes by which the process can be investigated in the best possible way while justifying the number of tests[30]. In designing of experiments, according to Table 1, the Design-Expert software with RSM was used.

Table 1. Machining parameters

No	LEVEL 1	LEVEL 2	LEVEL 3	Unit
1.Cutting Speed	31.4	44.58	62.8	*m/min*
2.Feed Rate	0.08	0.16	0.32	*Rev/mm*
3.Cutting Depth	0.5	1	1.5	*mm*
4.Tool Radius	0.4	0.8	1.2	*mm*

3 EXPERIMENTAL

Thirty tests were carried out to investigate the temperature and surface roughness in the 4340 AISI steel chipping process under dry conditions. Machining was performed on specimens with a diameter of 20 mm and a length of 70 mm using a TN50D lathe with a maximum spindle speed of 1000 rpm. To minimize the umbrella phenomenon, all components were positioned between the 3-jaw chuck and the tailstock during testing. In addition, the dial gauge was used to ensure that the cutting edge was orthogonal to the workpiece in vertical machining. In the temperature and surface roughness tests, the same conditions are considered. In both experiments, due to the accuracy of the design, Computer Aided Design (CAD) and Insert were used without a chip breaker. Experiments were performed according to Table 2, which included material properties and shear tools. Additionally, the ambient temperature was measured at 21°C.

Table 2. material and tool properties

No	Specification	Description
1.Material Properties	AISI 4340	1.6582-34crnimo6
	Chemical Properties	C:0.3,Si:0.1,Mn:0.5,Mo: 0.15, Ni:1.03
	Dimensions	Length × Diameter 70 ×20 mm
2.Insert	TNMA160404- TNMA160408- TNMA160412	
3.Holder	DTGNR/L – A167	

3.1 Temperature measurement

A digital recording device needs to be used to measure the temperature during the shearing. For this purpose, the thermal MASTECH-M56550A camera was used. To accurately measure the tool-chip interface temperature, a 1mm diameter hole was created on the insert using a thermometer wire. Due to the limited cutting edge resistance against the machining force and the proximity to the tool radius due to the full touch of the wire with the thermocouple wire, the hole location is of great importance. Therefore, for the reasons mentioned, the best position of the hole is 4 mm from the cutting edges. The position of the insert hole and the super drill machine are shown in Figure 2.

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Fig 2. (a) Position of the insert hole, (b) Insert piercing with the super drill

Figure 3 illustrates how to set up machining equipment for this test.

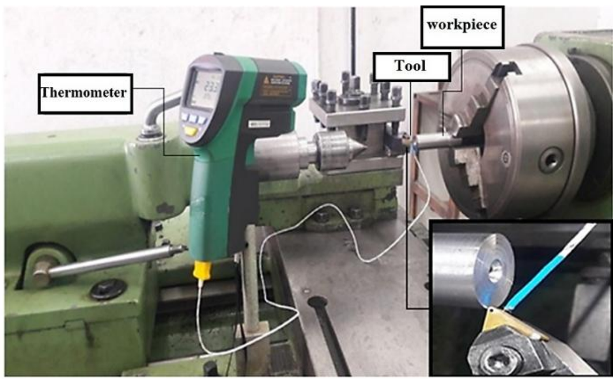


Fig 3. Equipment arrangement and placement

3.2 Surface roughness measurement

Different surface roughnesses are required for different functions. More or less surface roughness causes the parts not to function properly. This problem can be controlled by knowing the surface roughness and the impact of machining parameters on it. The present study used a Taylor Hobson roughness tester to measure surface roughness. Since the workpiece is round and the prop is also perpendicular to the tool sleep position, a V-Part is used to get it right. In addition, using the measuring cloths, the position of the workpiece head was stabilized in alignment. The prop length is 40 mm, the cut out is 0.25 and the accuracy is 0.01 µm. Figure 4 shows how the equipment is arranged and positioned.

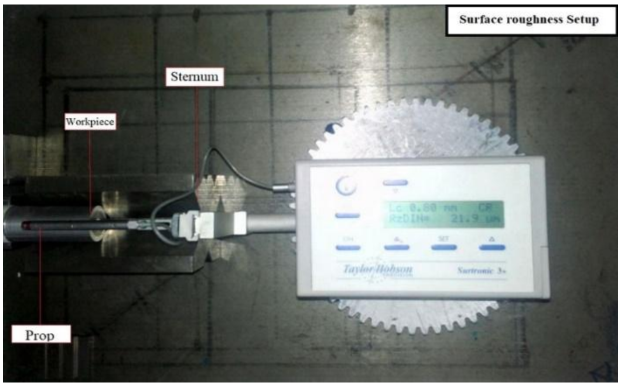


Fig 4. Roughness tester arrangement and placement

3.3 Experimental Results

As the machining parameters change the tool-workpiece interface temperature and the surface roughness change in AISI 4340 steel. Table 3 shows the results of the experimental tests based on four input parameters: cutting speed, feed rate, cutting depth, and tool radius, and two output temperature parameters between tool and workpiece and surface roughness. Since machining temperature(T) and surface roughness(SR) together influence machining performance, this study considers a combination of temperature and surface roughness with the same effect as the Function. Table 3 presents the values of temperature and surface roughness according to Equation 2 and 3 normalized as the Function.

$$\left(\frac{T_i - T_{min}}{T_{max} - T_{min}}\right) W_1 + \left(\frac{SR_i - SR_{min}}{SR_{max} - SR_{min}}\right) W_2 \quad (2)$$

$$W_1 = W_2 = 0.5 \quad (3)$$

In these relations, T_i is the machining temperature for each test, SR_i is the surface roughness for each test, T_{min} is the minimum measured temperature, T_{max} is the maximum measured temperature, SR_{min} is the minimum measured temperature, SR_{max} is the maximum measured surface roughness and W is a weight function.

Table 3. Values of input parameters, output parameters and Function

No	**input parameters**				**output parameters**		**Function**
	Cutting speed *m/min*	Feed rate *mm/rev*	Cutting Depth *mm*	Tool Radius *mm*	SR *µm*	Temp *c°*	
1	62.8	0.32	1.5	0.4	8.76	627	0.884024537
2	62.8	0.32	1.5	1.2	5.36	621	0.686937378
3	31.4	0.08	1.5	1.2	0.68	401	0.053082192
4	31.4	0.32	0.5	1.2	4.66	485	0.415599127
5	62.8	0.08	1.5	0.4	0.72	571	0.346375884
6	62.8	0.08	0.5	1.2	1.26	655	0.51988183
7	31.4	0.16	1	0.8	1.88	620	0.494016258
8	44.58	0.16	1	0.8	1.48	542	0.338476592

9	31.4	0.08	0.5	0.4	4.12	477	0.372230167
10	31.4	0.08	0.5	1.2	1.94	374	0.069230769
11	62.8	0.16	1	0.8	1.52	615	0.465674394
12	44.58	0.16	1	0.8	1.48	542	0.338476592
13	44.58	0.16	1	0.8	1.48	542	0.338476592
14	62.8	0.32	0.5	1.2	2.36	524	0.356006322
15	44.58	0.16	1	0.8	1.48	542	0.338476592
16	62.8	0.08	1.5	1.2	1.52	601	0.441701791
17	44.58	0.16	1	0.8	1.48	542	0.338476592
18	44.58	0.32	1	0.8	5.04	643	0.707026193
19	44.58	0.16	1	1.2	1.42	592	0.420796327
20	31.4	0.08	1.5	0.4	1.04	604	0.420465151
21	44.58	0.08	1	0.8	0.86	537	0.295849014
22	44.58	0.16	0.5	0.8	0.82	505	0.238856691
23	44.58	0.16	1	0.8	1.48	542	0.338476592
24	31.4	0.32	1.5	0.4	9.78	623	0.933219178
25	62.8	0.32	0.5	0.4	8.70	589	0.815659341
26	44.58	0.16	1.5	0.8	0.80	662	0.506593407
27	62.8	0.08	0.5	0.4	2.86	608	0.527314466
28	44.58	0.16	1	0.4	2.68	581	0.47119148
29	31.4	0.32	0.5	0.4	8.24	467	0.581480506
30	31.4	0.32	1.5	1.2	4.78	554	0.540343218

4 FINITE ELEMENT MODELLING

4.1 General recommendations

In this study, ABAQUS V4-6.13 and DEFORM V10 were used to simulate the machining temperature from the turning operation. Tool material and workpiece in both software are tungsten carbide and AISI 4340, respectively. In ABAQUS, modelling is done in 2.5D and in DEFORM in 3D, with a total machining friction value of 0.15. The chipping process consists of an elastic zone and a plastic zone. One of the most important and applicable relations is the Johnson-Cook equation, which expresses the changes in material plastic shape under different temperature conditions and strain rates. Relation 4 shows the Johnson-Cook equation, which consists of three parts. These parts, from left to right, are the effects of strain hardening, effects of effective strain rate, reference strain rate, workpiece strain, and current workpiece temperature, respectively. Moreover, parameter A represents yield stress, B represents the strength coefficient, C represents the strain-rate sensitivity coefficient, n represents the strain hardening coefficient and M represents the thermal softening coefficient.

$$\sigma = (A+B\varepsilon^{n})(1+C\ln\frac{\varepsilon^{p}}{\varepsilon^{0}})(1-[\frac{T-T_{room}}{T_{melt}-T_{room}}]^{m}) \quad (4)$$

Parameters related to physical properties, thermal coefficients, and Johnson-Cook coefficients of AISI 4340 were used to simulate according to Table 4.

Table 4. Parameters related to physical properties and coefficients of Johnson-Cook tool and workpiece[30]

	A *[MPa]*	B *[MPa]*	n	c	m	Density *[kg/m3]*	Young's modulus *[GPa]*	Poisson's ratio	melting temp *[K]*	thermal conductivity *[W/m.c]*	Specific Heat *[J/kgK]*	D1	D2	D3	D4	D5
W	792	510	0.26	–	1.03	7830	207	0.29	1793	40	477	0.05	3.44	-2.12	0.002	0.61
T						1500	200	0.2	–	46	203					

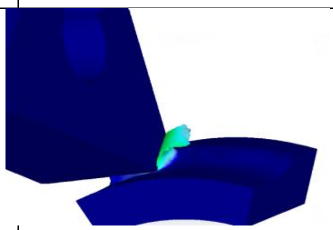
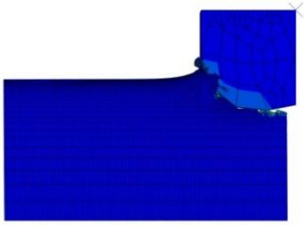
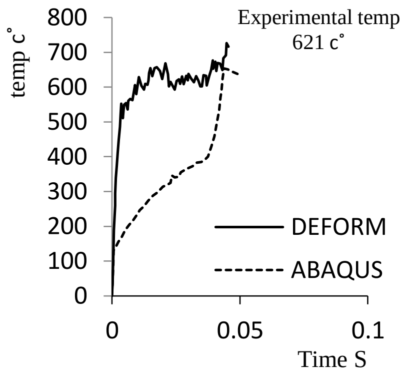
4.2 ABAQUS Simulation

In this simulation, the machining parameters are investigated according to Table 1. A dynamic-thermal coupling analysis was selected. Since the analysis is time-consuming, we split the part into two sections so that the meshes used are 2 mm smaller than others from the edge of the workpiece. The finer mesh size is 4E-5. Additionally, the elements used in this analysis are C3D8RT. To apply the boundary conditions in this analysis, all degrees of freedom (DoFs) of the bottom plane was modelled. The tool is rigid, and the workpiece is ductile.

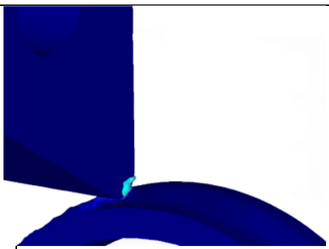
4.3 DEFORM Simulation

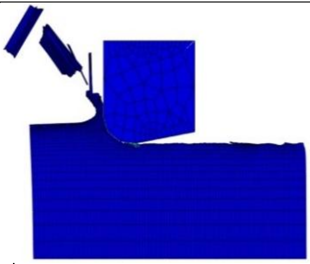
Process simulation is carried out by ABAQUS and also by DEFORM in 3D. In this analysis, the machining parameters were used according to Table 1, due to the absence of the desired tool geometry (without a chip breaker and different radii) in the DEFORM database, the tool was designed in the designing software Solidworks; this tool was used in DEFORM simulation. The material to be simulated is AISI4340, which is available in the software library. Areas affected by machining with finer meshing are considered for a detailed analysis relative to the rest of the workpiece. In the experimental tests, three of the experiments are simulated using the ABAQUS and DEFORM software. Table 5 shows the tool-workpiece interface temperature diagram derived from finite element simulations. The results have good validation.

Table 5. Tool-workpiece interface temperature from finite element simulation

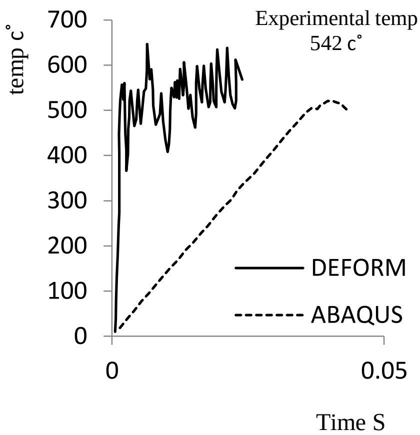
Test	DEFORM		ABAQUS		diagram
T2					
	Cutting speed 62.8 m/min	Feed rate 0.32 mm/rev	Cutting depth 1.5 mm	Tool Radius 1.2 mm	

T8

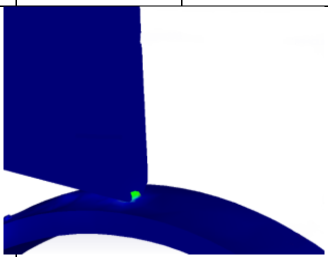


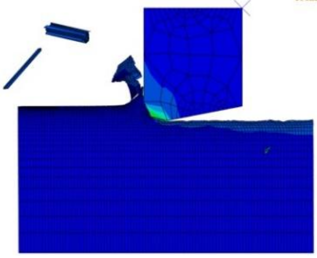


Cutting speed	Feed rate	Cutting depth	Tool Radius
44.58 m/min	0.16 mm/rev	1 mm	0.8 mm

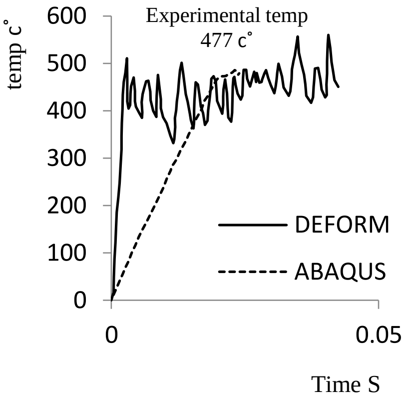


T9





Cutting speed	Feed rate	Cutting depth	Tool Radius
31.4 m/min	0.08 mm/rev	0.5 mm	0.4 mm



5 DISCUSSION AND RESULTS

In this study, AISI 4340 steel dry machining with variable parameters of cutting speed, feed rate, and cutting depth was investigated. To validate the tool-workpiece interface temperature, three experimental results have been simulated with ABAQUS and DEFORM finite element software, the results of which are obtained according to Table 5. Since the machining temperature and surface roughness together affect the machining performance, a composite function of temperature and surface roughness with uniform impact is considered as the Function.

5.1 Analysis of Variance

According to the results of temperature and surface roughness analysis, the results of the analysis of variance (ANOVA) are shown in Table 6. In the experiment design, the ANOVA table specifies the effect of input factors and their interactions on output response. Given the 95% reliability in engineering experiments, a P-value of less than 0.05 is considered to determine the effect of model components[31]. The SSE value of the data-matched model determines the accuracy of the model-governing equation and is vital in the experiment design. The lower this value in data-matched models, the lower the prediction error. In this study, the lowest number of these components was obtained for the full quadratic model.

Table 6. Results of Analysis of Variance

Source	Sum of Squares	df	Mean squares	F-Value	P-Value	
Model	1.06	14	0.0755	6.87	0.0003	▪
A-Cutting Speed	0.0761	1	0.0761	6.93	0.0188	▪
B-Feed rate	0.4656	1	0.4656	42.40	< 0.0001	▪
C-Cutting Depth	0.0537	1	0.0537	4.89	0.0430	▪
D-Tool Radius	0.1993	1	0.1993	18.15	0.0007	▪
AB	0.0258	1	0.0258	2.35	0.1463	
AC	0.0118	1	0.0118	1.07	0.3171	
AD	0.0282	1	0.0282	2.57	0.1298	

BC	0.0639	1	0.0639	5.82	0.0291	▪
BD	0.0266	1	0.0266	2.42	0.1408	
CD	0.0007	1	0.0007	0.0664	0.8001	
	0.0060	1	0.0060	0.5477	0.4707	
	0.0018	1	0.0018	0.1654	0.6899	
	0.0055	1	0.0055	0.5052	0.4881	
	0.0019	1	0.0019	0.1720	0.6842	
Residual	0.1647	15	0.0110			
Lack of Fit	0.1647	10	0.0165			
Pure Error	0.0000	5	0.0000			
Cor Total	1.22	29				

Given the lowest SSE value for the second-order model of the equation governing temperature and surface roughness, the process is as Equation 5.

F=0.521950 - 0.012454A + 1.13021B + 0.405569C - 0.712798D - 0.021141AB - 0.003449AC + 0.006676AD + 1.04674BC - 0.843560BD + 0.033754CD + 0.000201A^2 + 2.08530B^2 - 0.185081C^2 + 0.168741D^2 (5)

In the experiment design, one of the factors that determine the accuracy of the model governing the experiment is the R-sq value of the model. Another issue that determines the accuracy of modelling and results is the discussion of residual dispersion analysis. The model that has matched with the actual data must have passed close to the actual values, while the actual data distance from the matched regression model is low and random. R-sq indicates that this value is low. Figure 5 shows the distribution for each implementation. In this study, the model matched well and there is no particular order in residual dispersion, which is very good.

Fig 5. Dispersion per performance

Due to the modelling performed and its applicability to the experimental data and considering the effective term in the model, we try to explain the role of cutting speed, feed rate, cutting depth, and tool radius in surface roughness and temperature behaviour. Figure 6 presents the response procedure of surface roughness and temperature in terms of cutting speed and feed rate.

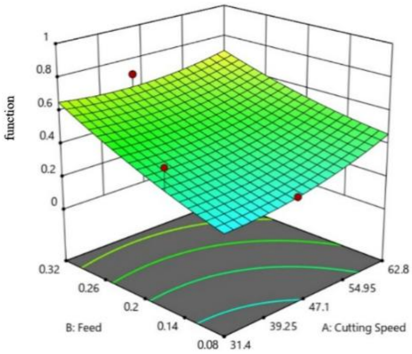


Fig 6. Response of surface roughness and temperature behavior

5.2 Effect of Input Parameters on Function

To investigate the effect of each input parameter on the response of the system as a Function, their "input factors effect" diagrams were analyzed by Design-Expert software. The relationship between surface roughness and the feed rate is according to Equation 6[32]. In this Equation, x represents front angle adjustment, x′ represents back angle adjustment, a_f represents feed rate, and H represents surface roughness. Since x and x′ are constant, surface roughness also increases by an increase in feed rate. In addition, the loading speed is increased, and the machining temperature is increased, which also increases the Function value.

$$H = \frac{a_f sinx' sinx}{sin(x' + x)} \quad (6)$$

Figure 7 shows the progressive changes in the response surface system as an Function. As the feed rate increases, the Function value also increases.

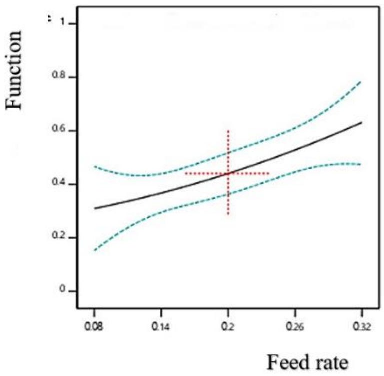


Fig 7. Feed rate changes in the response surface system

By examining the cutting depth changes, it can be concluded that by increasing the cutting depth in the response surface system, the Function value also increases with the cutting depth of 1.28 mm. Then, with increasing cutting depth, this value decreases, as shown in Figure 8.

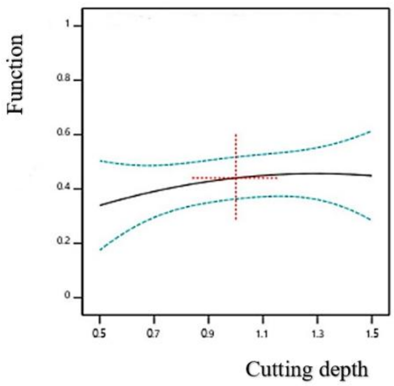


Fig 8. Cutting depth changes in the response surface system

An increase in the tool radius reduces the temperature and surface roughness. Equation 7 shows the relationship between surface roughness machined with the tool radius[32].

$$Ra = \frac{0.0321 a_f^2}{r_\varepsilon} \quad (7)$$

In this Equation, Ra represents the surface roughness, r_ε represents the tool radius, and a_f represents the feed rate. In the response surface system, the Function value decreases with increasing tool radius. Figure 9 illustrates these changes.

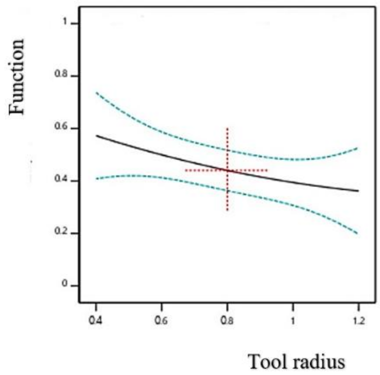


Fig 9. Tool radius changes in the response surface system

As the cutting speed increases, plastic deformation is facilitated. In addition, the friction between the chisel surface, chip, free surface, and machining surface is reduced. As shown in Figure 10, the cutting speed has not changed with an increasing cutting speed of up to 43 m/min. Then, because of the built-up edge, the Function value also increases.

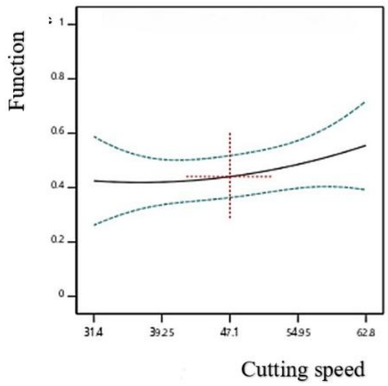


Fig 10. Cutting speed changes in the response surface system

5.3 Optimization

In the study of tool-workpiece interface temperature and surface roughness, RSM is used to optimize experimental conditions and find the highest impact, which is used to characterize the relationship between response and independent variables. This method designs the test matrix by benchmarking the number of variables as well as the maximum and minimum limits for each variable. Therefore, the number of tests and the levels of each variable in each test are specified, especially when there is a large number of variables. This method is superior to full-fledged methods, such as full factorial because it reduces the number of tests. Minimum values are considered to optimize the input parameters in the range of surface roughness and temperature tests. Table 7 shows the optimal value of the input and output parameters using the Design-Expert software.

Table 7. Optimal values of input and Function parameters

Cutting speed *m/min*	Feed rate *mm/rev*	Cutting depth *mm*	Tool Radius *mm*	RSM Function	Avg Function	Desirability
31.400	0.080	0.500	1.200	0.071	0.069	0.925

Three experiments with optimal input parameters were performed to verify the optimal Function value. The Function value in the response surface system and the mean of the Function obtained from the three experiments are in accordance with Table 7. The relative error of the optimal value and the mean value were calculated according to Equation 8, which is 2.5%.

$$\text{relative error} = \frac{|\text{real amount} - \text{Test result}|}{\text{real amount}} \times 100 \quad (8)$$

6 CONCLUSION

In this research, while using a suitable experiment design, modelling, simulation with finite element software and RSM optimization on AISI 4340 steel turning process with considering cutting speed, feed rate, cutting depth and the tool radius are defined as the input variables; the tool-workpiece interface temperature and the surface roughness are defined as the output variables. Additionally, a composite function of temperature and surface roughness with the same effect is considered as the Function. The behaviour of each of the variables in the process response has been carefully studied. The results of this study are as follows:

1- In the machining process of this steel under dry conditions, feed rate and tool radius have the most significant impact on the Function value.

2- According to the optimization performed in this study, it can be found that the Function minimum value in this process is obtained by using the lowest input parameters including the cutting speed of 31.4 m/min, feed rate of 0.08 mm/rev, cutting depth of 0.5 mm, and tool radius of 1.2 mm.

3- To verify the optimal Function value, three experiments with optimal input parameters have been performed. The relative error of the optimal value and the mean value is 2.5%.

4- From the quadratic mathematical equation of the in terms of input variables and modelling accuracy can be used for selecting the cutting parameters for forecast the given desired temperature and surface roughness.

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