INVESTIGATION OF FACTORS AFFECTING SURFACE ROUGHNESS OF HEAT TREATED 5040 STEEL BY EXPERIMENTAL DESIGN METHOD

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Abstract: One of the main problems to be tried to solve in machining is machinability. Manufacturer seeks answer of how he can produce his product cheaper and more quality. One of the main purposes in machining is to bring surface roughness to the top level. The stage where the most decisive work can be done in improving the product quality is the parameter design phase for both product and process design. In order to determine the most effective parameters and to evaluate the results more efficiently, the Taguchi experiment design technique is preferred to realize the experiments in a shorter time. This performed study was done by the aim of investigating the effect of change in terms of hardness, feed rate, and cutting tool of "Dual Phase" steel, which is a class of HSLA (High Strength Low Alloy) steels that increases usage and importance day by day, on surface quality in turning process in the pieces subjected to reasonable forces in machine, device, car manufacturing. Experimental design In the Minitab statistical analysis program, Taguchi experiment design technique and 9 trials according to L9 orthogonal design. Experiments were performed in dry cutting conditions in CNC Turning Table that has 1.5 kW power and rotates with maximum 2000 rpm. Variance analysis and signal / noise ratio were used in the evaluation of the test results. . It was possible to achieve the intended results with only one third of the number of experiments required in full factorial design (9 experiments instead of 27). In the experiments, the cutting tool type (CBN, Ceramic and Carbide cutter), the feed rate (0,02, 0,04 and 0,06 mm/cycle) and the material hardness (Material with three different hardness values obtained by annealing at 745, 760, and 775 degrees obtained after heat treatment) were used as the independent variable (factor). The mean surface roughness value (Ra) as a dependent variable was determined from measurements taken at 6 different points in three trials. As a result, the most effective parameters on the surface quality are the feed rate, the material hardness (microstructure) and the cutting tool. The results obtained are interpreted together with the evaluations which have been entered into the literature before.

Keywords: Taguchi, Dual Phase, Surface Quality, Machinability.

Introduction

Importance of heat treatment applied in the process of improving mechanical properties has gradually increased with growing technology. Heat treatment applied to steel plays an important role on defining machinability properties of steel (Uzkut and Ark., 2001., Çeviker, 1991., Demir and Ark., 2011). Material technology and cutting tool technology growing in recent years allows machinability of heat treated steels easily and quality (Elbestawi and Ark., 1996, Yaka and Ark., 2016). After heat treatment applied of steels, internal strains occur in material. This causes problems such as warping in workpiece, burning on surface, and micro crack. Arising these problems can be eliminated with various processes applied after heat treatment Çolak, 2006., Daghini ve Nicolescu., 2007., Binali and Ark., 2018).

Dewes et al., processed AISI H13 material with 52 HRc hardness by using WC solid milling machine coated with TiCN. They observed that cutting speed increase temperature, temperature increases as directly proportional with cutting speed, and temperature in cutting area decreases with increasing tool radius. Asilturk and Akkus (2011), investigated effect of cutting speed, cutting depth, and feed rate on surface roughness in turning process of hardened AISI 4140 (51 HRC) with coated carbide. As a result of experimental studies, they showed that feed rate has the most significant effect on Ra and Rz.

Ren at al. (2014) investigated the study about optimization of cutting geometry in last milling process on Ti-5Al-5Mo-5V-1Cr-1Fe alloy with Taguchi method. They aimed at reaching combination to minimize cutting forces and surface roughness, and to optimize cutting speed by changing milling cutter geometry in the study. As a result, they found that multi performance characteristics can be improved with grey-Taguchi method. Zhao (2017), performed an experimental study to understand the effect of cutting edge radius on workpiece machining performance with regards to surface roughness and tool abrasion in AISI52100 steel. Three groups of cutter

(CBN) with 20, 30, 40 μm nominal edge radius were used in the study. Change in cutting edge radius was evaluated with an optical microscope. The effect of surface radius and tool abrasion on cutting edge radius was investigated in different machining conditions with different machining tests by designing three-leveled, two-factored experiments with Taguchi. Variations tends to lower with increasing nominal values of cutting radius, and also, it was resulted that cutting radius has an important effect on surface roughness and tool abrasion.

The situation defined above is an example of typical problem showing up machining tool that is appropriate to tolerance in engineering and research and development studies. It is required to improve surface quality which is a measurement of machinability, to make experiment to investigate effect of tool type, cutting speed and feed rate on performance, and make optimization by evaluating these experiments.

The purpose of this study is to make optimization and investigate effect of material and cutting parameters (feed rate and cutting tool type) on workpiece surface roughness that is an important machinability criteria by doing machinability experiments with turning method on steels used in machine production industry. In this study, dual-phased steel specimen obtained in three different hardness after heat treatment was performed to turning process with three different feed rate by using three different cutter type by evaluating factors affecting turning surface quality after literature review. Results obtained from Taguchi optimization were evaluated with regards to adaptation to literature.

Experimental Study
Used Material and Properties
5040 ERDEMIR quality numbered SAE 1040 Standard Tool produced as hot mill product in Ereğli Iron and Steel Factories (ERDEMIR) T.A.S and given chemical composition in Table 1 was used by preparing 12 mm diameter, and hardness measurement was performed by doing heat treatment.

Table 1: Chemical Composition of 3936 quality steel

Quality	Standard	Chemical Composition (% Weight)					
		C	Mn	P	S	Si	Al
5040	SAE 1040	0.38	0.75	0.010	0.016	0.210	0.058

It was utilized from previous studies to define relevant annealing temperatures. Temperatures values in the study performed related to mechanical properties of materials having same chemical composition (Tayanç and Toktas, 2001).

It was given water in water to turning specimen annealed 30 minutes in 745, 760, and 775 C° temperatures on the purpose of obtaining three different hardness on same material in total. During preparation of specimen, it was waited to chill oven for two different temperatures to prevent different heat treatment conditions. Specimen were subjected to cooling in water after annealing process. Temperature-time diagram (T-t) belong to aforesaid heat treatment was shown in Figure 1.
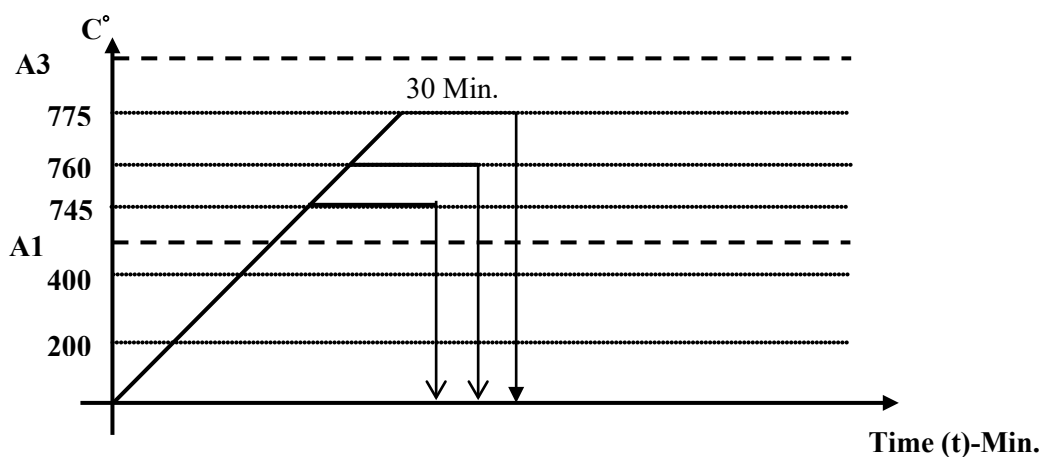

Figure 1. Temperature (T)-Time(t) diagram.

Microhardness Measurement

Hardness measurement of specimens were performed with micro Vickers method in Qness Q10 microhardness test equipment. HV 0,5 load and 10 seconds main loading values were defined as test parameters, and trace image was taken by the help of 40X lens. Hardness measurements of materials were obtained as Vickers (HV) in Qness Q10 microhardness equipment. Results were given in Table 2.

Table 2: Hardness Values

Materil	745∘	760∘	775∘
Meaurement 1 (HV)	174	360	429
Measurement 2 (HV)	175	389	434
Average Hardness (HV)	174,5	374,5	431,5

Surface Roughness Measurement

Surface roughness was measured with TIME TR200 surface roughness equipment. Three measurement trace to parallel and vertical to cutting direction were measured. The mean of three arithmetical average surface roughness measurement (Ra) in the direction and through cutting were used to show surface roughness of specimen.

Choosing Cutting Parameters and its Levels

Experimental studies within study were performed in CNC Turning Table that has 1.5 kW power and rotates with maximum 2000 rpm. Dual phase steels is a new class of high strenght-low alloy steels (HSLA). A cylindrical workpiece made from 5040 number steel having 0,38 % C ratio that is produced by ERDEMIR as special wheel steel was processed with Al_2O_3 coated Cementite Carbide, Ceramic, and CBN cutting tools by applying three different feed rate in dry cutting conditions in the study. Cutting area order is shown in Figure 2. Factors used in machining and its levels were defined with user experience and were specified in Table 3.
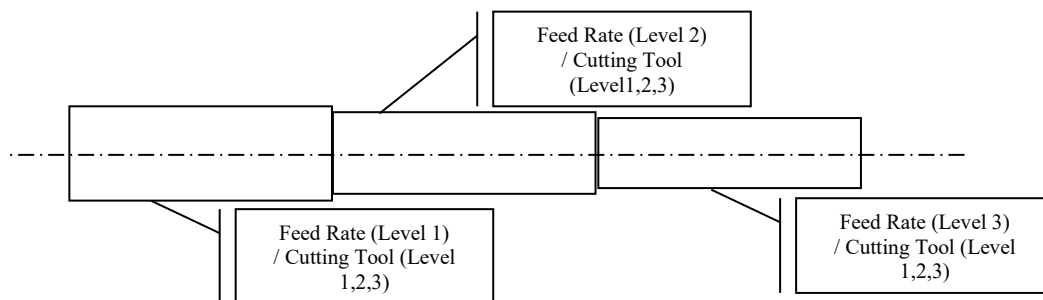

Figure 2. Cutting Area Order

Fishbone diagram is one of output in designing experiments. A fishbone diagram can be created to see relations defined factors to each other's exactly (Şirvancı, 1997). This diagram specifies all factors representing product or process quality and affecting measured values (Savaskan at al., 2004). It was decided variable and constant factors with the help of fishbone diagram. Factors affecting machinability are collected under four main categories (cutting parameters, rigidity, workpiece, cutting tool) as shown in Figure 3.

Values of variable parameters except factors that has to be constant and that cannot be controlled were taken as compatible with real working environment values as much as possible. Because cooling liquid usage will have positive effect to surface quality, experiments were planned in dry condition to keep experiment numbers in certain amount.

Table 3: Cutting Parameters

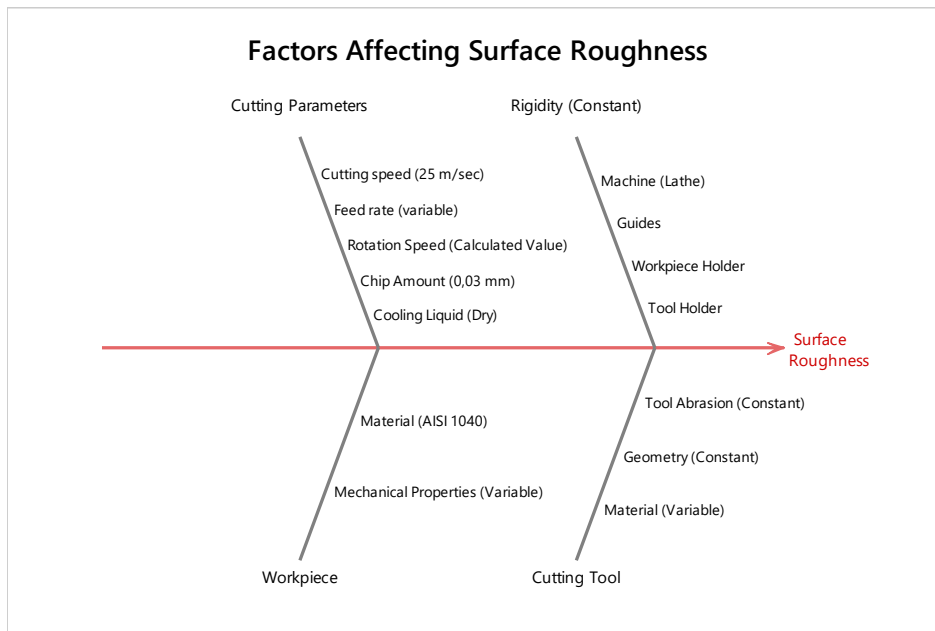| Factors	Unit	Symbol	Level 1	Level 2	Level 3
Cutting Tool	-	A	Carbide	Ceramic	CBN
Feed Rate	Mm/dev	B	0,02	0,04	0,06
Heat Treatment /Hardness	/Hv0.5	C	745∘C	760∘C	775∘C

Figure 3. Evaluation of Factors Affecting Surface Roughness with Fishbone Diagram

Taguchi Experiment Design

Choosing optimum process conditions is an extremely important subject since it defines surface quality of produced pieces and dimensional sensitivity. Contact surfaces of machine elements working together are desired to finish with particular rough, especially in machine design. Sometimes, sensitive surfaces are required, and sometimes rough surfaces are suitable to work machine properly, as well. Therefore, it is important to define surface roughness in design step, and to control in production step. After, surfaces can be operated in desired roughness values (Karayel, 2009). It is needed to optimize surface quality and to define optimum cutting parameters on the purpose of machining machine pieces as suitable to environment they will work. For this purpose, feed rate, cutting tool, and material hardness was defined as parameters to use in this study. Machining experiments were performed by considering Taguchi one patterned (each factor was taken three levels) L9 orthogonal design. Experiment index was given in Table 4.

Table 4: Taguchi L9 experiment design

Experiment Nu.	Control Factors		
	Cutting Tool (A)	Feed Rate (B)	Hardness (C)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Analysis of S/N Ratios

Taguchi experiment design and analysis were performed in Minitab 16.2 package program, and basic leveled (three level) L_9 orthogonal index was used. "Smallest-the best" formula specified equation 1 was used to evaluate obtained Signal-Noise Ratios (S/N).

$$\frac{S}{N} = -10 * \log\left[\sum_{i=1}^{n} \frac{Y_i^2}{n}\right]$$

Eq. (1)

S/N ratios were calculated by using "smallest-the best" equation after obtained surface roughness ratios in machining experiments of ERDEMIR 5040 quality steel according to performed Taguchi L9 experiment design. Surface roughness values and S/N ratios obtained after machining were shown in Table 5.

Table 5: Surface roughness values and S/N ratios obtained after machining

Experiment Nu.	Control Factors			Average Surface Roughness Value (Ra) μm	S/N Ratios (dB)
	Cutting Tool	Feed Rate	Hardness		
1	1	1	1	2,148	-6,6407
2	1	2	2	1,359	-2,6644
3	1	3	3	1,083	-0,6926
4	2	1	2	2,012	-6,0726
5	2	2	3	3,118	-9,8775
6	2	3	1	3,727	-11,4272
7	3	1	3	0,180	14,8945
8	3	2	1	0,432	7,2903
9	3	3	2	0,570	4,8825

Effect of control factors on surface roughness values was analyzed by using S/N response table. S/N response table was given in Table 6 for surface roughness. This table, which is created with Taguchi method to get optimum surface roughness value, shows optimum levels besides factor effect range. S/N values of control factors for surface roughness were shown in Figure 4.

Table 6: S/N response table for surface roughness

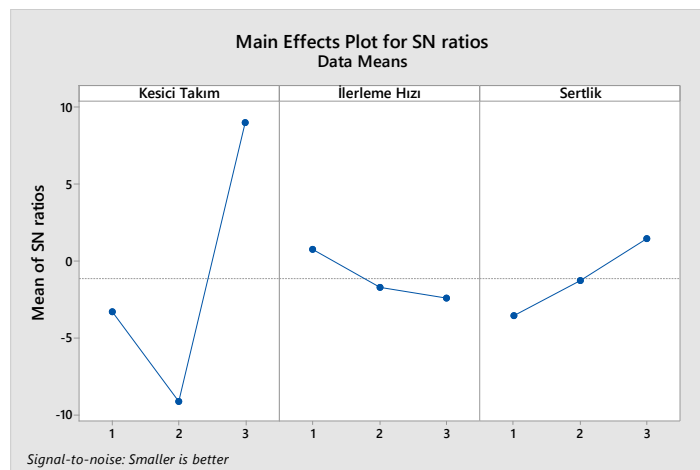| Level	Cutting Tool	Feed Rate	Hardness
1	-3,3325	0,7271	-3,5925
2	-9,1258	-1,7505	-1,2848
3	9,0225	-2,4124	1,4415
Delta	18,1482	3,1395	5,0340
Effect Range	1	3	2

Figure 4. S/N values of control factors for surface roughness

Optimum levels of control factors for surface roughness for A cutting tool (CBN-Level 3), B feed rate (0,02 mm/cyc-Level 1), C Hardness (775 C° Heat Treatment, Level 3) was measured 0,180 µm surface roughness value. However, anticipated S/N ratio is 13,47 and average value is 0,0501778 µm in Minitab program when optimum levels are given.

Prediction	
S/N Ratio	**Mean**
13,4744	0,0501778

Evaluation of Experiment Results

Change in surface roughness depending on cutting team and feed rate were explained in Figure 5 in turning ERDEMIR 5040 quality steel. While surface roughness values are almost equivalent in 0,02 mm/cyc for carbide ceramic cutter, surface roughness values showed an increase in 0,04 and 0,06 mm/cyc for ceramic cutters. Using CBN cutters in 0,02-0,04-0,06 feed rate increased surface roughness. Results correcting performance of CBN cutters, which supports optimization obtained from S/N ratios are clearly seen in graph. The best surface roughness values were obtained with CBN cutters in each three feed rates.
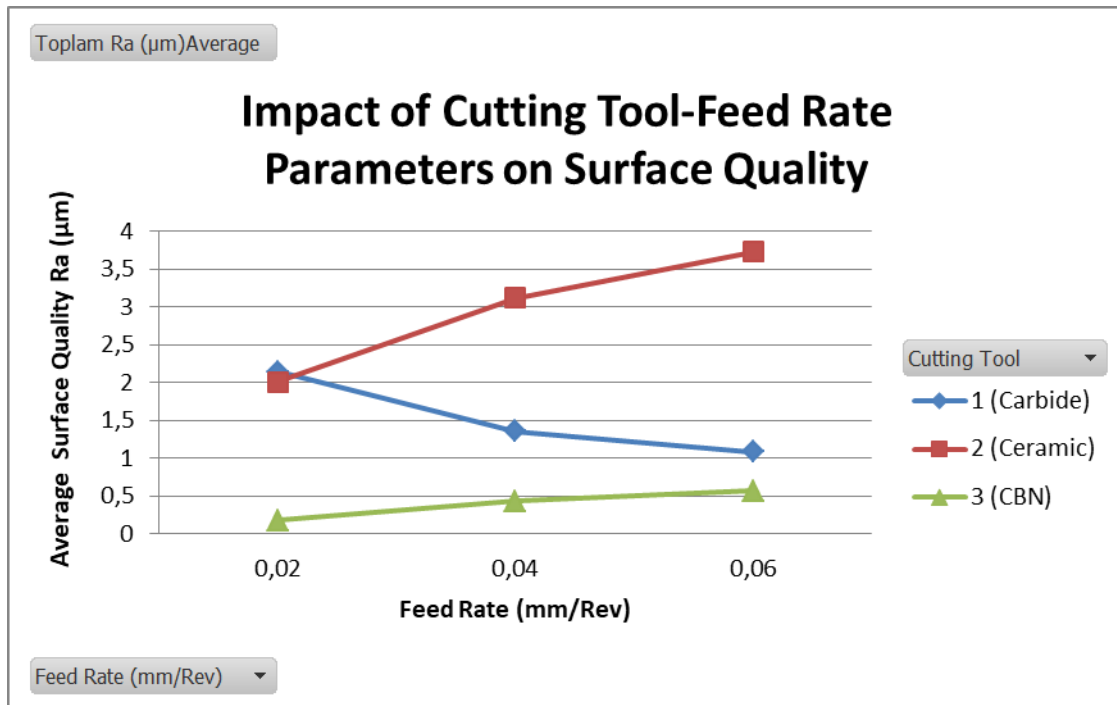

Figure 5. Change of surface roughness depending on cutting tool and feed rate in turning ERDEMIR 5040 Quality Steel
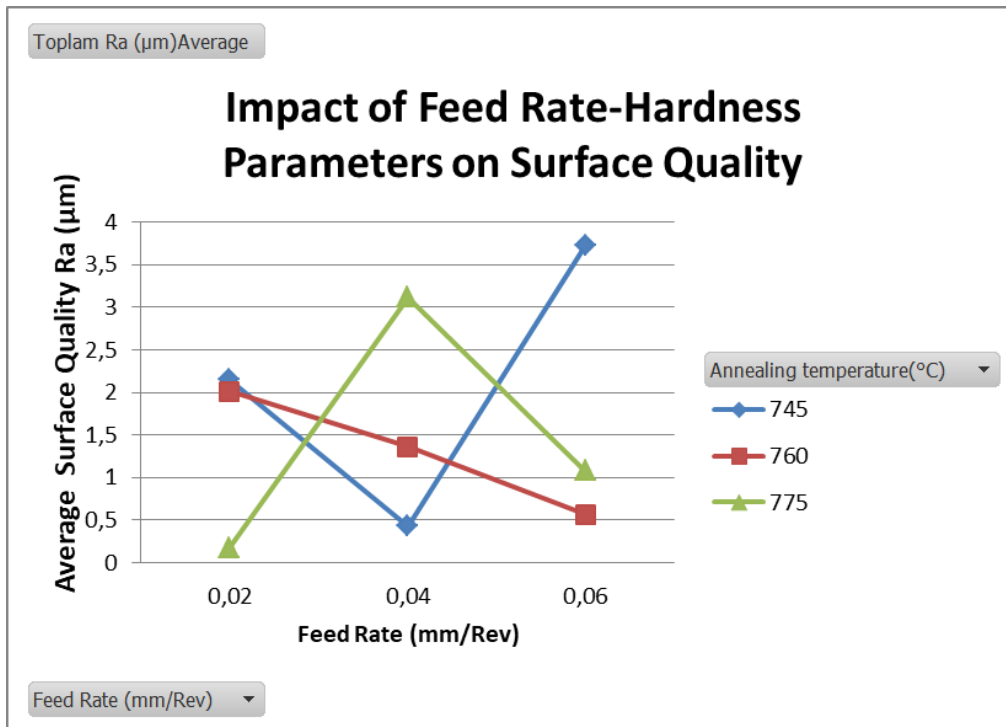
Figure 6. Change of surface roughness depending on hardness and feed rate in turning ERDEMIR 5040 Quality Steel

Change of surface roughness depending on hardness of workpiec and feed rate of cutting tool was explained in Figure 6. Lowest surface roughness in 0,02 mm/cyc feed rate was obtained from steel heat treated at 775 C^O. Almost equivalent surface roughness values in same feed rate were obtained in steels heat treated at 745 ve 760 C^o. Surface roughness value decreased when feed rate increased in steel heat tereated at 760 C^o. Ideal cutting conditions for every three cutters were occurred in medium steel heat treated at 760 C^o, and a decrease in surface roughness was observed depending on feed rate (3,5,16).
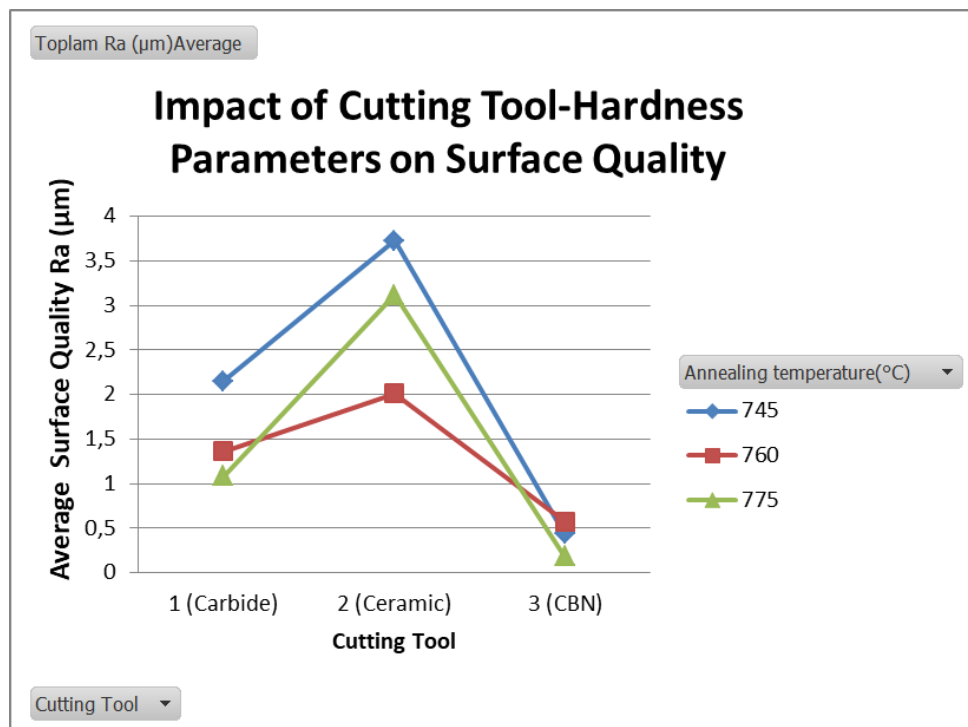

Figure 7. Change of surface roguhness depending on cutting tool and heat treatment (hardness) in turning ERDEMİR 5040 Quality Steel

Change in surface roughness depending on cutting tool and hardness level is explained in Figure 7. While CBN cutters exhibits the best performance for every three hardness, surface roughness value in ceramic cutters is higher than carbide cutters. Better surface quality was obtained with CBN cutters when high hardenability steel is used. This can be explained in two ways. Ceramic cutters were more unstable depending on heating in the effect of increasing friction forces when martensite distribution in material micro structure condensates, and CBN cutters kept stability. Tool abrasion in non-homogenous micro structure resulted in increase in surface roughness by increasing cutting surface (3,16).

Results

In this study, three different paramaters were evaluated and optimized with regards to machinability because Taguchi experiment design has wide usage area, and it enables to obtain results with both less experiments and lower costs compared with traditional experiment design.

Optimisation of cutting parameters affecting surface roughness values obtained from turning of ERDEMIR 5040 Quality steel was performed in this study. A cutter tool (CBN-Level 3), B feed rate (0,02 mm/cyc, Level 1), C hardness (775 C° heat treated-Level 3) surfce roughness value 0,180 µm was measured for lowest surface roughness value in the study made. According to analyse result, it was seen that the most efficient parameter on surface roughness was feed rate with 68,93 % content. Micro hardness values increased with martesite increase taking place in micro structure depending on heat treatment of ERDEMIR 5040 Quality steel. CBN exhibited the best performance depending on hardness.

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