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Impact Evaluation of Some Parameters Affecting Surface Qualities by Taguchi Experimental Design Method: An Experimental Study On Heat Treated Low Carbon Wheel Rim

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Abstract : *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 study was carried out to investigate the effect of HSLA (High Strength Low Alloy) steels, which are increasingly important in the automotive industry, as the locomotive of the economy, to the surface quality in turning operation depending on hardness, feed rate and cutting tool parameters. Experimental design in the Minitab statistical analysis program, Taguchi experiment design technique and 9 trials according to L9 orthogonal design. 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 two different hardness values obtained by annealing at 745 and 790 degrees without heat treatment and 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*

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I. Introduction

Making difference in terms of design has become more important with growing technology with increasing competition conditions each passing day. Designs, which are presented to obtain same strength with more light structures in every sector, will provide energy sources more efficient by only choosing right material and using machinability properties completely. At this point, material groups becoming prominent are low carbon steels and alloys in automotive, aeronautics and space sectors.

Choosing using material properly besides being growth technology to consume less fuel of today's vehicles and to decrease damages to environment has also critical importance. Dual phase low Carbon and high-strength steels and their alloys have become material groups that today's production technology uses intensively because of their high-strength and low intensity values. Therefore, special wheel steel of ERDEMIR was chosen as material in this study performed on machinability.

When we look at definition of machinability, it can be described as difficulty or easiness of machinability of a material in desired shape, size, and surface quality. Cutting parameters (cutting depth, feed rate, cutting speed and cutting tool geometry) and mechanical properties are determinative in obtaining proper machinability properties. Of course, rigidity of bench used during machinability are also effective factor to produce a quality product [1, 2, 3, 4].

It is required to consider all factors affecting product quality and to determine well what are these factors in order to increase quality of a product. Equation of quality-factor number-levels is one of the most important parameters for companies. Because, designer has to analyze a lot of data and to consider a lot of factor levels when specifying proper factor levels. The situation is also more complicated when these factors give different results as being used one by one or combined. Even though classical experiment design techniques provide more reliable data analysis with increasing factor and level numbers, their cost moves away from an efficient solution. Increasing experiment number directs companies to easier solutions with regards to time, effort, and cost. In this situation, developing and applying suitable scientific approaches aimed at problem solving provides important conveniences to designer.

In order to design experiments performed in process development researches in industry, various methods have been developed, which obtains most knowledge in within the shortest time with least cost and labor. Difficulties of some methods assumed as classical for experiment design have caused to do new studies in this subject. Taguchi method that have especially been used in product development after 1980 is one of these studies. Better predictions can be obtained for some design in Taguchi methods because visuality of orthogonal matrix shows that deflection arise from which components of interaction [5].

Experiment design is all process of determining factors and levels affecting experiment results, deciding repeat number for each factor, and analyzing and interpreting obtained experimental data results. In other words, it is to be observed, to be obtained and to be interpreted of variability on result of changes done in input variables of any process [6].

Akyuz and Senaysoy [7] investigated the effect of aging in AA6013 and AA6082 aluminum alloys on mechanical properties and machinability properties of alloys. AA6082 and AA6013 aluminum alloys used in the experiment submerged to hot water in 70 C^o after solution treating process of specimens in 530 C^o in heat treatment oven (8 hours). After that, artificial ageing process was performed in heat treatment oven at 180 C^o by being waited in different times (1, 3, 6, 9, 12, and 24 hours). They observed an increase in mechanical properties of both alloys. They obtained that cutting force occurring during machinability of alloys increased depending on increasing ageing time, and they achieved high mechanical properties at the end of 6 hours ageing process. They didn't get a significant difference between mechanical and machinability properties at the end of 6 hours ageing process and 24 hours ageing process in alloys.

Demir and Ozlu [8] performed machining experiments on microalloyed 30MnVS6 steel workpiece, which is high-strength and low alloyed (HSLA) and is subjected to heat treatment and hardening in water and oil. Experiments were done with turning method in four different cutting speeds (90, 120, 150, 180 m/min), with 0,1 mm/rev feed rate, in 1 mm cutting depth, in dry conditions without using cooling liquid. Applied heat treatments changed microstructure and hardness of workpieces, and they investigated the effect of these microstructures and hardness on cutting force and surface roughness. They observed that workpieces cooled in water caused very fast wear in cutting tool. Cutting force and surface roughness values in experiments performed on workpieces hardened in water were higher than those values in experiments performed on workpieces hardened in oil.

Zhao et al. [9] stated that cutting tool performance is affected from microgeometry such as edge radius during hard turn. They actualized an experimental research to understand the effect of cutting-edge radius on tool machining performance with regards to surface roughness and tool wear in study performed on AISI52100 steel. Three group cutters with 20, 30, 40 µm nominal edge radius (CBN) was used in the study. Change of cutting edge-radius was evaluated with the aid of optical microscope. They investigated the effect of cutting edge-radius on surface radius and tool wear in machining conditions that have different machining test by designing three-leveled, two-factored Taguchi method. Variations tend to smaller with increasing nominal value of edge-radius. They also concluded that edge-radiuses have a significant effect on surface roughness and tool wear.

Asilturk and Akkus [10] studied the effects of cutting speed, feed rate, and dept of cut on surface roughness in turning process of hardened AISI 4140 (51 HRC) with coated carbide. As a result of experimental results, they showed that feed rate has the most significant effect on Ra and Rz.

Material removal (especially turning) in metal working industry has an important place. Surface roughness performance increase provided here will significantly contribute to costs and quality. Quality of machined surfaces plays an important role on material removal performance. a quality machined surface both increases fatigue and corrosion resistance and significantly enhances wear life resulted from friction. Surface quality also affects various functional properties of tools causing friction such as contact, wear, conduction, oil film formation ability. Therefore, desired surface quality is specified within desired tolerance, and machining is done with suitable parameters to reach needed quality.

The situation indicated above is a typical problem sample showing up in tool machining suitable to tolerances in engineering research-development studies. It is required to make experiments for improving surface quality that is also a measurement of machinability and make optimization by evaluating result of these experiments.

The purpose of this study is to investigate the effect of material and cutting parameters (feed rate and cutting tool type) on workpiece surface roughness that is an important machinability criterion by performing machining experiments via turning methods on steels used in machine production industry, and to optimize. In this study, factors affecting surface quality in turning were evaluated after literature review, and dual phased steel specimen in three different hardness obtained after heat treatment was subjected to turning process in three different feed rates by using three different cutters. Results gotten in Taguchi optimization were evaluated in terms of consistency of obtained findings with literature and optimization in the study.

II. Experimental Study

2.1. Material Used and Their Properties

3936 ERDEMIR quality special wheel steel produced as hot mill product in Eregli 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 belong to 3936 Quality Steel.

Quality	Standard	Chemical Composition (% Weight)					
		C	Mn	P	S	Si	Al
3936	Erdemir Special Wheel Steel-01	0.085	0.33	0.011	0.009	0.06	0.062

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 [11].
It was given water in water to turning specimen annealed 30 minutes in 745 and 790 C° temperatures besides non-heat-treated specimen 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 Fig. 1.

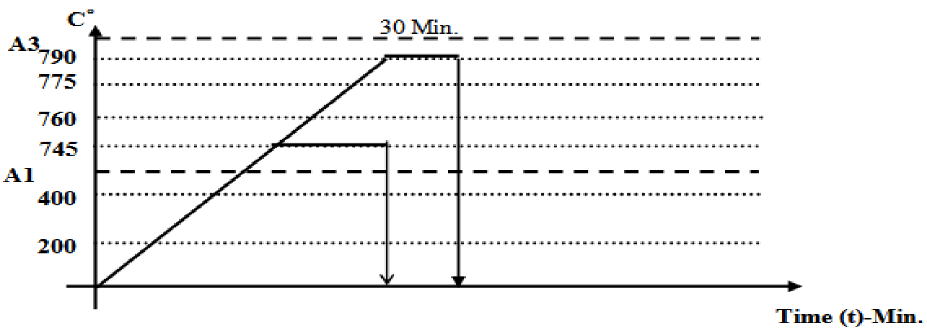

Figure 1. Temperature (T)-Time(t) diagram.

2.2. 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

Material	Non-Heat Treated	745◦	790◦
Measurement 1 (HV)	100	150	173
Measurement 2 (HV)	105	155	177
Average Hardness (HV)	102,5	152.5	175

2.3. 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.

2.4. Choosing Cutting Parameters and Their 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 are a new class of high strength-low alloy steels (HSLA). A cylindrical workpiece made from 3936 number steel having 0,085 % 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 rates in dry cutting conditions in the study. Cutting area order is shown in Fig. 2. Factors used in machining and its levels were defined with user experience and were specified in Table 3.

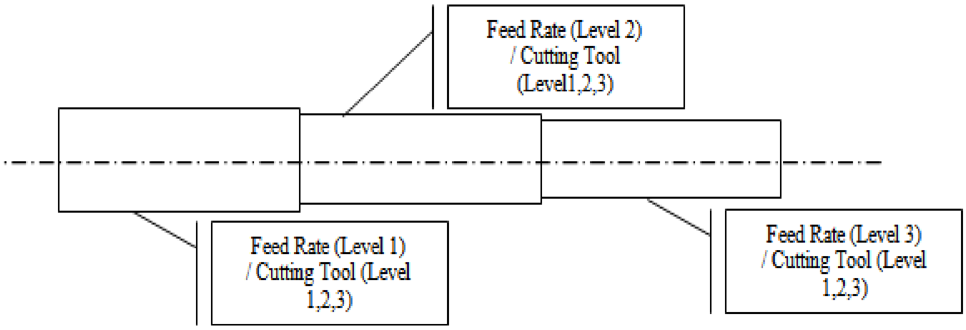

Figure 2: Cutting Area Order

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 [5]. This diagram specifies all factors representing product or process quality and affecting measured values [12]. 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 Fig. 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.

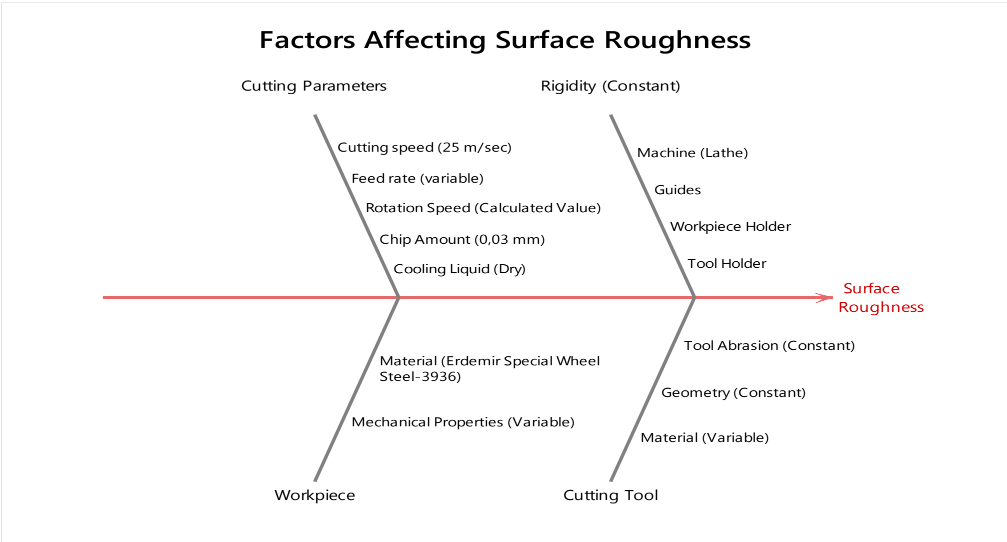

Figure 3. Evaluation of Factors Affecting Surface Roughness with Fishbone Diagram

Table 3: Cutting Parameters

Factors	Unit	Symbol	Level 1	Level 2	Level 3
Cutting Tool	-	A	Carbide	Ceramic	CBN
Feed Rate	mm/rev	B	0,02	0,04	0,06
Heat Treatment /Hardness	/Hv0.5	C	Non-processed	760◦C	775◦C

2.5. 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 [13]. 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.

2.6. Analysis of S/N Ratios

Taguchi experiment design and analysis were performed in Minitab 16.1 package program, and basic leveled (three level) L9 orthogonal index was used. "Smallest-the best" formula specified equation (1) was used to evaluate obtained Signal-Noise Ratios (S/N).

$$\frac{S}{N} = -10 * \log\left[\sum_{i=1}^{n} \frac{{Y_i}^2}{n}\right] \qquad \text{Eq. (1)}$$

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

Taguchi method provides time and cost saving with less experiment, and this method can be used as decision tool [14]. Taguchi method is a pretty useful method to determine the best combination from among different levels of different parameters. In situation requiring making too much experiments for all combinations including every level of every parameter, it is possible to land up with a lot fewer experimental study by using orthogonal index table (Table 4) in Taguchi method [15].

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	0,687	3,260
2	1	2	2	2,613	-8,343
3	1	3	3	3,413	-10,663
4	2	1	2	0,889	1,018
5	2	2	3	3,040	-9,658
6	2	3	1	1,431	-3,112
7	3	1	3	1,850	-5,344
8	3	2	1	3,490	-10,857
9	3	3	2	0,997	0,0278

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 Fig. 4.

Table 6: S/N response table for surface roughness

Level	Cutting Tool	Feed Rate	Hardness
1	-5,2486	-3,5698	-0,3552
2	-3,9178	-2,4325	-9,6199
3	-5,3913	-8,5554	-4,5827
Delta	1,4736	6,1229	9,2647
Effect Range	3	2	1

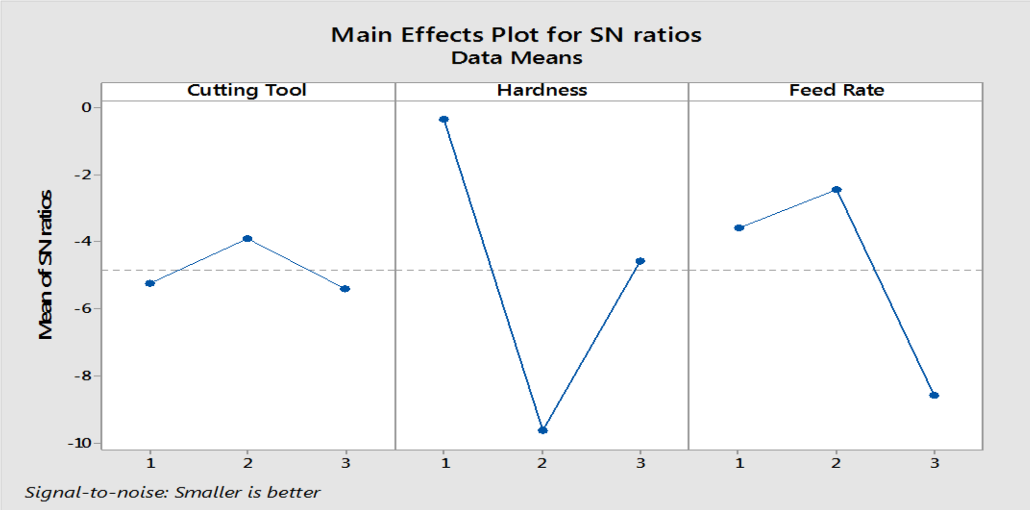

Figure 4. S/N values of control factors for surface roughness

Optimum levels of control factors for surface roughness for A cutting tool (Ceramic-Level 2), B feed rate (0,04 mm/rev-Level 2), C Hardness (Non-Heat Treatment, Level 1) was measured 0,889 µm surface roughness value. However, anticipated S/N ratio is 2,99 and average value is 0,337 µm in Minitab program when optimum levels are given.

III. Evaluation Of Experiment Results

Change in surface roughness depending on cutting team and feed rate were explained in Fig. 5 in turning ERDEMIR 3936 quality steel. While surface roughness values are almost equivalent in 0,02 mm/rev for carbide and ceramic cutter, surface roughness values showed an increase in 0,04 mm/rev. Using ceramic and CBN cutters in 0,06 mm/rev increased surface quality. Results correcting performance of ceramic cutters, which supports optimization obtained from S/N ratios are clearly seen in graph. The lowest average Ra value was observed with 1,78 µm in ceramic edges for each three feed rates.

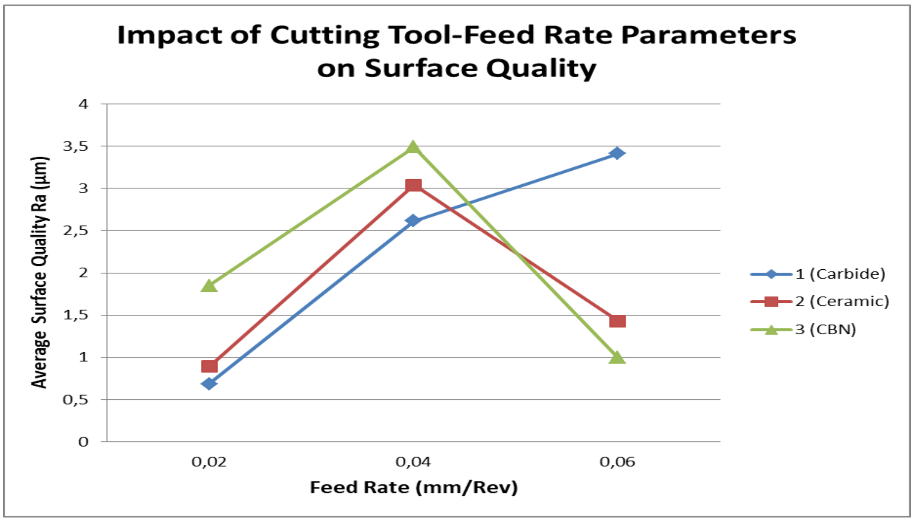

Figure 5. Change of surface roughness depending on cutting tool and feed rate in turning ERDEMIR 3936 Quality Steel

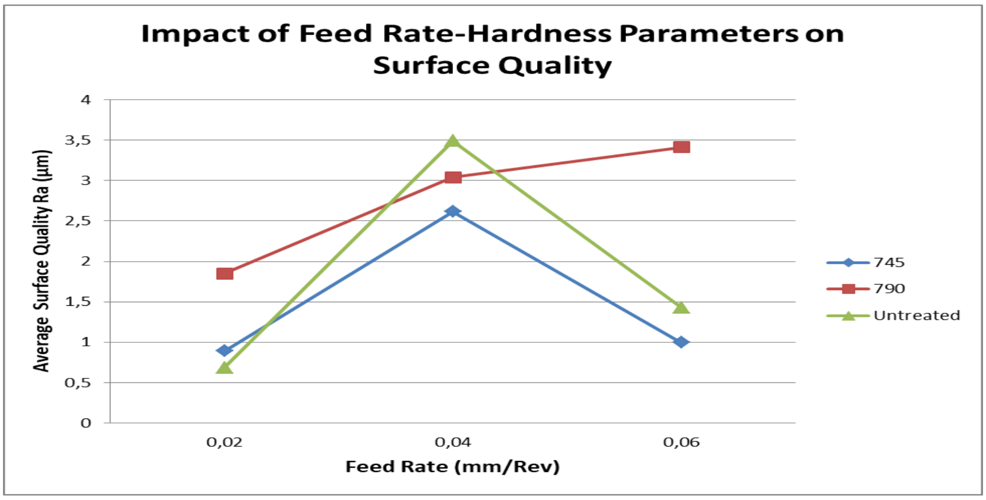

Figure 6. Change of surface roughness depending on hardness and feed rate in turning ERDEMIR 3936 Quality Steel

Change of surface roughness depending on hardness of workpiece and feed rate of cutting tool was explained in Fig. 6. Surface roughness values are almost equivalent in 0,02 mm/rev feed rate in low and medium hardness specimens, surface roughness values increased in 0,04 mm/rev feed rate. Surface roughness in 0,06 mm/rev feed rate for medium hardness work piece increased compared with 0,04 mm/rev feed rate. Results correcting high surface quality, which supports optimization obtained from S/N ratios in especially high feed rates for medium hardness specimens are clearly seen in graph. The lowest average Ra value was observed with 1,49 µm in medium hardness specimens for each three feed rates. Other values for low and high hardness are 1,86 µm and 2,76 µm, respectively.

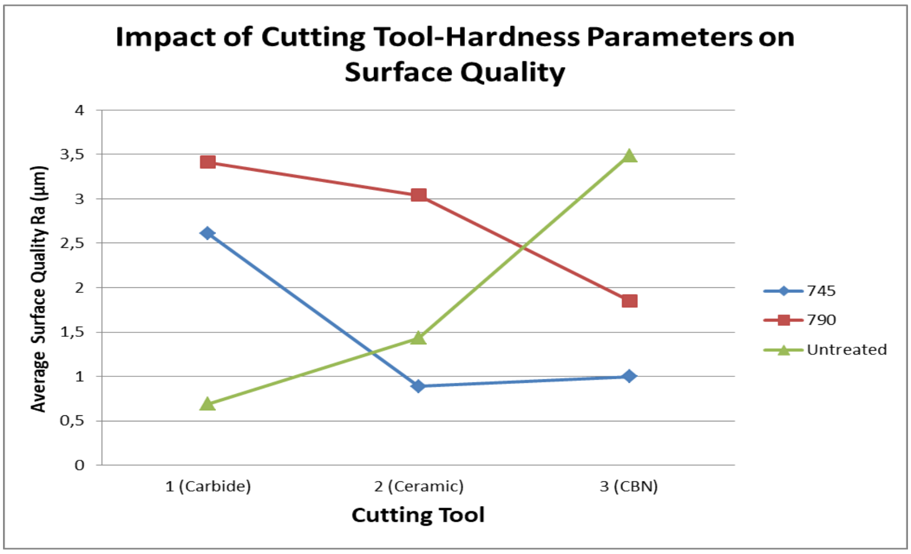

Figure 7. Change of surface roguhness depending on cutting tool and heat treatment (hardness) in turning ERDEMİR 3936 Quality Steel

Change in surface roughness depending on cutting tool and hardness level is explained in Fig. 7. While carbide edges exhibited better performance in low hardness, CBN edges produces better results in medium hardness. Better surface quality was obtained with CBN cutters when high hardenability steel is used. The best surface for each cutters quality was obtained in medium hardness specimens as average. The lowest average Ra value was observed with 1,49 µm in medium hardness specimens.

IV. 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 3936 Quality steel was performed in this study. Obtained results in studies done was indicated below. A cutter tool (Ceramic-Level 2), B feed rate (0,04 mm/cyc, Level 2), C hardness (Non-heat treatment-Level 1) surface roughness value 0,889 µm was measured for lowest surface roughness value in the study made. However, anticipated S/N ratio is 2,99 and average value is 0,337 µm in Minitab program when optimum levels are given. According to analyse results, it was seen that the most efficient parameter on surface roughness was feed rate with 54,94 % content. Micro hardness values increased with martesite increase taking place in micro structure depending on heat treatment of ERDEMIR 53936 Quality steel. This hardness increase has a positive effect to surface roughness values in turning including medium hardness, while has negative effect in high hardness.

V. Acknowledgements

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