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Approach by the response surface method to determine the cutting cemperature of AISI 1060 steel

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Abstract. The surface response method is widely used in many sectors of the industry, this method is a set of statistical and mathematical techniques used to minimize or maximize the factors of production by optimizing inputs factors. The use of this method helps to improve the quality of the products and processes while reducing the time and cost of producing the products. Our goal is to use this method to reduce the number of experiments and analyse the interaction between the cutting parameters (cutting speed, feed rate and depth of cut) and to predict the response (cutting temperature) during the machinability of the AISI 1060 steel, by turning. The results found the predicted values obtained by the mathematical model show good agreement with the experimental results, the error percentage of the numerical models and the accuracy were 5.15% and 94.85% respectively.

1. Introduction

The objective of mechanical engineering research has always been to find solutions to improve the productivity and quality of finished products [1]. The control and optimization of manufacturing processes, in particular manufacturing by material removal, is a major challenge, making it possible to minimize manufacturing costs and delays and to satisfy the technical and dimensional requirements of the workpiece. Cutting temperature is one of the most important factors in machining operations because it affects the life of the cutting tool and machined alloys [2-3].

The parts obtained by the removal of material must satisfy geometrical properties and quality characteristics. In order to meet these requirements, several experimental tests based on the choice of cutting conditions are often necessary before arriving at a satisfactory part. Currently, the use of these tests is costly and gives a wide range of choice of the parameters according to their need [4-5].

To optimize the organization of experiments and to exploit effectively the results obtained, it may be advantageous to use methods such as the surface response method. The general principle consists in studying only certain points of the experimental field, while apprehending the physical phenomenon to be studied over the whole field considered. In this work we use an optimization method to find the optimal cutting conditions (cutting speed, feed per revolution and depth of cut) to optimize the effect of cutting temperature on the process of machining.

2. Experimental procedure

For the experiments we used solid cylinders specimens of length 500 and diameter 40 held on the lap joint assembly (by a mandrel and counter - tip). The machine used to perform our tests is a tour parallel model EMCO Power: 6.6 kW. The grade of the steel used is AISI 1060 according to AISI. The chemical composition of the steel used presented in the following table.

Table 1. Chemical composition of the workpiece.

C%	Si%	Mn%	P%	S%	Cr%	Ni%	Mo%
0.440	0.250	0.610	0.016	0.024	0.160	0.040	0.005

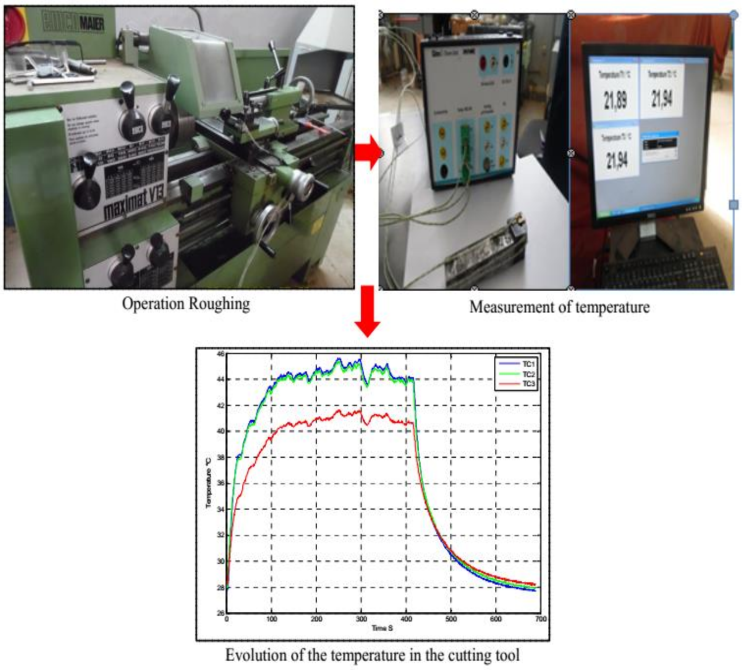


Figure 1. Experimental procedure of cutting temperature measurement and data Acquisition System.

The following table shows the measured values of the cutting temperature according to cutting parameters.

Table 2. Experimental values cutting temperature according to various cutting parameters.

Run	N(rev/min)	F(mm/rev)	a(mm)	T(°C)	N	N(rev/min)	F(mm/v)	a(mm)	T(°C)
1	440	0.045	0.25	34.81602	51	1500	0.045	0.25	41.74879
2	440	0.045	0.5	42.49966	52	1500	0.045	0.5	52.53566
3	440	0.045	0.75	49.65751	53	1500	0.045	0.75	67.86526
4	440	0.045	1	54.39473	54	1500	0.045	1	72.56069
5	440	0.045	1.5	70.23352	55	1500	0.045	1.5	91.23734
6	440	0.084	0.25	41.19957	56	1500	0.084	0.25	48.87676
7	440	0.084	0.5	48.02595	57	1500	0.084	0.5	55.5092
8	440	0.084	0.75	62.46925	58	1500	0.084	0.75	73.07277
9	440	0.084	1	63.26483	59	1500	0.084	1	75.65859
10	440	0.084	1.5	75.77341	60	1500	0.084	1.5	88.72293
11	440	0.112	0.25	47.47618	61	1500	0.112	0.25	59.13
12	440	0.112	0.5	62.84757	62	1500	0.112	0.5	68.02743
13	440	0.112	0.75	67.34698	63	1500	0.112	0.75	75.26166
14	440	0.112	1	75.51597	64	1500	0.112	1	86.79667

15	440	0.112	1.5	75.21156	65	1500	0.112	1.5	104.3033
16	440	0.157	0.25	52.69	66	1500	0.157	0.25	56.16
17	440	0.157	0.5	65.15	67	1500	0.157	0.5	84.65
18	440	0.157	0.75	70.05	68	1500	0.157	0.75	90.51
19	440	0.157	1	78.75	69	1500	0.157	1	101.77
20	440	0.157	1.5	85.99	70	1500	0.157	1.5	112.37
21	440	0.225	0.25	62.7822	71	1500	0.225	0.25	71.87695
22	440	0.225	0.5	73.39	72	1500	0.225	0.5	95.5
23	440	0.225	0.75	104.40569	73	1500	0.225	0.75	101.25232
24	440	0.225	1	88.54329	74	1500	0.225	1	118.65136
25	440	0.225	1.5	110.9689	75	1500	0.225	1.5	156.7865
26	900	0.045	0.25	38.89048	76	2500	0.045	0.25	45.03051
27	900	0.045	0.5	52.53644	77	2500	0.045	0.5	70.33218
28	900	0.045	0.75	68.37647	78	2500	0.045	0.75	78.72327
29	900	0.045	1	67.60899	79	2500	0.045	1	81.88612
30	900	0.045	1.5	82.4442	80	2500	0.045	1.5	86.06115
31	900	0.084	0.25	47.84	81	2500	0.084	0.25	49.05
32	900	0.084	0.5	54.74091	82	2500	0.084	0.5	71.53265
33	900	0.084	0.75	70.48588	83	2500	0.084	0.75	84.19038
34	900	0.084	1	74.62096	84	2500	0.084	1	100.3564
35	900	0.084	1.5	85.78947	85	2500	0.084	1.5	89.51166
36	900	0.112	0.25	55.98479	86	2500	0.112	0.25	61.77
37	900	0.112	0.5	67.56335	87	2500	0.112	0.5	74.78
38	900	0.112	0.75	75.87891	88	2500	0.112	0.75	88.132
39	900	0.112	1	85.22277	89	2500	0.112	1	107.8
40	900	0.112	1.5	88.95226	90	2500	0.112	1.5	104.3127
41	900	0.157	0.25	54.76	91	2500	0.157	0.25	66.1
42	900	0.157	0.5	75.21	92	2500	0.157	0.5	89.78
43	900	0.157	0.75	84.89	93	2500	0.157	0.75	92.65
44	900	0.157	1	93.51	94	2500	0.157	1	110.65
45	900	0.157	1.5	97.23	95	2500	0.157	1.5	114.6
46	900	0.225	0.25	64.16409	96	2500	0.225	0.25	85.8
47	900	0.225	0.5	82.71809	97	2500	0.225	0.5	93.85018
48	900	0.225	0.75	104.60367	98	2500	0.225	0.75	106.25538
49	900	0.225	1	99.44313	99	2500	0.225	1	145.38815
50	900	0.225	1.5	143.2811	100	2500	0.225	1.5	155.712

3. Response Surface Methodology

The Response Surface Methodology (RSM) is a combination of statistical and mathematical techniques useful for the development, improvement and optimization of processes [6-7]. It is widely used in the industrial world, especially when several input variables influence the results (output variables).

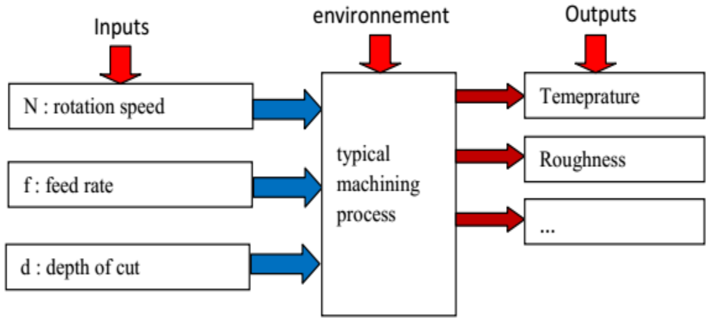


Figure 2. Response Surface Method System.

4. Analysis of ANOVA

ANOVA is useful for determining the influence of given input parameters from a series of experimental results by the experimental design method for the machining processes, It also provides an interpretation of the output data. It consists essentially of dividing the total variation of an experiment into components attributable to the controlled factors and the errors generated [8-9].

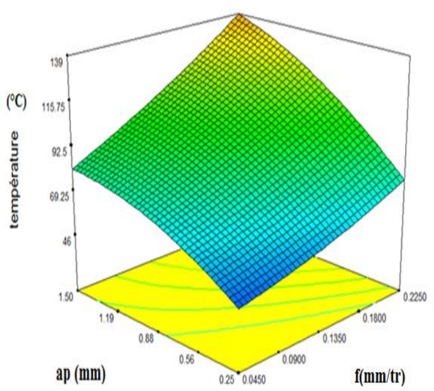
Table 3. Variance analysis for temperature.

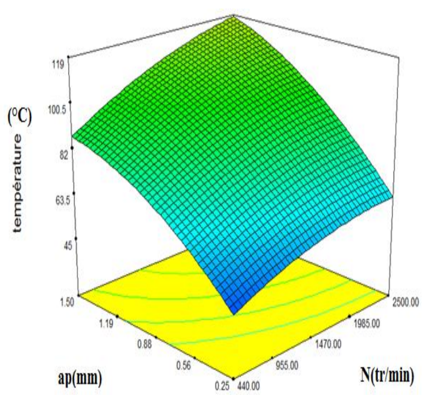
Source	Sum of Squares	df	Mean Square	F Value	P Value	sign
Model	54951.31	9	6105.70	148.56	< 0.0001	sign
A-N	7608.86	1	7608.86	185.13	< 0.0001	sign
B-f	20704.80	1	20704.80	503.77	< 0.0001	sign
C-d	26616.52	1	26616.52	647.61	< 0.0001	sign
N*f	141.21	1	141.21	3.44	0.0671	non sign
N*ap	299.92	1	299.92	7.30	0.0083	non sign
f *ap	1197.20	1	1197.20	29.13	< 0.0001	sign
N^2	327.22	1	327.22	7.96	0.0059	non sign
f^2	159.64	1	159.64	3.88	0.0518	non sign
d^2	1109.29	1	1109.29	26.99	< 0.0001	sign
Residual	3698.95	90	41.10			
Total	58650.26	99				

Table 3 shows the results of the (ANOVA) analysis, which shows that the model is significant because its F value is 148.56, it will be noted that the terms of model with P values (Prob> F) greater than 10^{-4} are not significant. In addition, the table also shows that the rotation speed (N), the advance per revolution (f), the depth of cut (d) and the quadratic value of the advance per revolution (d^2) 'advance per revolution and depth (d * f) of cut all have a significant effect on the cutting temperature. Whereas the quadratic value of the revolution per revolution (f^2) and the rotational speed (N^2), the interaction between rotation speed and feed per revolution (N * f), and the interaction between and the feed depth (f *d) have no significant effect on the cutting temperature

4.1. The effect of the cutting parameters on the cutting temperature

The influence of cutting parameters (depth of cut, feed per revolution and rotational speed) on the cutting temperature are illustrated in figures 3-5.





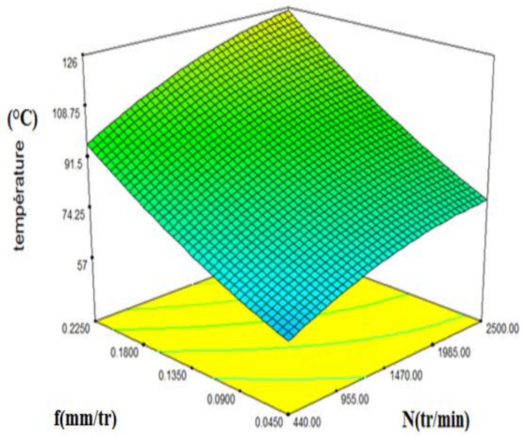


Figure 3. Effect of cutting parameters on the cutting temperature.

Figure 3 shows the effect of depth of cut (d), speed rotation (N) and feed rate (f) on the cutting temperature, the temperature increases when the feed per revolution and feed depth increases, the maximum temperature value is reached for maximum feed rate and depth of curt. Accordingly, it is to be understood that the cutting depth is the most influential factor on the cutting temperature. In other words, the cutting temperature can be minimized by using reliable values of feed per revolution, feed depth and rotational speed, while the highest values are in feed rate maximum and at the in feed depth

4.2. Regression equation

The final equation of the cutting temperature that connects the input and output parameters is modeled by a quadratic regression and represented as follows

$$T = 16.74942 + 0.015315 \times N - 9.36188 \times f + 48.32460 \times d + 0.024841 \times N \times f + 5.22569E-003 \times N \times d + 129.57028 \times f \times d - 3.92408E-006 \times N^2 + 365.98 \times f^2 - 19.66883 \times d^2 \quad (1)$$

Diagnostic control of the model was performed by residue examination. They represent the differences between the respective observed and predicted responses

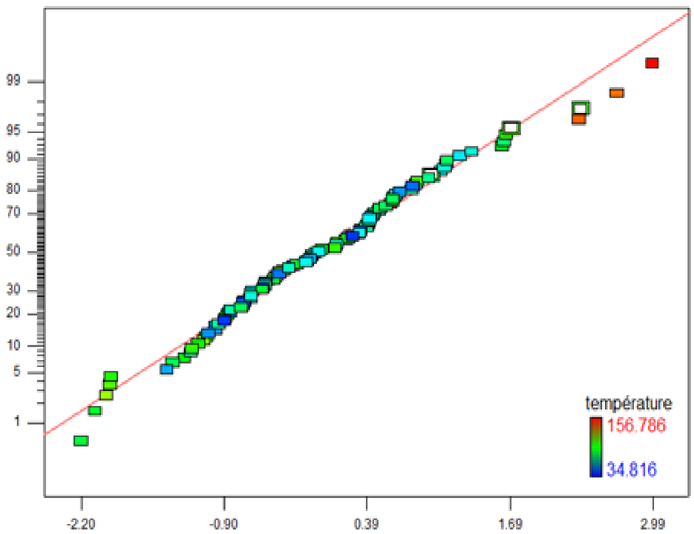


Figure 4. Normal probability of temperature residues.

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Table 4. Optimal solutions.

Run	N (rev/min)	f (mm/rev)	d (mm)	T (°C)	Desi	Run	N (rev/min)	f (mm/rev)	d (mm)	T (°C)	Desi
1	2196.27	0.0450	0.25	49.411	0,939	15	854.12	0.0450	0.25	41.667	0.922
2	2226.61	0.0450	0.25	49.422	0.938	16	2499.67	0.0495	0.25	49.743	0.915
3	2238.86	0.0450	0.25	49.429	0.938	17	490.13	0.0450	0.25	37.130	0.914
4	1958.57	0.0450	0.25	49.069	0.937	18	471.97	0.0450	0.25	36.918	0.874
5	2080.29	0.0454	0.25	49.346	0.937	19	440.01	0.0450	0.39	42.726	0.871
6	1899.22	0.0450	0.25	48.915	0.936	**20**	440.00	0.0450	0.40	43.129	0.865
7	1717.34	0.0450	0.25	48.270	0.934	21	2500.00	0.0450	0.52	63.363	0.854
8	2166.43	0.0450	0.27	50.444	0.934	22	440.00	0.0450	0.47	45.895	0.817
9	1525.19	0.0450	0.25	47.306	0.932	23	2499.99	0.0450	0.72	71.91	0.788
10	1342.30	0.0450	0.25	46.119	0.929	24	836.87	0.0450	0.85	63.598	0.766
11	1241.14	0.0450	0.25	45.350	0.928	25	486.27	0.0450	1.01	61.372	0.495
12	1198.37	0.0450	0.25	45.001	0.927	26	440.00	0.2250	0.25	60.310	0.484
13	1150.31	0.0450	0.25	44.591	0.927	27	904.44	0.2216	0.25	67.461	0.922
14	915.53	0.0450	0.25	42.330	0.923						

4.3. Regression equation

We have tested the model by the equations obtained, in order to describe the experimental results.

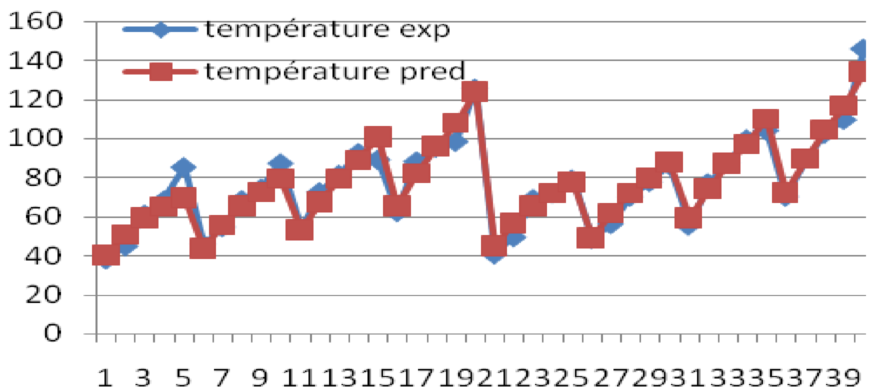

Figure 5. Validation of the results of the cutting temperature.

5. Conclusion

The purpose of this study is to determine the optimal experimental conditions (cutting parameters) during the turning of AISI 1060 steel, in order to minimize the cutting temperature which will help the increase of the life of the cutting tools. The model of the cutting temperature, developed by the response surface method has allowed us to go out with the following conclusions:

The results show that the cutting temperature increases with the increase of the cutting parameters. In the combination of the cutting parameters the first parameter that has the greatest influence on the cutting temperature is the depth of cut followed by the feed per revolution and finally the speed of rotation.

A comparison between the experimental and predictive results was made, the confirmatory test shows that the predictive values are in good agreement with the experimental values. The error percentage of numerical models and accuracy were 5.15% and 94.85% respectively. The percentage reduction in the number of experiments is 73%.

6. References

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