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INVESTIGATION OF THE INTERACTION BETWEEN THE SURFACE QUALITY AND RAKE ANGLE IN MACHINING OF AISI 1040 STEEL

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ABSTRACT

In all manufacturing processes, surface quality has a great significance beside dimensional and geometrical tolerances of the products. Performance and strength of machine parts are highly affected by the surface quality. In this research, the effect of the rake angle on surface quality for AISI 1040 steel in turning operations was investigated. For this purpose, eight different rake angles varying from negative to positive and five different cutting speeds were used in the experiments. Depth of cut and feed rate were kept constant throughout the experiments. The results showed that negative rake angle resulted in poor surface quality. Improvement in surface quality continued when the rake angle increasing in positive direction up to a certain limit (10°) after which no further improvement was determined. Moreover, the analysis of variance was used based on factorial design of experiment to evaluate effectiveness of the rake angle and cutting speed in the medium machining. Statistical analysis results showed that the rake angle is the dominant parameter associated with the surface roughness.

Keywords: Rake angle, surface roughness.

AISI 1040 ÇELİK MALZEMENİN İŞLENMESİNDE YÜZEY KALİTESİ VE TALAŞ AÇISI ARASINDAKİ ETKİLEŞİMİN ARAŞTIRILMASI

ÖZET

Bütün imalat yöntemlerinde ürünlerin ölçü ve geometrik toleranslarının yanında yüzey kalitesi büyük bir öneme sahiptir. Makine parçalarının performansı ve mekanik ömrü büyük oranda yüzey kalitesinden etkilenmektedir. Bu çalışmada, tornalama işleminde AISI 1040 çeliği kullanılarak kesici takım talaş açısının yüzey pürüzlülüğü üzerindeki etkileri incelenmiştir. Bu amaçla, deneylerde negatiften pozitife değişen sekiz farklı talaş açısı ve beş farklı kesme hızı kullanılmıştır. Deneylerde kesme derinliği ve ilerleme sabit tutulmuştur. Yapılan deneyler sonucunda negatif talaş açısının yüzey pürüzlülüğü üzerinde olumsuz bir etkiye sahip olduğu görülmüştür. Pozitif talaş açılarında 10°'ye kadar yüzey kalitesinde bir iyileşme olurken, talaş açısının artırılması ile birlikte yüzey kalitesindeki iyileşmenin önemli olmadığı belirlenmiştir. Ayrıca, faktöriyel deney tasarımına bağlı olarak talaş açısı ve kesme hızının orta işleme şartlarındaki etkinliğini değerlendirmek için varyans analizi yapılmıştır. İstatistiksel analiz sonucunda, talaş açısının yüzey pürüzlülüğü üzerinde daha etkin bir parametre olduğu görülmüştür.

Anahtar Sözcükler: Talaş açısı, yüzey pürüzlülüğü.

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1. INTRODUCTION

Surface roughness is generated from two components, the ideal or geometric finish and natural finish. While the ideal finish results from kinematic motions of the tool and the geometry such as tool nose radius, tool rake angle and lead angle, the natural finish can result from cutting tool vibration, tool wear, and workpiece material effects such as built-up edge formation, rupture at low cutting speeds. In many applications, especially finishing operations, the surface finish requirement restricts the range of tool geometries and feed rates which can be used. Moreover, since the machined surface finish becomes rougher and less consistent as the tool wears, stringent finish requirements may also limit tool life and thus strongly influence machining productivity and tooling costs [1]. Thus, the selection of optimized cutting parameters is extremely important as these ones determine surface quality and dimensional precision of manufactured parts [2, 3].

A large number of analytical and experimental studies have been conducted on surface roughness in turning operations [4]. The first standardization work on surface roughness was carried out in Germany in 1931, which led to the establishment of DIN 140 standard. DIN 140 classified surface quality grades. These grades were defined as coarse, medium, and fine [5]. In the study of Özses, it is shown that the surface quality is affected by the hardness and the mechanical properties of various steel materials. It was also reported that surface quality was affected by cutting parameters. It was observed that surface quality was improved with increased cutting speeds. Nevertheless, high cutting speeds cause excessive tool wear and as a result short tool life. The most important parameter, which affects the surface quality, is feed rate. Low feed rate results in better surface finish. Tool nose radius is another factor affecting the surface roughness. Increasing tool nose radius improves surface quality [6].

Lin conducted an experimental research on surface roughness and cutting forces using S55C steel. He formalized the results by regression method. He modelled the effect of cutting parameters on surface roughness and cutting forces [7]. Risbood, Petropulos, Sekulic, Gadelmavla, Davim, et al. carried out similar works [8-12]. Abouletta observed that surface roughness depended on cutting parameters and also tool vibration. He developed four different mathematical models in terms of cutting parameters and vibration in feed and radial directions. Experimental results showed that surface roughness did not only depend on cutting forces but also vibration. It was observed that maximum surface roughness was mostly affected by cutting speed and workpiece diameter [13].

One of the main problems in machining of ductile materials is formation of build up edge (BUE). Beside its negative affect on tool life, BUE is also responsible for poor surface quality. In order to avoid the formation of BUE, high cutting speed and high positive rake angle were recommended [14]. Unfortunately, surface roughness does not depend solely on the feed rate, the tool nose radius and cutting speed; the surface can also be deteriorated by excessive tool vibrations, the built-up edge, the friction of the cut surface against the tool point, and the embedding of the particles of the materials being machined. Hence, the forces, which can be considered as the sum of steady, harmonic and random forces, act on the cutting tool and contribute to the modification of the dynamic response of the tool, by affecting its stiffness and damping. These stiffness and damping variations are attributable to parameters that cannot be easily predicted in practice (regenerative process, penetration rate, friction, variation in rake angle, cutting speed, etc.) [15].

Most researchers have investigated the effects of cutting parameters such as speed, feed, and depth of cut on surface roughness by used one variable at a time approach. In order to institute an adequate functional relationship between the surface roughness and the cutting parameters, a large number of tests are required, requiring a separate set of tests for each and every combination of cutting tool and workpiece material. This increases the whole number of tests and as a result the experimentation coast also increases. According to Choudhury and Dabnun, surface finish can be characterised by design of experiments in metal cutting. The statistical method used in this analysis is known as response surface methodology which is a combination of the design of experiments and regression analysis and statistical inferences. Response surface methodology coupled with the factorial design of experiments is a better alternative than the traditional one-variable-at-a-time approach. This provides a large amount of information with a lesser number of experiments [16, 17].

It is necessary to employ theoretical models making it feasible to do predictions in function of operation conditions such as part dimensions, rotating speed of spindle, feeds, cutting depth and so on. In this research, the effect of rake angle on surface roughness for AISI 1040 steel was investigated at 5 different cutting speeds and 8 different rake angles. Also, a factorial design and analysis of variance (ANOVA) performed to determine of the interaction between the surface roughness and rake angle.

2. MATERIALS AND METHOD

2.1. Experimental Samples

The experimental samples were made of AISI 1040 steel with dimensions ϕ 40x200mm. Prior the experiments, the samples were turned with a depth of cut of 0.5 mm in order to remove the outer layer which might have been hardened by rolling process in production stage.

2.2. Experimental Setup

All cutting tests were conducted in TC-35 JOHNFORD CNC turning centre. The cutting tool was a commercial product available from Stellram, consisting of a tool holder and indexable inserts suited to ISO 5608 and ISO 1832, respectively. Product no. of the tool holder is SSBCR 2525 M12. The uncoated carbide inserts were SCMW 12M508 and SCMT 12M508. Both inserts suited to ISO P20. Their rake angles were different. While both inserts had 7° of clearance angle, the first one, SCMW 12M508-S2F, had 0° rake angle and the other second had 7° rake angle. The reason for choosing cutting tools with different rake angles is that when mounting mechanism of tooling system was adjusted to give SCMW tool a rake angle of over 7°, the tool's clearance angle becomes less than 0°, which makes cutting operation impossible. Therefore, for rake angles over 7°, SCMT tool should be preferred because it has 7° clearance angle as a result of when the rake angle was adjusted to its largest value used in the experiments, i.e. 12.5°, the clearance angle becomes 2°. The other characteristics, geometry and grade of both inserts other than rake angle were the same.

Cutting parameters, i.e. cutting speed, depth of cut, and feed rate, rake angle, were suggested by cutting tool suppliers and were selected according to ISO 3685. As suggested in ISO 3685, five different cutting speeds were used based on tool supplier's suggestions. The reference values of depth of cut and feed rate (a=2.5 mm and f=0.25 mm/rev) in ISO 3685 for 0.8 mm were chosen tool radius. Measurements were taken cutting a length of every 100 mm on each sample. The experiments were carried out with 8 different rake angles, which varied from -5° to 12.5° with 2.5° increments. At each rake angle, five different cutting speeds were used [18]. The equipment used for measuring the surface roughness was a surface roughness tester, Mahr Perthometer-M1 type of portable. The surface roughness average (Ra) was taken as a parameter, defined on the basis of the ISO 4287 norm [19] as the arithmetical mean of the deviations of the roughness profile from the central line along the measurement.

2.3. Experimental Design and Analysis

In general, the roughness parameters mainly depend on the manufacturing conditions employed, such as feed rate, depth of cut, cutting speed, machine tool and cutting tool geometry, etc. So, a complete modelling of these parameters should take into account the previous factors [3]. On the other hand, tool rake angle are certainly effect chip formations by changing of shear angle at first deformation region during the material removal process. And also, this formation is effect quality of machined surface. Meanwhile, the temperature occurred at the deformation region which is change depending on cutting speed, this situation is effect cutting process by changing chip flow velocity [14, 20]. Hence, the effect on surface roughness of rake angle and cutting speed was investigated based on experimental and statistical results.

Using the analysis of variance (ANOVA) and factorial design of experiment, the effectiveness on the surface roughness of the rake angle and cutting speed were investigated. Results from ANOVA can determine very clearly the impact of each factor on the outputs [4, 15]. An ANOVA was applied to investigate the main effects of cutting speed (V) and rake angle (γ). The ANOVA output and the calculated F-ratios are shown in Table 3 for each significant effect. It was selected the 0.05 level for testing the significance of the main effects. Factorial design and analysis of variance were applied to the experimental data by using MINITAB statistical software. The factors and factor levels are summarized in Table 2. These factor levels result in a total of 40 unique factor level combinations.

Table 2. Factors and factor levels.

Factors	Factor levels
Cutting speed (V)	80, 100, 120, 150, 180 (m/min)
Rake angle (γ)	-5, -2.5, 0, 2.5, 5, 7.5, 10, 12.5 (degree)

3. RESULTS AND DISCUSSION

In order to evaluate the effect of rake angle on surface quality, measurements were taken at three different locations in longitudinal direction. In collecting the surface roughness data of the experimental sample with the surface profilometer, three measurements are taken along the axis for each experimental sample and measurement is about 120° apart. So a total of 9 measurements were taken on each machined surface. The surface roughness (Ra) value was calculated by averaging these 9 measurements. Interaction between cutting speed and rake angle on surface roughness are shown in Fig. 1.

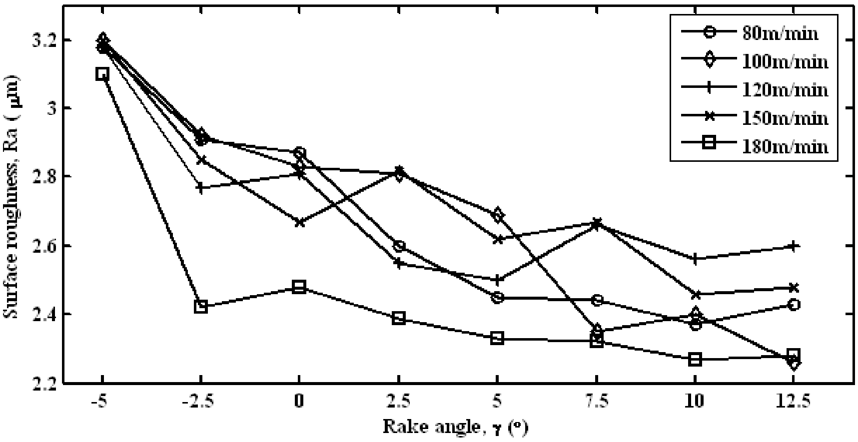

Figure 1. Interaction between cutting speed and rake angle on surface roughness.

The most remarkable result in Fig.1 that negative rake angles especially for -5° surface roughness value was quite high, but positive rake angles beginning from 0°, surface roughness is noticeable decrase. Surface roughness values for -5° rake angle are higher than obtained for the other rake angles at all cutting speeds. Negative rake angles cause larger contact area cause also higher chip volume, which both result in increased heat generation [18]. This poor surface quality can be attributed to the higher cutting forces and negative effect of chip flow on surface with negative rake angle [4].

It can be observed in Fig. 1 that surface roughness has change significantly for rake angles in the range between –2.5° and 12.5°. This can be attributed to the lower coefficient of friction on the tool rake face due to decreasing BUE the tendency with increasing rake angle [14]. This indicates that positive rake angles have a regularly effect on the surface roughness at machining of AISI 1040 steel. This conclusion can be drawn from deviation between the maximum and minimum surface roughness values obtained within this rake angle range (Ra_{max}=2.92 μm for γ=-2.5°; Ra_{min}=2.28μm for γ=12.5°). Better surface quality obtained at 180 m/min cutting speed (except for -5° rake angle) can be attributed to the well-known positive effect of high cutting speeds on surface finish [14, 20].

AISI 1040 steel is considered to be one of the best materials in terms of machinability because of its carbon content and mechanical properties. Therefore, surface quality of this material is not expected to exhibit poor characteristics especially at high cutting speeds. However, formation of BUE encountered at moderate and low cutting speeds especially when machining ductile materials is known to deteriorate surface finish. One of the best precautions to eliminate this problem is to increase rake angle in positive direction [4, 14, 18]. For this purpose, a factorial design and analysis of variance (ANOVA) were applied to determine the effects of the cutting speed and rake angle on the surface roughness. Additionally, the main effect plot of significant factors corresponding to ANOVA analysis was constructed (Figure 2). This plot provide a more in-depth analysis of the significant factors related to the surface roughness in the medium machining. The ANOVA table for surface roughness parameters is given in Table 3. All F-ratios are based on the residual mean square error. The ANOVA table decomposes the variability of eigenvalues into contributions due to independent factors. The P-value tests the statistical significance of each of these factors. Since the P-value of rake angle in the ANOVA table is less than 0.05, this factor has a statistically significant effect on surface roughness at the 95% confidence level.

Table 3. Analysis of variance for surface roughness.

Source	Degrees of freedom (DF)	Sum of squares (SS)	Mean squares	F-ratio	P-value
Cutting Speed	4	0.24031	0.06008	1.34	0.281
Rake Angle	7	3.93147	0.56164	12.49	0.000
Error	28	1.25873	0.04495		
Total	39	5.43051			

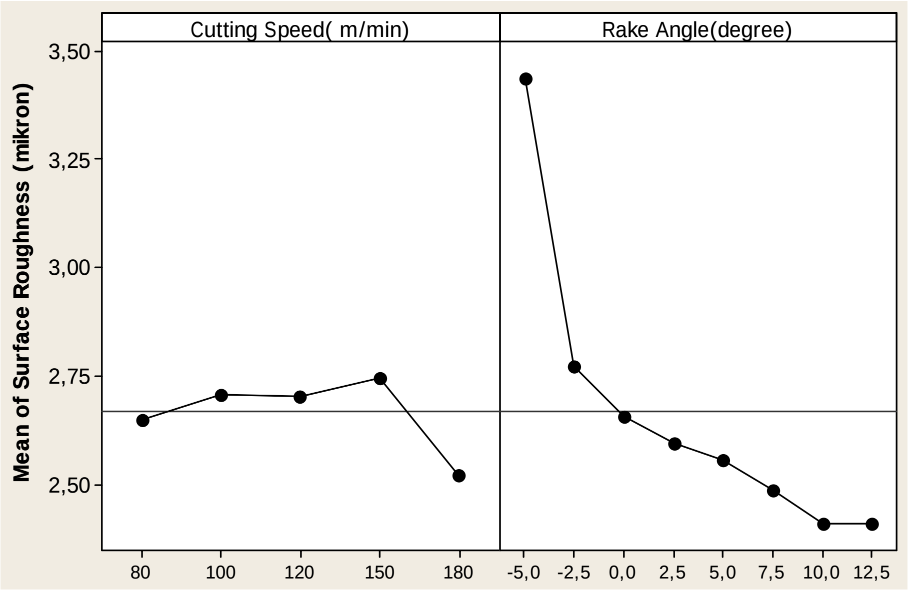

Figure 2. Main effects plot for surface roughness.

It is seen from Fig. 2 and the P-value of cutting speed in the ANOVA table that, the effect of cutting speed on surface roughness (Ra) is not a statistically significant. Also, it can be seen in Fig. 2 that especially, the negative rake angle has very significiant effect on the Ra. The results shows that surface roughness depend mainly on the rake angle.

3. CONCLUSION

The results obtained in this research can be summarized as follows:

- Negative rake angles result in poor surface finish while positive rake angles beginning from 0° produce better surface.
- Improvement in surface quality continued when the rake angle increasing in positive direction up to a certain limit (10°) after which no further improvement was observed.
- Consistency between the ANOVA results and measured surface roughness values shows that rake angle is more effective than cutting speed on surface roughness.

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