Investigation of Energy Consumption and Surface Roughness in Hot Work Tool Steel (DIN 1.2367) and Cold Work Tool steel (DIN 1.2550)

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Abstract

Energy consumption and processing of hard materials in the manufacturing industry are important research topics. In this study, in order to increase the surface quality and reduce energy consumption two steel materials (DIN 1.2367 and DIN 1.2550 with 55 HRC hardness) were machined two different insert radii, three different cutting speeds, three different feed rate, three different cutting depths with carbide tools. According to the test results, the surface roughness increases with increasing feed rate. The roughness value decreases with increasing tip radius. The effect of the feed rate is 49%, the effect of the tool radius is 39%. The effect of depth of cut and feed rate on power consumption is 45% and 28%, respectively. On the energy consumption, the effect of depth of cut and feed rate is 48%, 36%. In addition, surface roughness, power consumption and energy consumption can be estimated with 97.49%, 97.78%, 98.25% accuracy with the created regression equations. Finally, according to the optimization result, the surface roughness decreased by 25.71% and the energy consumption decreased by 50.65%.

Keywords: power consumption, energy consumption, DIN 1.2367, DIN 1.2550, hard turning, surface roughness, ANOVA

1. Introduction

Hardened materials are widely used in the manufacturing industry due to their excellent strength, high corrosion and wear resistance [1]. With the increasing hardness value, the mechanical properties of the materials improve. Hard turning is an important research topic as it is much more advantageous than cylindrical grinding [2]. Compared to grinding, in hard turning no coolant is used it is easy to process in the form of a profile, a grinding quality surface is obtained, energy consumption is low, machining time is very short [1], investment costs are low [3]. Hard turning is environmentally friendly as no coolant is used.

Moreover, the processing time is very short compared to grinding. Therefore, it has a significant advantage in terms of energy consumption. it also reduces the need for a cylindrical grinding machine. Since there is no need for a cylindrical grinding machine, extra machine tool investment is reduced. In addition to these advantages, turning hardened steels is a difficult process [4], a good surface quality is required [2] and tooling costs are high. But hardened materials are difficult to machine. Determination of suitable cutting conditions is of great importance. Inappropriate cutting parameters cause tool breakage and damage to the machine tool. Therefore, this study, it is aimed to determine the most suitable cutting parameters with carbide tools.

Another important research topic in recent years is energy consumption [5][6][7]. Because as energy consumption increases, the climate balance deteriorates. More fossil fuels are consumed to produce more energy. A significant portion of energy consumption belongs to the manufacturing industry [8]. Therefore, in this study, the effect of different cutting conditions on power consumption and energy consumption in different steels was investigated.

DIN 1.2367 (X38CrMoV5-3) is a steel that can remain hard at high temperatures. These steels are used in places that require high strength and wear resistance, especially in cutting, crushing and plastering molds. DIN 1.2367 hot work tool steel has very high corrosion and wear resistance due to its high Mo (2.65%) and low Si (0.37%) content [9]. The heat treatment applied to the steel increased the strength of the material. Energy efficiency increases with increasing wear resistance [10]. Das et al. [11] machined EN-24 alloy steel (55 HRC) with a coated cermet insert. Zhao et al. machined 06Cr19Ni10 stainless steel with a carbide tip [12]. He examined the relationship between tool wear and energy consumption. As tool wear increased, energy consumption increased. Padhan et al. [2], conducted machining experiments on AISI D3 steel (61 HRC), with sintered carbide inserts. According to the test results, power consumption increased with increasing ***Vc***, ***f*** and ***a***. It is stated that the most effective parameter on power consumption is cutting speed (75%). Grzesik et al. [13] machined AISI 5115 (60 HRC) steel under different cutting conditions with a CBN insert. According to the test results, cutting forces and energy consumption increased with increasing tool wear. Özdemir et al. [14], according to his research, the ***f*** has an effect of 62% and the tip radius has an effect of 12% on the ***Ra*** .It is of great importance to determine the cutting conditions that will minimize energy consumption. Thus, a sustainable production is ensured [15]. In order to reduce the amount of energy consumption, Nguyen [5] turned 9XC steel (51 HRC). Energy consumption decreases with increasing ***f***. Bagaber et al. [8] stated that energy consumption decreases as the ***f*** and ***a*** increase. In the study of Padhan et al. [2], power consumption increases as the ***a*** and ***f*** increase.

Cutting force and surface roughness values were investigated in studies on hard turning. There have been many essential studies on energy consumption. However, examining many input parameters (different cutting speeds, feed rates, depth of cut, tool nose radius and material type) together is essential regarding machinability. Many experiments need to be done. This experimental study investigated many input parameters and energy consumption, instantaneous power consumption and surface roughness values. Thus, the effects of input parameters on output parameters were examined together.

As can be seen, although energy consumption is a fundamental issue, different results have been obtained in studies. In this study, the reason for this situation is explained in detail. Power consumption and energy consumption are compared. Two different steels such as DIN 1.2367 and DIN 1.2550 were machined at three different feed rates, cutting speeds and three different depths of cut using cutting tools with two different insert radii. The Ra, power consumption and energy consumption were investigated. In addition, the effect ratios of the machining parameters were determined according to the ANOVA results. Finally, mathematical models have been developed that predict Ra, instantaneous power consumption and energy consumption according to different cutting conditions.

2. Materials and Methods

This experimental study was carried out according to ISO 3685 standards. DIN 1.2367 and DIN 1.2550 tool steels were machined with a diameter of 50 mm and a length of 250 mm. Both steel materials are vacuum hardened. After the tempering process, the hardness value of 55 HRC was measured with a hardness device. Similarly, Padhan et al. reached 61 HRC hardness value by tempering AISI D3 Steel at 420 ^{o}C after heating it at 900 ^{o}C [2]. The chemical component of DIN 1.2367 and DIN 1.2550 steel material applied heat treatment and mechanical properties are shown in Table 1. DIN 1.2367 steel has excellent strength due to its high Cr (5.1%) and Mo (2.9%) ratio. DIN 1.2367 steel material has 175% higher strength [14] than 42 CrMo4 (Cr 0.9%, Mo 0.18%) with 55 HRC Hardness.

Machining experiments were used with coolant. 20 mm of material was removed for each experiment. The machine tool, cutting tool and measuring tools used in the experiment are given in Table 2. Surface roughness values Ra (according to ISO 4287 standards) were measured. The roughness value was measured from 3 different points with the Mitutoyo SJ 201 roughness device and its arithmetic average was calculated.

In the experiment, a full factorial experimental design was made. The surface roughness value and energy consumption of two different materials with high hardness were investigated. A sampling interval of 0.8 mm was preferred for surface roughness measurement. For energy consumption, the energy consumption required for machining each part is calculated. AL_2O_3 Coated carbide insert with high wear resistance, produced for turning hard materials, is used as cutting tool. Carbide inserts have shorter tool life than CBN and ceramic inserts but are more economical. It has widespread use. the insert radius of the insert was compared as 0.4mm and 0.8mm.

3. Results and Discussion

The experiment result, surface roughness, power consumption and energy consumption values under different cutting conditions show Table3.

Surface Roughness

In the manufacturing industry, it is desired that the roughness value on the surface of the machine parts is low. Low ***Ra*** values extend the service life of machine parts. It also ensures that the friction force is low. Low friction force increases energy efficiency.

In this experimental study, the ***Ra*** was investigated in five different conditions. As seen in Figure 1 and Table 4 the most affecting ***Ra*** is the ***f*** with 49.39%. The depth of the helical channels on the surface increases with increasing ***f*** [16] [17]. As seen in, Figure 2 in addition, with increasing ***f***, more material is removed, and vibration increases. Therefore, the surface quality deteriorates with the increase in ***f*** [4] [14]. The vibration value affects the surface quality [18]. In addition, Das et al. [11] stated in their study that the ***Ra*** increased due to the increase in friction force. The second most effective parameter on the ***Ra*** is the insert radius with an effect rate of 39%. Similarly, in the study of Rao et al. [18], the surface roughness value decreased with increasing cutting tool nose radius.

Regression Model for Surface Roughness

The R^2 value for ***Ra*** of this equation is 97.93 %. With this equation, it can predict ***Ra*** with 97.49 % accuracy. Eq.(1) is predict model for ***Ra***.

$$Ra= 0,142 - 0,1285\ M+ 0,584\ Re+ 2,028\ a+ 0,004259\ V- 2,86\ f+ 31,17\ f*f+ 2,870\ M*f -2,472\ Re*a- 0,00625\ Re*V \quad (1)$$

Power Consumption and Energy Consumption

Depth of cut and feed rate have a significant effect on power consumption and energy consumption[6]. As seen in Figure 3 with increasing ***a*** and increasing ***f***, a greater load is placed on the machine tool. Therefore, with this increased load, it causes more current to occur in the machine tool. Thus, the power consumption value increases with increasing current amount. Although the instantaneous current value increases with increasing ***f*** and ***a***, the time required to machine a workpiece is shortened. As the machining time is shortened, the energy required to machine a workpiece is reduced. As the ***Vc*** increases, the cutting force decreases. However, the power consumption increases slightly with increasing spindle speed. The higher the ***Vc***, the shorter the machining time. Similarly, energy consumption decreases as processing time decreases. In the study of Zhao et al., it was stated that with the increase in material removal rate, the processing time is shortened and the energy consumption is reduced [12].

When the increase in the tool radius, more friction occurs at the insert and chip interface. Due to this, the power consumption and energy consumption are slightly increased. In the study of Grzesik et al., it was stated that the cutting energy slightly increased with the increase in the insert nose radius [13].The yield strength of DIN 1.2550 material is higher than DIN 1.2367 material. Therefore, more power consumption and energy consumption occur for the machining of DIN 1.2550 steel material. Studies have shown that power consumption is a function of shear force. Power consumption increases with increasing cutting forces [13]. The equation (P=Fc*Vc/60.000) shows the relationship between power and shear force [17]. The relationship between cutting force and vibration is important in machinability. Cutting force and energy consumption are related to each other[19]. In machinability, processing time affects energy consumption[7][20].

Significant parameters on power consumption and energy consumption were determined according to 95% ($P<0.05$) confidence interval. ANOVA results are shown in Table 4. The effects of ***a***, ***f*** and tool radius on power consumption are 45.83%, 28.36% and 10.79%, respectively. The error rate was calculated as 1.94%. The effects of ***a*** and ***f*** on energy consumption are 48.28% and 36.50%, respectively. The error rate was calculated as 1.46%. Nguyen stated the effect of ***f***, ***Vc*** and ***a*** on energy consumption as 32%, 10% and 4%, respectively[5].

Mat: Material type, **Re**: cutting tool tip radius, **a**: Depth of cut, **v**: Cutting speed, **f**: federate DF: degrees of freedom

In Figure 4 (a) (d), at a cutting speed of 170 m/min and a cutting depth of 0.05 mm, the power consumption is 2900 Watt, and the energy consumption is 40 kW/p. At a cutting speed of 170 m/min and the ***a*** of 0.15 mm, the power consumption increases by 3260 watts and the energy consumption decreases by 12.5 kW/p. While the ***a*** increased by 300%, the power consumption increased by 12% and the energy consumption decreased by 68.75%.

In Figure 4 (b) (e), with a tool radius of 0.8 mm, at the ***f*** of 0.04 mm/rev, the power consumption is 2950 Watt, and the energy consumption is 45 kW/p. With the tool radius of 0.8 mm, at the ***f*** of 0.1 mm/rev, power consumption increases by 3250 watts, while energy consumption decreases to 13.5 kW/p. The ***f*** increased by 250%, the power consumption increased by 10%, and the energy consumption decreased by 70%.

In Figure 4 (c) (f), DIN 1.2367 steel material, at 0.1 mm/rev ***f*** , power consumption is 3150 Watt and energy consumption is 14 kW/p. DIN 1.2550 Steel material has the ***f*** of 0.1 mm/rev, power consumption of 3240 Watt, and an energy consumption of 15 kW/p. Compared to DIN 1.2367 steel, the power consumption in the processing of DIN 1.2550 steel material increased by 2.85%, while the energy consumption increased by 7.14%.

Regression model for power consumption and energy consumption

In Figure 5, the effects of the parameters on the power consumption are shown in the graphs. Effective parameters are shown with 95% confidence interval. The effects of ***a***, ***f*** and cutter radius on power consumption and energy consumption are 48.6%, 38.4%, 23.7% and 57.15%, 49.70% 8.321%, respectively.

Effective parameters were determined using the standard effects plots in Figure 5 . The R^2 value for power consumption and energy consumption of this equation is 98.06% and 98.54%, respectively. With this equation, it can predict power consumption and energy consumption with 97.78% and 98.25% accuracy. Eq.(2) is predict model for power consumption. Eq.(3) is predict model for Energy consumption.

$$P(Watt)=1351{,}0 + 100{,}82\ M + 157{,}4\ Re + 2439\ a + 4{,}924\ V + 4832\ f + 2076\ Re*a \qquad (2)$$

$$EC(Watt/p)= 199{,}06 + 1{,}066\ M + 7{,}48\ Re - 1250{,}3\ a - 0{,}1533\ V - 1827{,}9\ f$$

$$+ 3103\ a*a + 6584\ f*f + 4486\ a*f \qquad (3)$$

4. Optimization

The cutting conditions for the lowest ***Ra*** value and the lowest energy consumption value are given in Table 5. The average of the lowest ***Ra*** value is 0.45 µm. The lowest energy consumption value average is 11,44 kW/p.

There are five input parameters and two output parameters in this experimental setup. The lowest energy consumption was seen in DIN 1.2367 Material. In addition, although the increase in the tip radius increased the energy consumption slightly, the surface roughness value decreased significantly. Therefore, the cutting tool with a tip radius of 0.8 mm is more advantageous in terms of optimization. As seen in Table 5, energy consumption decreases as the feed rate, cutting speed and depth of cut increase. However, as the feed rate increases, the surface roughness increases. Therefore, choosing a low feed rate is more advantageous in terms of optimization, while high cutting speed and high depth of cut are preferred. The optimum value in terms of both energy consumption and surface roughness is given in Table 5.

According to the experiment results, the average ***Ra*** is 0.70 µm. The average energy consumption is 32.20 kW/p. Cutting conditions were determined for the lowest roughness value. The ***Ra*** decreased by 35.21%. But Energy consumption increased by 139.34%. At the lowest energy consumption, energy consumption decreased by 64.47%, while the ***Ra*** was reduced by 4.28%. The most ideal cutting conditions were determined for both the ***Ra*** and the energy consumption. In DIN 1.2367 material, tool radius of 0.8 mm should be used. As cutting parameters; 0.15 mm depth of cut, 170 m/min cutting speed, 0.07 mm/rev

f should be preferred. When cutting under these conditions, ***Ra*** decreased by 25.71% and power consumption by 50.65%.

5. Conclusion

Machining experiments were carried out with 55 HRC hardness, DIN 1.2367 and DIN 1.2550 steel materials, with two different tip radii (0.4-0.8 mm), 3 different cutting depths (0.5-0.1-0.15 mm), three different cutting speeds (140-155-170 m/min), three different feed rates (0.04-0.07-0.1mm/rev), using coolant, with carbide tools. The main results obtained are as follows.

- The most effective parameters on ***Ra*** are ***f*** and tool tip radius. The ***Ra*** increases with increasing ***f***. The ***Ra*** decreases with the increase in the tip radius. The effect of the ***f*** is 49%, while the effect of tip radius is 39%. The ***Ra*** obtained in DIN 1.2367 steel is lower than DIN 1.2550. With the model created for the ***Ra***, the test results could be predicted with an accuracy of 97.49%.
- Depth of cut has 45.83% effect on power consumption. This is followed by the ***f*** with 28.36%. Power consumption increases with increasing ***a***, ***f***, and insert radius. With the mathematical model of power consumption, experimental results can be predicted with an accuracy of 97.78%.
- Depth of cut and ***f*** have the highest impact on energy consumption. While the effect of ***a*** is 48.28%, the effect of ***f*** is 36.5%. The energy consumption is calculated according to the fixed amount of material removal. Therefore, machining time decreased with increasing ***a***, ***f***, and ***Vc***. Energy consumption decreased with the reduction of processing time. In addition, the created regression model estimated energy consumption with an accuracy of 98.25%.
- The lowest ***Ra*** and the lowest energy consumption were calculated by optimizing the machining conditions. Suitable cutting conditions are specified for both the lowest surface roughness and the lowest energy consumption. DIN 1.2367 Material, 0.8 mm tip radius, 0.15 mm depth of cut, 170 m/min cutting speed, 0.07 mm/rev ***f*** ideal cutting conditions are provided. In machining under these conditions, it was observed that the ***Ra*** value decreased by 25.71% and the power consumption value decreased by 50.65%.

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Biography of the author

Dr. Şahinoğlu was born in Malatya (Turkey) in 1981. He completed his undergraduate and graduate education at Gazi University in manufacturing engineering. He works in the field of machine manufacturing and design. He has three patents in machine design and manufacture. One of them is the “intelligent tool machining design” which determines the cutting parameters according to the sound and vibration analysis. He has published some papers related to the machining operation. He has worked at Çankırı Karatekin University, department of mechanical and metal technology as an instructor from 2012-2020. Since 2020, he has been working at Manisa Celal Bayar University, department of mechanical and metal technology as an associate professor.

Figures caption list

Figures

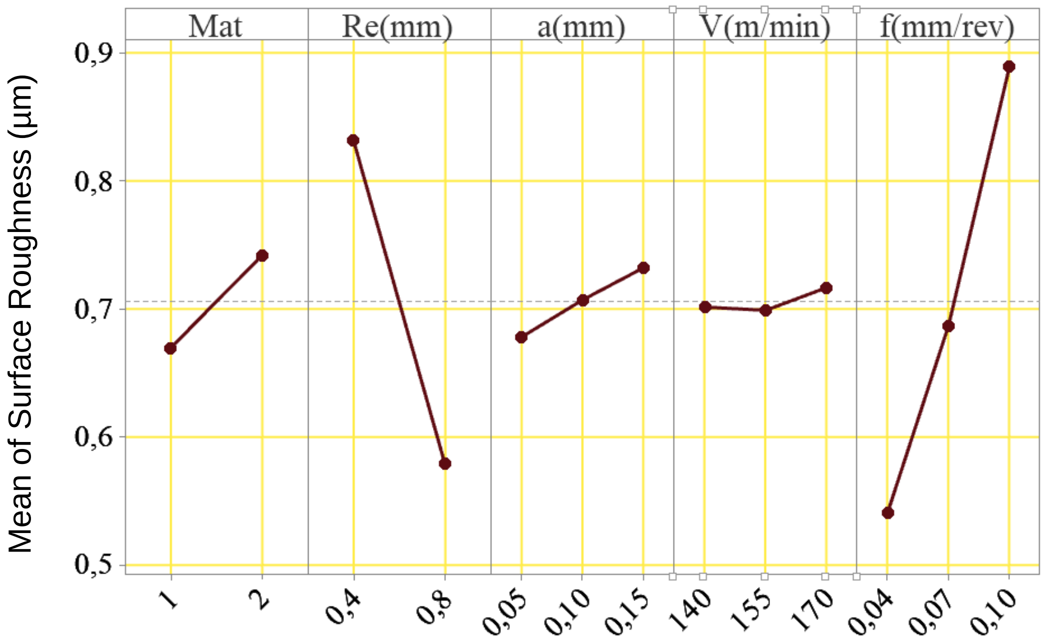
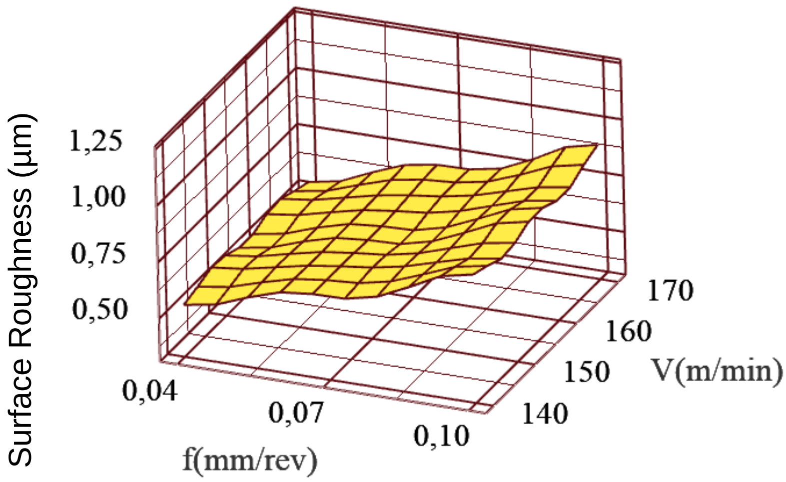
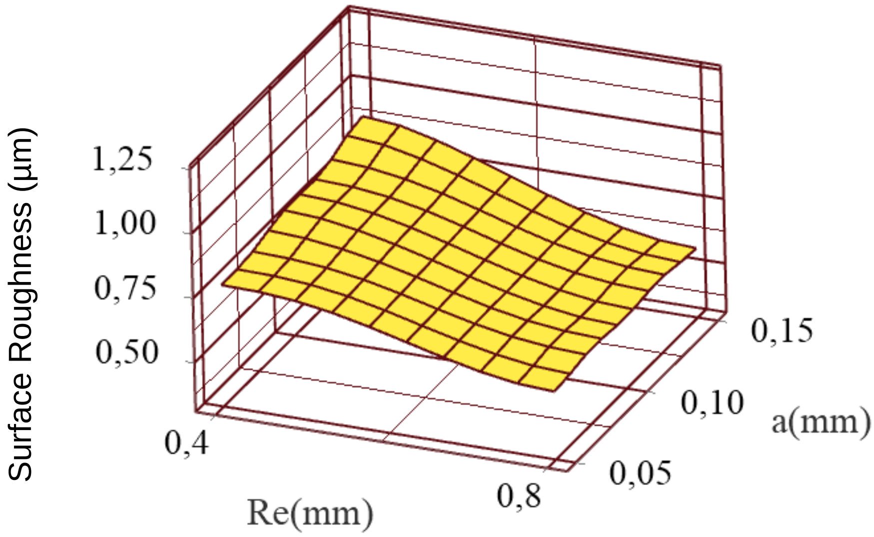


Figure 1



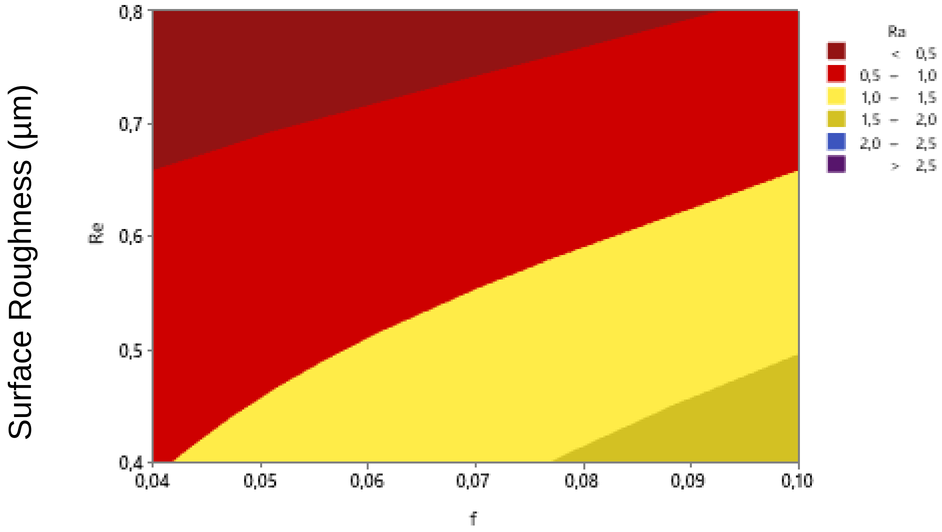
Surface Roughness (µm)
1,25
1,00
0,75
0,50
0,04
0,07
0,10
f(mm/rev)
170
160
150
140
V(m/min)

a)



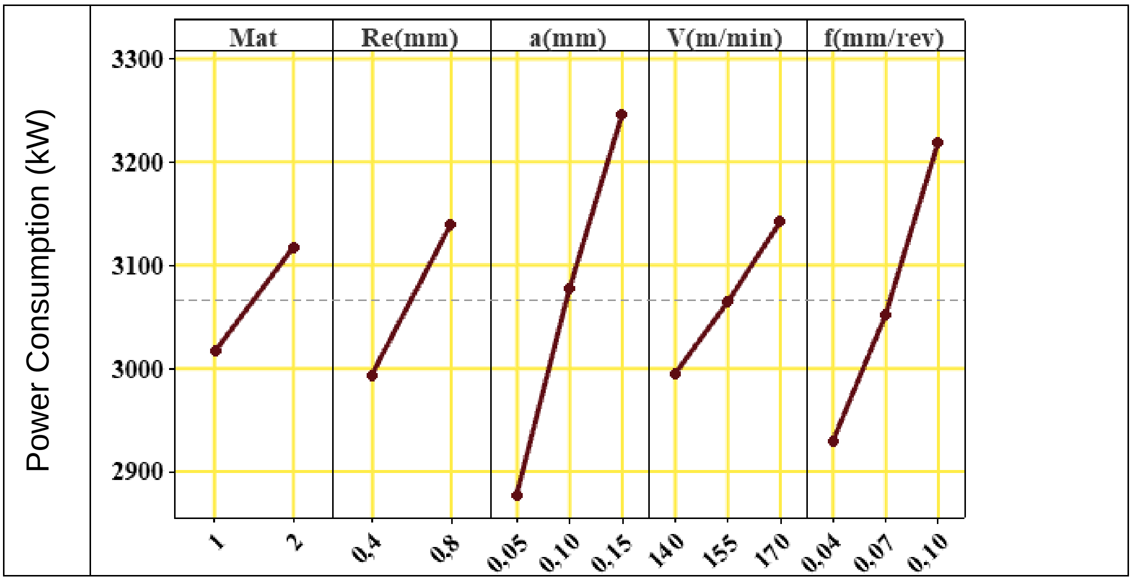
Surface Roughness (µm)
1,25
1,00
0,75
0,50
0,4
0,8
Re(mm)
0,15
0,10
0,05
a(mm)

b)


Surface Roughness (µm)
Re
f
Ra
< 0,5
0,5 – 1,0
1,0 – 1,5
1,5 – 2,0
2,0 – 2,5
> 2,5

c)

Figure 2


Power Consumption (kW)
Mat
Re(mm)
a(mm)
V(m/min)
f(mm/rev)

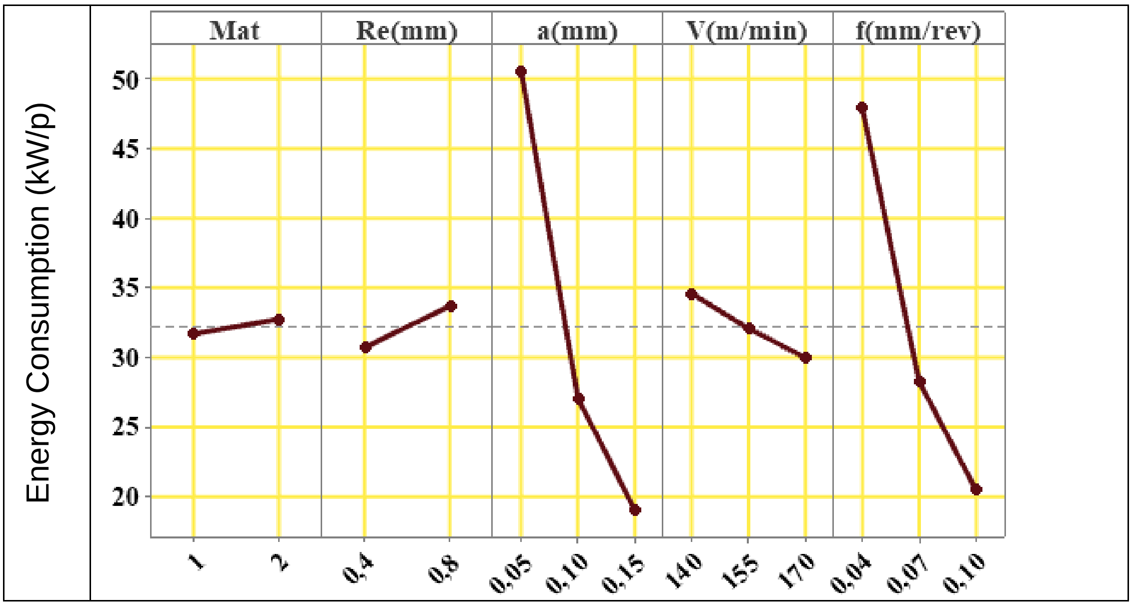
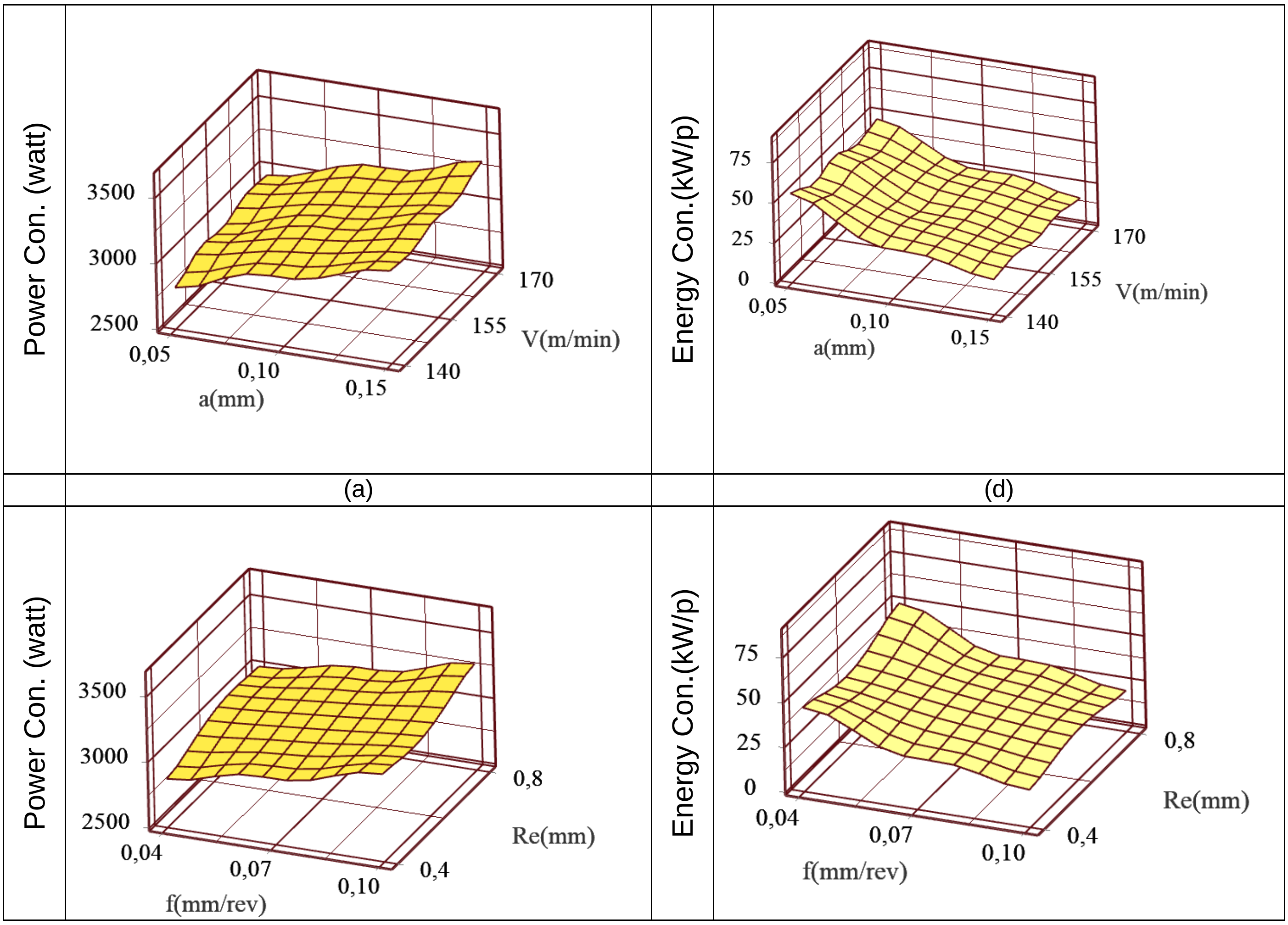

Energy Consumption (kW/p)
Mat
Re(mm)
a(mm)
V(m/min)
f(mm/rev)
50
45
40
35
30
25
20
1
2
0,4
0,8
0,05
0,10
0,15
140
155
170
0,04
0,07
0,10

Figure 3


Power Con. (watt)
3500
3000
2500
0,05
0,10
0,15
a(mm)
170
155
140
V(m/min)
(a)
Energy Con.(kW/p)
75
50
25
0
0,05
0,10
0,15
a(mm)
170
155
140
V(m/min)
(d)
Power Con. (watt)
3500
3000
2500
0,04
0,07
0,10
f(mm/rev)
0,8
0,4
Re(mm)
Energy Con.(kW/p)
75
50
25
0
0,04
0,07
0,10
f(mm/rev)
0,8
0,4
Re(mm)

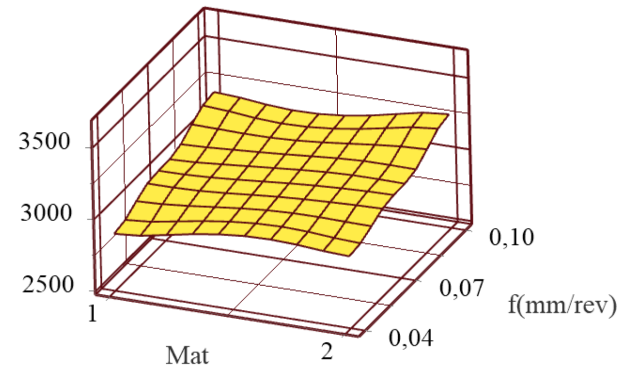
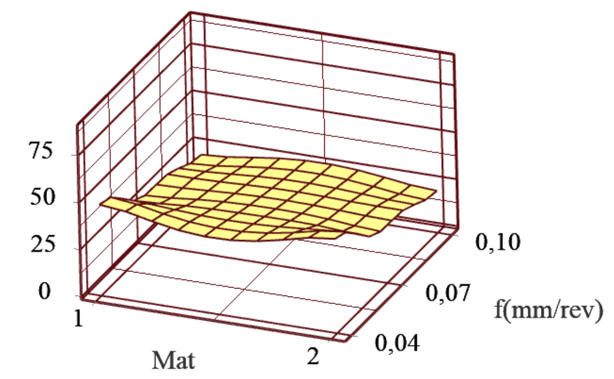
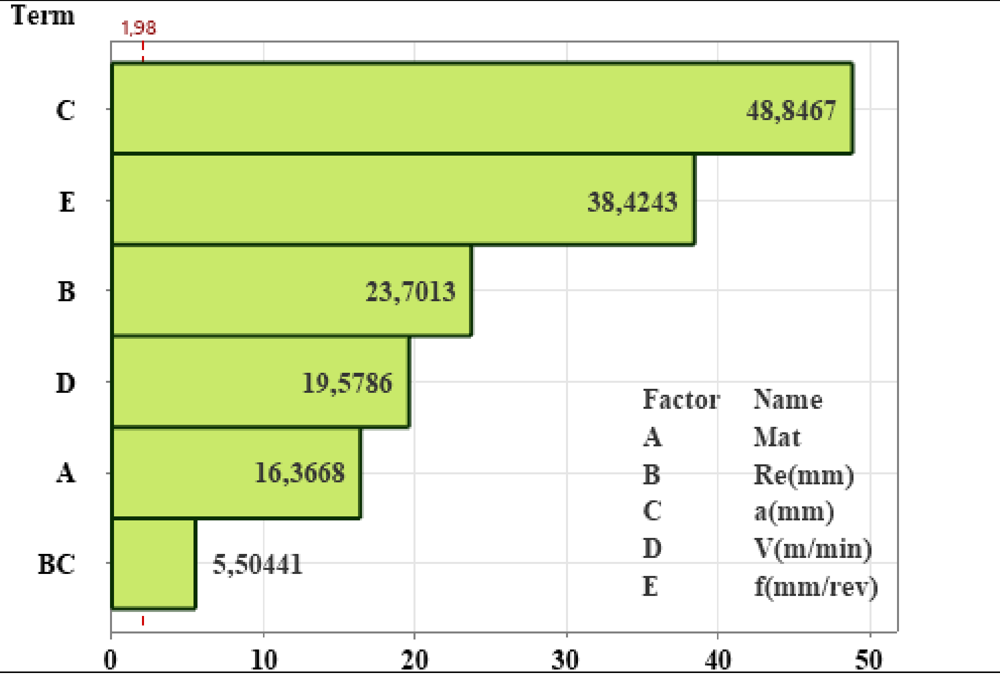
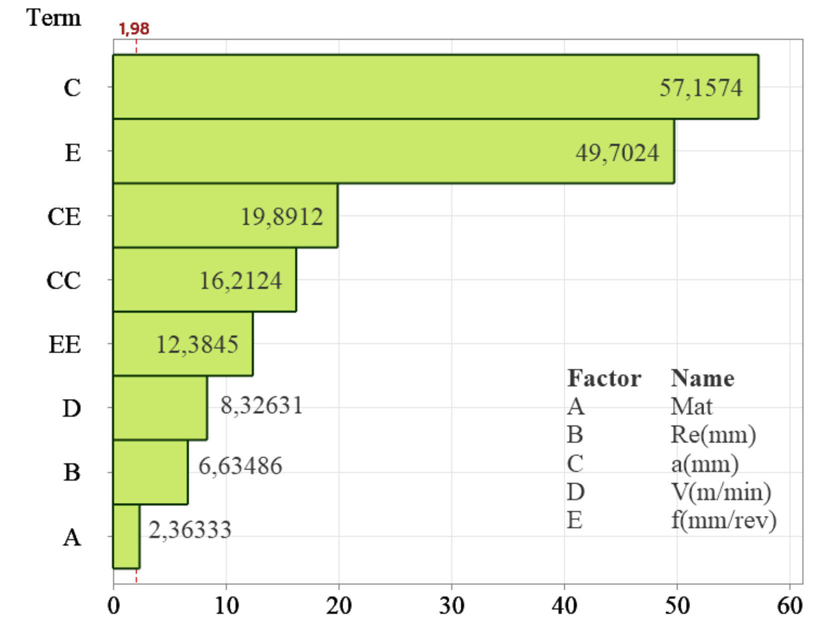
	(b)		(e)
Power Con. (watt)		Energy Con.(kW/p)	
	(c)		(f)

Figure 4



a)



b)

Figure 5

Tables caption list

Table 1. Features of DIN 1.2367- 1.2550 steel.

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Tables

Table 1

	Chemical components							Heat treatment			Mec. properties
MAT.	C	Si	Mn	Cr	Mo	V	W	Austen °C	Temp. °C	Cool.	Hard. (HRC)
1.2367	0,35	0,4	0,4	5,1	2,9	0,5	-	1050	500	oil	55
1.2550	0,65	0,6	0,3	1,1	-	0,2	2	900	200	oil	55

Table 2

CNC Machine tool	Taksan TTC 630	20 kw, Max 4000 rpm/min	
Workpieces	DIN 1.2367 - DIN 1.2550	Ø45-50 mm L=250 mmm	
Cutting tools	Coated carbide tool	DCMT11T304- DCMT 11T308	
Cutting parameters	Cutting speed Feed rate Depth of cut	140, 155, 170 (m/min) 0.04, 0.07, 01 (mm/rev) 0.05,0.1,0.15 (mm)	
Surface roughness	Mitutoyo SJ 201	Ra	
Power and energy	Clamp meter	PCE	

Table 3

Run	Machining Parameters				1.2367			1.2550		
	Re (mm)	a (mm)	V (m/min)	f (mm/rev)	P (Watt)	EC (Watt/p)	Ra (µm)	P (Watt)	EC (Watt/p)	Ra (µm)
1	0.4	0.05	140	0.04	2548	75.0	0.58	2650	78.0	0.62
2	0.4	0.05	140	0.07	2664	44.4	0.71	2748	45.8	0.82
3	0.4	0.05	140	0.1	2860	32.6	0.9	2954	33.7	1.01
4	0.4	0.05	155	0.04	2606	69.3	0.57	2711	72.1	0.63
5	0.4	0.05	155	0.07	2805	42.2	0.7	2889	43.5	0.78
6	0.4	0.05	155	0.1	2925	30.1	0.9	3030	31.3	1.01
7	0.4	0.05	170	0.04	2748	66.6	0.62	2860	69.3	0.65

8	0.4	0.05	170	0.07	2860	39.3	0.78	2939	40.4	0.84
9	0.4	0.05	170	0.1	2958	27.8	0.9	3055	28.7	1.05
10	0.4	0.1	140	0.04	2733	40.2	0.61	2831	41.7	0.68
11	0.4	0.1	140	0.07	2903	24.2	0.8	3005	25.1	0.79
12	0.4	0.1	140	0.1	3077	17.6	0.95	3153	18.0	1.03
13	0.4	0.1	155	0.04	2856	38.0	0.66	2939	39.1	0.65
14	0.4	0.1	155	0.07	2925	22.0	0.78	3008	22.7	0.89
15	0.4	0.1	155	0.1	3110	16.1	0.95	3211	16.6	1.05
16	0.4	0.1	170	0.04	2856	34.6	0.68	2950	35.8	0.63
17	0.4	0.1	170	0.07	3001	20.6	0.86	3095	21.3	0.85
18	0.4	0.1	170	0.1	3196	15.1	0.96	3298	15.5	1.1
19	0.4	0.15	140	0.04	2878	28.2	0.67	2979	29.2	0.69
20	0.4	0.15	140	0.07	3055	17.0	0.81	3149	17.5	0.85
21	0.4	0.15	140	0.1	3222	12.3	0.96	3298	12.6	1.1
22	0.4	0.15	155	0.04	2979	26.4	0.7	3059	27.1	0.71
23	0.4	0.15	155	0.07	3044	15.3	0.85	3139	15.8	0.89
24	0.4	0.15	155	0.1	3240	11.2	0.95	3334	11.5	1.15
25	0.4	0.15	170	0.04	3034	24.5	0.75	3099	25.0	0.74
26	0.4	0.15	170	0.07	3167	14.5	0.89	3269	15.0	0.95
27	0.4	0.15	170	0.1	3338	10.5	1.09	3414	10.7	1.19
28	0.8	0.05	140	0.04	2697	83.6	0.44	2809	86.9	0.45
29	0.8	0.05	140	0.07	2805	49.2	0.53	2820	49.4	0.64
30	0.8	0.05	140	0.1	2950	35.4	0.65	3044	36.5	0.87
31	0.8	0.05	155	0.04	2755	77.1	0.45	2867	80.1	0.43
32	0.8	0.05	155	0.07	2853	45.1	0.46	2968	46.9	0.58
33	0.8	0.05	155	0.1	3044	32.9	0.65	3153	34.1	0.79
34	0.8	0.05	170	0.04	2798	71.3	0.43	2900	73.8	0.36
35	0.8	0.05	170	0.07	2925	42.2	0.48	3026	43.6	0.61
36	0.8	0.05	170	0.1	3113	30.7	0.66	3244	32.0	0.85
37	0.8	0.1	140	0.04	2874	44.4	0.45	2976	45.9	0.4
38	0.8	0.1	140	0.07	2997	26.2	0.5	3099	27.1	0.6
39	0.8	0.1	140	0.1	3139	18.8	0.69	3233	19.3	0.87
40	0.8	0.1	155	0.04	2961	41.3	0.47	3037	42.3	0.39
41	0.8	0.1	155	0.07	3095	24.4	0.5	3160	24.9	0.58
42	0.8	0.1	155	0.1	3244	17.5	0.7	3341	18.1	0.89
43	0.8	0.1	170	0.04	3081	39.1	0.42	3178	40.3	0.36
44	0.8	0.1	170	0.07	3204	23.0	0.51	3301	23.7	0.62
45	0.8	0.1	170	0.1	3287	16.2	0.7	3406	16.8	0.88
46	0.8	0.15	140	0.04	3026	31.1	0.48	3157	32.4	0.43
47	0.8	0.15	140	0.07	3204	18.6	0.51	3327	19.3	0.61
48	0.8	0.15	140	0.1	3388	13.5	0.66	3537	14.1	0.89
49	0.8	0.15	155	0.04	3124	29.0	0.46	3265	30.2	0.41
50	0.8	0.15	155	0.07	3269	17.2	0.5	3374	17.7	0.58
51	0.8	0.15	155	0.1	3417	12.3	0.65	3558	12.8	0.85
52	0.8	0.15	170	0.04	3233	27.3	0.43	3396	28.6	0.37
53	0.8	0.15	170	0.07	3316	15.9	0.52	3446	16.5	0.56
54	0.8	0.15	170	0.1	3486	11.4	0.67	3631	11.9	0.84

Table 4

Surface Roughness						
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**Cont.%**
Mat	1	0,14156	0,14156	151,44	0,000	3,20
Re	**1**	**1,72521**	**1,72521**	**1845,71**	**0,000**	**39,02**
a	1	0,05336	0,05336	57,08	0,000	1,21
V	1	0,00420	0,00420	4,49	0,037	0,09
f	**1**	**2,18405**	**2,18405**	**2336,60**	**0,000**	**49,39**
f*f	1	0,01889	0,01889	20,21	0,000	0,43
Mat*f	1	0,13347	0,13347	142,79	0,000	3,02
Re*a	1	0,04401	0,04401	47,08	0,000	1,00
Re*V	1	0,02531	0,02531	27,08	0,000	0,57
Error	98	0,09160	0,00093			2,07
Total	107	4,42165				100
Power Consumption						
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**Cont.%**
Mat	1	274464	274464	267,87	0,000	5,14
Re	1	575580	575580	561,75	0,000	10,79
a	**1**	**2444721**	**2444721**	**2386,00**	**0,000**	**45,83**
V	1	392758	392758	383,32	0,000	7,36
f	**1**	**1512762**	**1512762**	**1476,42**	**0,000**	**28,36**
Re*a	1	31044	31044	30,30	0,000	0,58
Error	101	103486	1025			1,94
Total	107	5334815				100,00
Energy Consumption						
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**Cont.%**
Mat	1	30,7	30,7	5,59	0,020	0,08
Re	1	241,8	241,8	44,02	0,000	0,65
a	**1**	**17947,1**	**17947,1**	**3266,97**	**0,000**	**48,28**
V	1	380,9	380,9	69,33	0,000	1,02
f	**1**	**13570,8**	**13570,8**	**2470,33**	**0,000**	**36,50**
a*a	1	1443,9	1443,9	262,84	0,000	3,88
f*f	1	842,6	842,6	153,38	0,000	2,27
a*f	1	2173,6	2173,6	395,66	0,000	5,85
Error	99	543,9	5,5			1,46
Total	107	37175,2				100

Table 5

	Cutting condition					Result		İmprovement %	
The lowest value	Steel	Re (mm)	a (mm)	V (m/min)	f (mm/rev)	Ra (μm)	E.C. (kW/p)	Ra%	E.C %

Surface roughness	1,2367	0,8	0,05	155	0,04	0,45	77,07	35,21	-139,34
Eng. consumption	1,2367	0,8	0,15	170	0,1	0,67	11,44	4,28	64,47
Optimum value	**1,2367**	**0,8**	**0,15**	**170**	**0,07**	**0,52**	**15,89**	**25,71**	**50,65**