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Research Article

Investigating the Relationship between Chuck and Tailstock Pressure in Turning by Using Full Factorial Design

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ABSTRACT

The failure of the workpieces to be attached to the lathe at a suitable chuck and tailstock pressure values causes to the run-out rotation of the workpiece and surface irregularities, resulting in deterioration of the dimensional accuracy and surface roughness values. In order to eliminate such negativities, it is quite important to determine the ideal chuck and tailstock pressure values. The aim of this study is to obtain the lowest surface roughness value by determining the relations between the chuck and tailstock pressure and their optimum pressure via using a 2^k full factorial design. In order to see the effect of chuck and tailstock pressure, the experiments were repeated 3 times at the lowest and highest chuck and tailstock pressures determined in the constant cutting parameters of AISI 304 stainless steel. For the surface roughness values obtained as a result of 3 repetitions, the full factorial design, the optimum chuck and tailstock pressure and their relations with each other were determined with ANOVA table. According to the results of full factorial design and ANOVA, chuck and tailstock pressure and their relations with each other were found significant. The most effective parameters on surface roughness were obtained as chuck pressure, tailstock pressure and chuck- tailstock pressure, respectively. According to the full factorial design results, it was determined that the lowest surface roughness values were obtained at 17 chuck pressure and 5 tailstock pressure. The R^2 value obtained in the factorial regression was 98.24% and the corrected R^2 value was 96.77%. As a result, it is understood that the full factorial design is an efficient and effective method in determining the chuck and tailstock pressure.

1. INTRODUCTION

In machining, the requirements for correct machining of a workpiece include the correct attachment of the workpiece to the machine. Failure in attachment of a workpiece at ideal tailstock and chuck pressure will increase the vibrations, oscillations and stretching that will occur while the workpiece is being machined, resulting in undesirable high surface roughness values on the workpiece. The aim of the manufacturing process is to obtain parts with an ideal surface roughness according to a certain tolerance and accuracy level, both in terms of low cost and time, as well as geometry and dimensional. While the workpieces are being machined, the first step in eliminating the undesirable high surface roughness values is the attaching of the workpiece with a correct chuck and tailstock pressure. In order to evaluate the surface roughness results obtained while machining a workpiece, statistical tools should be used, which provides great convenience in terms of both time and cost, especially by reducing the number of experiments. The first of these is the full factorial design (FFD). Experiment design methods are often preferred in the evaluation of the results obtained in turning experiments. These methods are used to determine the effect of control factors on the response and their relationships with each other. One of the experimental design methods used in the literature to evaluate the test results and to select the optimum parameters is FFD. In the literature, there are very few studies on the evaluation of surface roughness results with FFD, and the studies conducted are summarized below:

Kechagias et al. used FFD for the estimation of machinability in turning titanium alloys. According to the FFD results, they determined that the most important effect on the surface roughness is the feed rate, while the least effect is the depth of cut [1]. Athreya et al. investigated the effect of cutting parameters on surface roughness in turning medium carbon steel using FFD. In their FFD study, the authors obtained optimum surface roughness results using less number of experiments, when the cutting speed was 960 rpm, the feed rate was 145 mm/rev and the depth of cut was 0.3 mm. In addition, they also performed a confirmation test for the validity of the experimental results in their study [2]. Das et al. used FFD to evaluate the surface roughness results in hard turning of AISI 4340 steel. According to FFD results, the authors determined that the most effective parameters on the surface roughness at the 95% confidence interval were the feed rate and the cutting speed, respectively. They also revealed that the two-level interactions of depth of cut-cutting speed, depth of cut-feed rate and feed rate-depth of cut have significant effects on surface roughness [3]. Leksycki and Feldshtein revealed the effect of machining parameters on the surface roughness values obtained in turning of AISI 316L steel using FFD. According to FFD results, the authors revealed that not only the feed rate and cutting speed but also the dual interaction, namely cutting speed-feed rate, is effective on the surface roughness [4]. Rafidah et al. carried out a study revealing the effect of surface roughness measurement parameters on surface roughness values using FFD. According to FFD results, the authors determined that the temperature, sampling length and cut of length parameters had no effect on the surface roughness values [5]. Vikram et al., using FFD, demonstrated the effect of cutting parameters on the surface roughness results obtained in turning brass material with HSS and carbide cutting tools. The authors found that cutting speed and feed rate had a significant effect on the surface roughness values, but the cutting speed-feed rate was less effective in their dual interaction [6].

When the literature is examined, very few experimental and statistical studies have been carried out with FFD, which is one of the experimental design methods, to determine the effects of cutting parameters on surface roughness [1-6]. At the same time, both experimental and statistical studies are available in the literature to reveal the effect of cutting conditions and cutting parameters on surface roughness [7-12]. However, no statistical study has been conducted with FFD to determine the effect of chuck and tailstock pressure on surface roughness values. Only a few studies on optimization have been carried out to determine the effect of chuck and tailstock pressure on surface roughness values [13-16]. With this experimental and statistical study, the optimum chuck and tailstock pressure will be determined, and it will contribute to those who will work on turning with the results obtained by reducing the machining costs in terms of both time and cost.

2. MATERIALS AND METHOD

2.1. Workpiece material, cutting tools and tool holder

In this research, AISI 304 stainless steel, which is the most widely used in the stainless steel group and has good corrosion resistance, was used as the workpiece material. The workpieces were supplied with a diameter of 36 mm, then they were first reduced to 35 mm in diameter on the CNC lathe in order to eliminate external negativities on the surface, and finally they were prepared with a length of 300 mm so that each workpiece could be processed under equal test conditions. The chemical composition in terms of weight percentage and hardness value of the workpiece are shown in Table 1.

TABLE I

Chemical composition and hardness value of the workpiece material

% Cr	% C	% Si	% Mn	% P
19.50-17.50	0.070-0.024	1.00-0.39	2.0-1.45	0.045-0.036
% N	**% Ni**	**% Co**	**% S**	**Hardness**
0.100-0.085	10.50-8.00	0.15(max)	0.030-0.029	215 HB

WNMG 080408-OMM PVD-coated inserts with positive rake angle were selected for the machining of AISI 304 austenitic stainless steel at different cutting parameters on a CNC lathe. PWLNR 2525M08 tool holder suitable for these inserts was used. The cutting tips and tool holder were obtained from the OKE cutting tool manufacturer Fidan Cutting Tool Company Shapes of carbide inserts and tool holder are given in Figure 1.

a) **b)**

Figure 1. a) WNMG cutting tool used in the experiments b) PWLNR 2525M08 tool holder

2.2. Cutting parameters and machine tool

Machining experiments were carried out on TAKISAWA EX-310 brand CNC lathe. In the selection of the cutting parameters used in the machining experiments, the experimental set was created by taking into account the cutting tool catalog values and ISO 3685 standards, which are the recommendations of the manufacturer cutting tool company. In the experiments, the constant feed rate, the cutting speed and the depth of cutting were determined as 0.2 mm/rev, 250 m/min and 2 mm, respectively. Machining experiments were carried out using five different chuck and tailstock pressures at constant cutting parameters. Chuck and tailstock pressure were determined as variable parameters and shown in Figure 2.

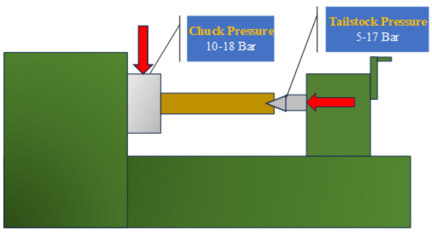

Figure 2. Parameters used in the experiments

The numerical values of the chuck and tailstock pressure and cutting parameters used in the turning experiments are given in Table 2.

TABLE II

Cutting parameters used in machining experiments

Chuck Pressure, P (bar)	10 - 18
Tailstock Pressure, P (bar)	5 - 17
Depth of cut, a (mm)	2
Feed rate (mm/rev)	0.2
Cutting Speed, V (m/min)	250

2.3. Surface Roughness Measurement

The surface roughness values on the workpiece surface resulting from the machining experiments were measured using a portable TR 200 measuring device. In determining surface roughness values, five different measurement zones were determined on the workpiece surface. Average surface roughness values were determined from each measurement region with a measurement length of 5.6 mm. The average surface roughness values of the workpiece were calculated by taking the arithmetic average of the 5 detected surface roughness values. The experimental setup established to see the effect of chuck and tailstock pressure on surface roughness values in turning AISI 304 steel at constant cutting parameters is shown in Figure 3.

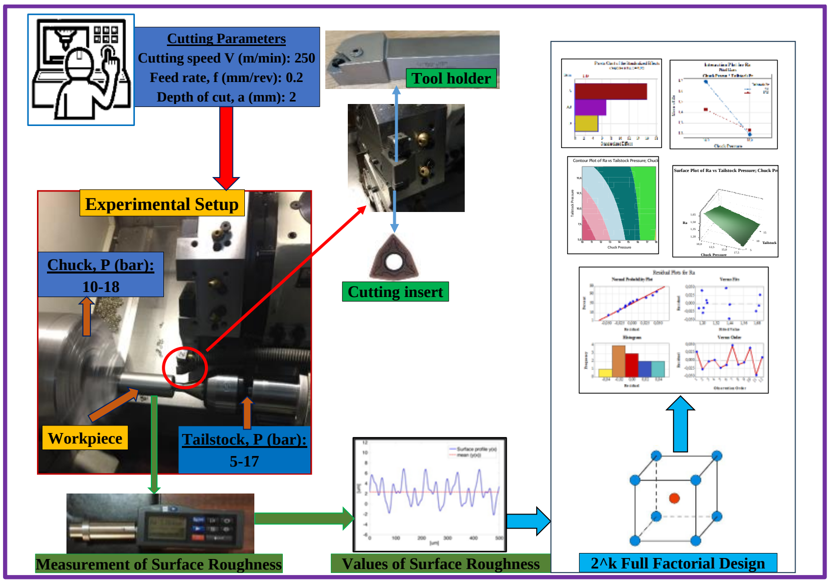

Figure 3. Schematic representation of the experimental setup.

2.4. Full Factorial Design (FFD)

FFD, a statistical methodology, was used in the experimental design, which was used to see the effect of chuck and tailstock pressure on the surface roughness of the experimental study. FFD is an experimental design method used to see the effects of 2 or more factors both separately and with each other. Full factorial regression is performed to show the effects of control factors on response [2, 4]. In this study, while the chuck and tailstock pressures were taken as control factors, the surface roughness values were taken as the response. FFD was performed to reveal the separate and dual relations on the surface roughness, which is the response of these control factors.

2.5. ANOVA

In ANOVA, which is a statistical method, there are two types of variables: control factors and response values. The purpose of ANOVA is to determine how effective the control factors are on the response value. The importance of control factors in ANOVA is determined according to the P values of each control factor in ANOVA table. If the P value is less than 0.05, it is significant, if the P value is greater than 0.05, it is meaningless. An ANOVA table generally includes: sum of squares (SS), degrees of freedom (DF), mean of squares (MS), significance level (P) and statistical (F) values [17-19].

3. RESULTS AND DISCUSSION

In this experimental study, the surface roughness values were optimized by using 2^2 FFD method with 3 repetitions by connecting the workpieces to the CNC lathe at the lowest and highest chuck and tailstock pressures at constant cutting parameters. Surface roughness tests were carried out on a CNC lathe by taking two factors and the lowest and highest chuck and tailstock pressures in 3 repetitions. Considering the surface roughness values as the response, chuck and tailstock pressure as the control factors, and the lowest and highest levels of these factors, the relationships between these two factors on the response were revealed. The control factors used in the turning experiments and their minimum and maximum values are given in Table 3.

TABLE III
Minimum and maximum control factors

Factors	Low	High
Chuck Pressure	10	18
Tailstock Pressure	5	17

3.1. FFD Results

Surface roughness values obtained from the surfaces of the workpiece machined in constant machining parameters on the CNC lathe, control factors and the lowest and highest values of these control factors are given in Table 4. The experiment carried out and the 3 replications of these experiments and the order of the experiments for these blocks are also shown in Table 4. The Main Effects Plot graph showing the effects of the lowest and highest chuck and tailstock pressure on the surface roughness is given in Figure 4. When the Main Effect Plot in Figure 4 is examined, it is seen that the chuck and tailstock pressure have an effect on the surface roughness. It is seen in the graph in Figure 4 that as the chuck pressure value increases, the surface roughness values decrease, while the surface roughness values decrease as the tailstock pressure values increase.

TABLE IV

2^2 (2^k) Full Factorial Design and 3 repetitive surface roughness values.

Run Order	Blocks	Chuck Pressure, Bar	Tailstock Pressure, Bar	Surface Roughness, Ra (μm)	Prediction, Ra (μm)
1	1	10	5	1.735	1.69367
2	1	18	5	1.179	1.19267
3	1	10	17	1.441	1.43000
4	1	18	17	1.247	1.23133
5	2	10	5	1.651	1.69367
6	2	18	5	1.159	1.19267
7	2	10	17	1.458	1.43000
8	2	18	17	1.199	1.23133
9	3	10	5	1.695	1.69367
10	3	18	5	1.240	1.19267
11	3	10	17	1.391	1.43000
12	3	18	17	1.248	1.23133

In addition, it is clearly understood that the chuck pressure is more effective on the surface roughness than the tailstock pressure, due to the larger vertical distance between the mean lower and upper values.

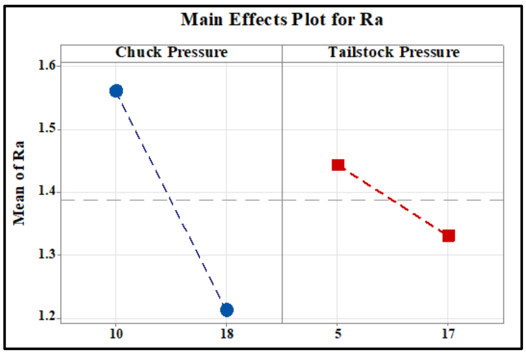

Figure 4. Main Effect Plots for Surface Roughness

The interaction plot graph showing the relationships between these factors is shown in Figure 5.

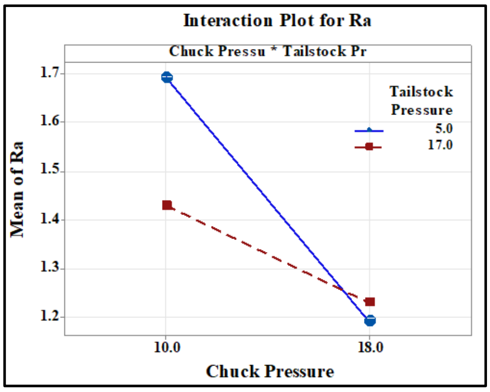

Figure 5. Interaction Plot for Surface Roughness

Interaction graph showing the effect between chuck and tailstock pressure is given in Figure 5. When the graph in the figure is examined, it is seen that there is a relationship between chuck and tailstock pressure. Since the blue line and the dashed maroon line intersect in this stage, it can be said that the chuck-tailstock pressure dual relationship is effective on the surface roughness. As can be seen from the graph, it was determined that the chuck pressure intersects at 17 bar and the tailstock pressure at 5 bar and there is a high relationship between these values. The full factorial regression results performed according to the lowest and highest values of chuck and tailstock pressure are given in Table 5.

TABLE V

FFD regression results

Term	Effect	Coef	SE Coef	95% CI	T-Value	P-Value	VIF
Constant		1.3869	0.0109	(1.3603; 1.4136)	127.29	0.000	
Blocks							
1		0.0136	0.0154	(-0.0241; 0.0513)	0.88	0.412	1.33
2		-0.0202	0.0154	(-0.0579; 0.0175)	-1.31	0.239	1.33
Chuck Pr. (A)	-0.3498	-0.1749	0.0109	(-0.2016; -0.1483)	-16.05	0.000	1.00
Tailstock Pr. (B)	-0.1125	-0.0563	0.0109	(-0.0829; -0.0296)	-5.16	0.002	1.00
A*B	0.1512	0.0756	0.0109	(0.0489; 0.1022)	6.94	0.000	1.00

The equation obtained as a result of factorial regression is given in Equation 1 below. This equation was formed as a result of the interaction of chuck pressure, tailstock pressure and chuck*tailstock pressure. R^2 value of the equation estimating the surface roughness values is 98.24% and the corrected R^2 value is 96.77%. According to R^2 results of the equation estimating the surface roughness values, factorial regression was found to be successful.

$$Ra = 2.5872 - 0.07837\,Chuck\ Pressure - 0.05347\,Tailstock\ Pressure + 0.003149\,Chuck\ Pressure \times Tailstock\ Pressure \tag{1}$$

3.2. ANOVA results

ANOVA (Analysis of Variance) is a statistical tool that reveals the effect of control factors on response.In this experimental study, chuck and tailstock pressures were taken as control factors, while surface roughness values were taken as a response. ANOVA results based on Full Factorial regression depending on the lowest and highest chuck and tailstock pressure are given in Table 6.

Table VI

ANOVA results

Source	DF	Seq SS	Cont.	Adj SS	Adj MS	F-Value	P-Value
Model	5	0.476211	98.24%	0.476211	0.095242	66.85	0.000
Blocks	2	0.002538	0.52%	0.002538	0.001269	0.89	0.458
Linear	2	0.405119	83.57%	0.405119	0.202559	142.18	0.000
Chuck Pressure	1	0.367150	75.74%	0.367150	0.367150	257.71	0.000
Tailstock Pressure	1	0.037969	7.83%	0.037969	0.037969	26.65	0.002
2-Way Interac.	1	0.068554	14.14%	0.068554	0.068554	48.12	0.000
Chuck*Tailstock	1	0.068554	14.14%	0.068554	0.068554	48.12	0.000
Error	6	0.008548	1.76%	0.008548	0.001425		
Total	11	0.484759	100.00 %				

Whether the control factors in the ANOVA table and their relations with each other are statistically significant can be expressed by whether P-Value value is less than 0.05 [17-19]. When the "P-values" in Table 6 are examined, it can be concluded that only not the "Blocks" value is statistically significant but also the others are significant. In order to understand which control factor has the greatest effect on surface roughness, when the "contribution" values in Table 6 are examined, it will be seen that it is chuck pressure with 75.74%. This value is then followed by the chuck-tailstock pressure at the rate of 14.14%, while the tailstock pressure with the least effect is followed by 7.83%. "F-value" value in ANOVA table is a value that shows the effect of control factors on the response. A high F-value indicates that that value is very effective on the response. In this context, it can be said that the chuck pressure has the greatest effect on surface roughness. The Pareto chart showing the effect of chuck and tailstock pressure on the surface roughness is given in Figure 6.

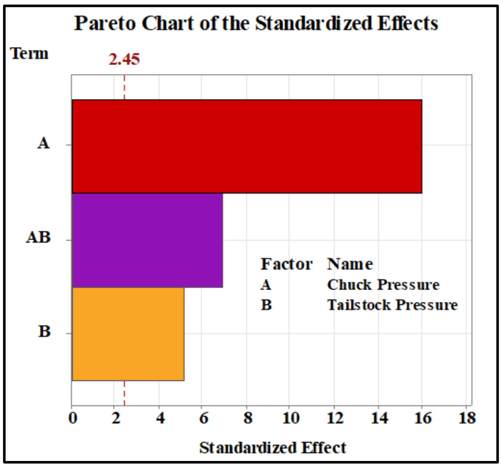

Figure 6. Pareto Chart for Ra values

When the Pareto chart of standardized effects in Figure 6 are examined, it is understood that the parameters that affect the surface roughness most are A (Chuck pressure) and AB (Chuck-tailstock pressure) and finally B (tailstock pressure) from top to bottom. In other words, it shows that the area that takes up the most space on the line is more effective on the surface roughness. The normal probability plot graph obtained as a result of the factorial regression is given in Figure 7.

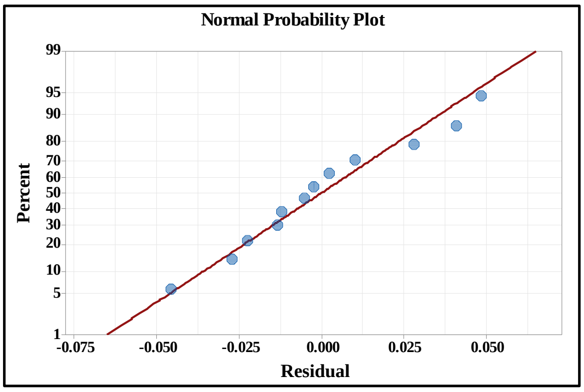

Figure 7. Normal probability plot for Ra values

When the graph in Figure 7 is examined, it is seen that the surface roughness values are estimated at very high rates since the values are collected around the normal probability plot linear line. The contour plot graph of the surface roughness created according to the FFD depending on the chuck and tailstock pressure is given in Figure 8.

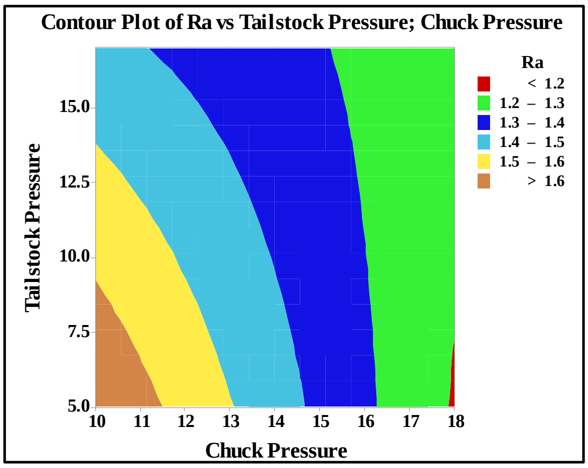

Figure 8. Contour plot

When the contour plot graph in Figure 8 is examined, each color range and area represent the surface roughness value. It is seen that the lowest surface roughness values occur when the chuck pressure is between 17 and 18 and the tailstock pressure is between 5 and 7. It can be seen from this graph that as the chuck pressure increases and the tailstock pressure decreases, the surface roughness values decrease. The surface plot graph showing the effect of chuck and tailstock pressure on the surface roughness is given in Figure 9.

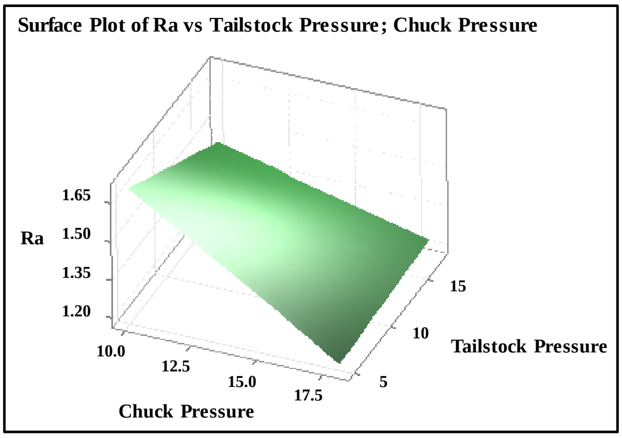

Figure 9. Surface plot for surface roughness values

When the surface response graph in Figure 9 is examined, it is understood that the lowest surface roughness value is 18 bars at chuck pressure and 5 bars at tailstock pressure. In addition, it is understood that the chuck pressure is more effective on the surface roughness than the tailstock pressure. As the chuck pressure decreases, the surface roughness values increase; on the other hand, the surface roughness values increase as the tailstock pressure values increase. In other words, chuck and tailstock pressure affect the surface roughness inversely proportionally. While it is recommended to use high chuck pressures for low surface roughness values, the opposite should be preferred for tailstock pressure. The graphics and values obtained with the multiple response performed to obtain the optimum chuck and tailstock pressure in order to minimize the surface roughness are given in Figure 10.

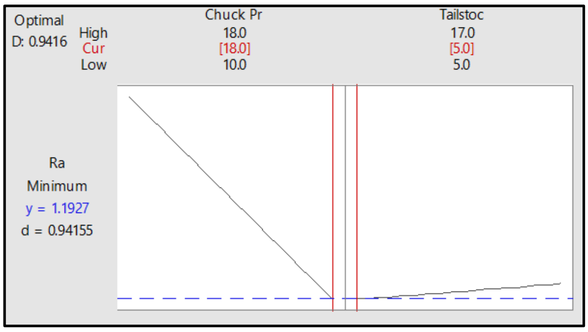

Figure 10. Optimization results for Ra values

When the graph obtained according to the surface response method in Figure 10 is examined, it is seen that the values that minimize the surface roughness value are 18 bar for the chuck pressure and 5 bar for the tailstock pressure. It is seen that the "y" value that minimizes the surface roughness value is 1.927, while the "d" value is 0.94155. It is understood that the values that minimize the surface roughness according to the chuck and tailstock pressure are high chuck pressure and low tailstock pressure. Figure 11 shows the comparison of the estimations and the actual values obtained according to the factorial regression results created to estimate the surface roughness values.

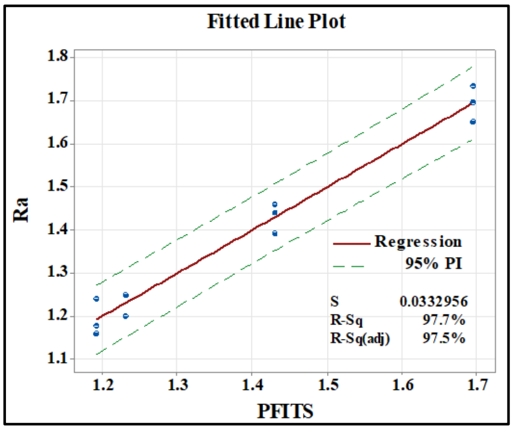

Figure 11. Fitted line plot chart

When the Fitted line plot graph in Figure 11 is examined, it is seen that the surface roughness and estimated values are at 95% confidence interval, while R^2 value is at 97.7%. It is clearly seen that the actual values and the predicted values are gathered around the fitted line and provide this confidence interval.

4. RESULTS

In this experimental and statistical study, FFD was used to reveal the effect of chuck and tailstock pressure on the surface roughness values formed as a result of turning AISI 304 austenitic stainless steel on a CNC lathe at constant cutting parameters. Obtained results are summarized below.

- According to the Main Effect Plot graph, it was determined that as the chuck pressure value increases, the surface roughness value decreases and as the tailstock pressure value increases, the surface roughness values decrease. In addition, it was observed that the chuck pressure is more effective than the tailstock pressure on the surface roughness.
- According to the Interaction graph showing the effect between the chuck and the tailstock pressure, it has been determined that there is a relationship between the chuck and tailstock pressure. At the same time, it can be said that the chuck and the tailstock pressure intersect at 17 and 5 bar, respectively; and there is a high correlation at these values.
- According to the ANOVA results, it was determined that the greatest effect on the surface roughness values was the chuck pressure with 75.74%, then the chuck-tailstock pressure with 14.14%; on the other hand, the least effect on surface roughness was the tailstock pressure with 7.83%.This situation is similarly obtained from the Pareto chart of standardized effects.
- Since the surface roughness values were collected around the linear line in the normal probability plot graph, it was observed that the surface roughness values are estimated at very high rates.
- When the fitted line plot graph was examined, it was determined that the surface roughness and estimated values are at the 95% confidence interval, and the R^2 value is 97.7%. In addition, it was determined that the actual and estimated values gathered around the fitted line and provided this confidence interval.
- When the multiple response graph was examined, it was determined that the chuck pressure was 18 bar and the tailstock pressure was 5 bar for the optimum surface roughness value.
- It was understood that the values that minimize the surface roughness according to the chuck and tailstock pressure are high chuck pressure and low tailstock pressure.
- According to the surface response graph, the lowest surface roughness value was determined to be at 18 bar chuck pressure and 5 bar tailstock pressure. In addition, it was understood that the effect of chuck pressure on surface roughness is more effective than tailstock pressure. While it was recommended to use high chuck pressures for low surface roughness values, the opposite should be preferred for tailstock pressure.
- When the contour plot graph was examined, it was seen that the lowest surface roughness values were in the range of chuck pressure, while the tailstock pressure was in the range of 5-7, and the surface roughness values decreased when the chuck pressure increased and the tailstock pressure decreased.

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