Avrupa Bilim ve Teknoloji Dergisi
Sayı 21, S. 410-415, Ocak 2021
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Araştırma Makalesi

www.ejosat.com ISSN:2148-2683

European Journal of Science and Technology
No 21, pp. 410-415, January 2021
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Research Article

Effect of Machining on the Surface Roughness of 31CrMoV9 and 34CrAIMo5 Steels After Nitriding

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(First received 29 September 2020 and in final form 25 January 2021)

(**DOI:** 10.31590/ejosat.801595)

ATIF/REFERENCE: Şahinoğulları, E., Luş, H.M. (2021). Effect of Machining on the Surface Roughness of 31CrMoV9 and 34CrAIMo5 Steels After Nitriding. *European Journal of Science and Technology*, (21), 410-415.

Abstract

31CrMoV9 and 34CrAlMo5 are high-performance steels used in many industrial applications in which machines and components are exposed to high surface stresses and dynamic loads. Depending on the customer needs, these steels are first machined on CNC machines and then their surfaces are hardened by nitriding. After nitriding, grinding is needed to reduce the surface roughness values of the product according to the customer demand or the need of the production. Grinding is a chip removal process that uses an a grinding wheel as the cutting tool. However, one of the major drawback for grinding process is significant amount of processing costs. For some applications, such as pump drive shaft, it is foreseen that elimination of grinding step in workflow may reduce significantly cost item for the manufacturer. In this study, the machining parameters of hydraulic pump drive shafts produced from 31CrMoV9 and 34CrAlMo5 materials were changed before nitriding process and after nitriding no grinding process was applied and surface roughness after heat treatment was measured. In the final machining process, 54 hydraulic pump drive shaft samples made of both 31CrMoV9 and 34CrAlMo5 steel material were processed and the cutting edge moving value was used as a variable parameter. Thus, it was investigated whether it is possible to remove the grinding step after nitriding. According to the measurement results, it was observed that the surface roughness of the pump shafts made of both steel materials was negatively affected after the heat treatment, but this change was limited by changing the turning conditions. Finally, by removing the grinding process from the production process, it is aimed to shorten the total production time of the products and reduce the production cost.

Keywords: 31CrMoV9, 34CrAlMo5, Surface roughness, Machining, Turning, Nitriding.

31CrMoV9 ve 34CrAIMo5 Çeliklerinin Nitrürleme Sonrası Yüzey Pürüzlüğüne Talaşlı İmalatın Etkisi

Öz

31CrMoV9 ve 34CrAlMo5, makine parçalarının, yüksek yüzey gerilimlerine ve dinamik yüklere maruz kaldığı birçok endüstriyel uygulamada kullanılan yüksek performanslı çeliklerdir. Müşteri ihtiyacına bağlı olarak bu çelikler önce CNC tezgahlarda işlenir ve daha sonra yüzeyleri nitrürleme ile sertleştirilir. Nitrürlemeden sonra, müşteri talebine veya üretim ihtiyacına göre ürünün yüzey pürüzlülük değerlerini düşürmek için taşlama yapılması gerekmektedir. Taşlama, kesici alet olarak bir taşlama taşı kullanan az miktarda talaş kaldırma işlemidir ve özellikle silindirik parçalar da yüzey kalitesini iyileştirmek için tercih edilir. Bununla birlikte, taşlama işleminin en büyük dezavantajlarından biri, önemli miktarda işlem maliyetidir. Bu nedenle pompa tahrik mili gibi bazı uygulamalarda, iş akışında taşlama adımının ortadan kaldırılmasının imalatçı için önemli maliyet kalemini azaltabileceği öngörülmektedir. Bu çalışmada, 31CrMoV9 ve 34CrAlMo5 malzemelerinden üretilen hidrolik pompa tahrik millerinin işleme parametreleri, nitrürleme işlemi öncesi değiştirilmiş ve nitrürleme sonrasında herhangi bir taşlama işlemi uygulanmamış ve ısıl işlem sonrası yüzey pürüzlülüğü ölçülmüştür. Son işleme sürecinde, 31CrMoV9 ve 34CrAlMo5 çelik malzemeden yapılan 54 adet hidrolik pompa tahrik mili numunesi işlenmiş ve değişken bir parametre olarak kesici kenar ilerleme hızı kullanılmıştır. Böylece nitrürlemeden sonra taşlama adımının kaldırılmasının mümkün olup olmadığı araştırılmıştır. Ölçüm sonuçlarına göre her iki çelik malzemeden imal edilen pompa şaftlarının yüzey pürüzlülüğünün ısıl işlem sonrasında olumsuz etkilendiği ancak bu değişimin dönüş koşullarının değişmesiyle sınırlı kaldığı görülmüştür. Böylece toplam üretim süresinin kısaltılması ve üretim maliyetinin düşürülmesi hedeflenmektedir.

Anahtar Kelimeler: 31CrMoV9, 34CrAlMo5, Yüzey pürüzlülüğü, Talaşlı işleme, Tornalama, Nitrürleme.

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1. Introduction

31CrAlMo5 and 34CrMoV9 steels are used in the production of parts such as crankshafts, drive shafts, screws, bolts, etc. that are subject to fatigue and high pressure due to their strength properties. Most of these parts are produced by machining process, their surfaces are hardened with nitriding heat treatment to improve abrasion resistance and surface roughness values are improved by grinding process depending on customer demand. Nitriding is a heat treatment process that enables forming nitride compounds in the material with thermochemical diffusion of nitrogen into the iron in the ferrite phase as an interatitial atom, thereby increasing the hardness value and fatigue strength on the surface [1, 2]. The nitriding process was first carried out by Machlet in nitrogen environment containing hydrogen in the early 1900s and continues to be used in many industrial applications today [3,4]. Diffusion of nitrogen atoms to the steel material can be done in various ways depending on the conditions in which the nitrogen atom is provided, and gas nitriding is the leading of these methods. However, there are various sub-methods such as plasma nitriding and salt bath nitriding according to the needs of the industry [5-8].

Due to the nature of the processes, there is a certain amount of roughness on the surfaces of the machine parts after production in machining and chipless machining process. This condition, which creates irregular deviations below and above the nominal surface line, is called surface roughness [9]. Surface roughness is a parameter that can take very variable values and is specified within the specific tolerances on the part technical drawing. Even if the same surface roughness results of materials of similar type with different processes are reached, the effect on the material may be different. For this reason, the process to be applied as well as the surface roughness value of the machine parts used in the industry is specified in particular cases. Surface quality definitions are made according to the differences between the nominal profile on the workpiece and the measured values, for example the quality of a surface according to the ISO 1302 standard consists of 4 elements which are roughness, waviness, traces and errors [10,11]. Within the machining processes, the turning process includes that the workpiece is shaped by removing the chips from the surface of the workpiece during turning of the workpiece in a certain direction. The turning process directly affects the surface roughness of the workpiece with the nitriding heat treatment [12]. The surface roughness of a workpiece produced by turning is affected by many factors, which can be divided into four main categories. These are factors based on factors related to machining parameters such as feed rate, cutting speed and depth of cut, factors related to cutting tool parameters such as tool wear, tool geometry and tool material, factors resulting from machine tool conditions and finally workpiece material properties in turn [13].

In the machining process, the surface roughness quality parameters specified on the technical drawing are defined by Ra and Rz values. Here Ra is called the arithmetic average roughness value. Ra is calculated by taking the arithmetic average of the profile deviations occurring at the sampling length limits, above and below the center line, and is an important criterion that creates an idea about the surface structure of the section profile in general [14]. Ra value is important because of the accuracy of the measurement technique, low cost and because its method of measurement does not damage the part. However, since the Ra value is a statistical, it is not affected by individual deviations, which may mean that an elevation or a pit on the surface is overlooked [15]. In the surface profile, the maximum height value on the surface measured is called Rz. In other words, Rz is the distance between the largest trough (valley) point (Rv) and the highest peak (Rp) [16].

In this research, the surface roughness value of hydraulic motor drive shafts produced with different turning parameters after heat treatment has been investigated. Figure 1 shows a typical hydraulic motor and its components. The function of hydraulic motors is to create force by means of pressure fluid and to provide controlled movement. Main examples of the usage areas of hydraulic motors are motion systems of heavy equipment, drawbridges and satellites.

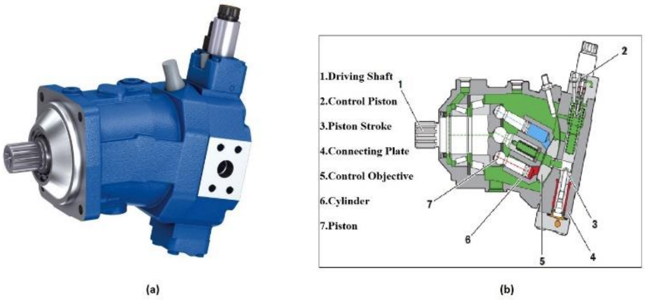

Figure 1. A typical Hydraulic motor-Bosch Rexroth (a) and variable displacement hydraulic motor image (b) [17].

In the conventional manufacturing flow chart, the surface of the hydraulic motor's drive shafts, which are produced from 31CrMoV9 and 34CrAlMo5 steels reaches a certain abrasion resistance with shaving machining, nitriding and subsequent grinding process, and the surface roughness values are also reduced to the desired level. The aim of this study is to prove that the surface roughness tolerances can be achieved by machining and optimizing the turning process parameters of the drive shaft, without the need for grinding after the nitriding process. Thus, a more cost effective drive shaft production will be possible.

2. Material and Method

2.1. Material

The samples of this experimental study were prepared in a DMG CTX Gamma 2000 TC, 5-axis CNC machine in a drive shaft manufacturing facility and have been subsequently subjected to gas nitriding. The drive shafts used in the experiments are made of 31CrMoV9 and 34CrAlMo5 forged steel materials by machining on CNC machines. In the manufacturing process, rough and final turning operations have been made on the surface of the part on the CNC machine, the process parameters have been changed in the final turning operation and no grinding operation has been applied to these parts after nitriding heat treatment. Before measuring each part, measurement control has been made with the reference gauge for calibration and control and no deviation has been encountered. In CNC machine, turning plate numbered DNMG 110408-PF 4315, belonging to Sandvik, has been used as a cutting edge.

Steels used in drive shaft production are commercially available 31CrMoV9 and 34CrAlMo5 forged steels. The chemical composition and physical properties of the 31CrMoV9 and 34CrAlMo9 materials are specified in Table 1 and Table 2 below.

Table 1. Chemical and physical properties of 31CrMoV9 (1.8519) steel [18].

DIN EN 31CrMoV9 (40mm < d < 100mm)

Chemical Compositon		Min. - Max. (%)	
C	Si	Mn	P
0.27-0.34	0.40	0.40-0.70	0.025
S	Cr	Mo	V
0.035	2.30-2.79	0.15-0.25	0.15-0.25

Properties		
UTS (Rm)	1000-1200	N/mm^2
YS	Min. 800	N/mm^2
Elongation	10	%
Raw materials hardness	Max. 248	HB
Hardness after nitriding	~800	HV1

Table 2. Chemical and physical properties of 34CrAlMo5 (1.8507) steel [19].

DIN EN 34CrAlMo5 (40mm < d < 100mm)

Chemical Compositon		Min. - Max. (%)	
C	Si	Mn	P
0.30-0.37	0.40	0.40-0.70	0.025
S	Cr	Mo	Al
0.035	1.00-1.30	0.15-0.25	0.80-1.20

Properties		
UTS (Rm)	800-1000	N/mm^2
YS	Min. 600	N/mm^2
Elongation	14	%
Raw materials hardness	Max. 248	HB
Hardness after nitriding	~950	HV1

2.2. Turning Process and Heat Treatment

In the final turning operation, the turning plate of Sandvik company whose process type is suitable for final turning, cutting edge size and shape are DN1104, internal tangent diameter (IC) is 9,525 mm, effective cutting edge length (LE) is 10,828 mm, nose radius (RE) is 0,794 mm, coating material is CVD Ti (C, N) + Al2O3 + TiN, coding plate is DNMG 110408-PF 4315 that can be seen in Figure 2 is used as a cutting edge.

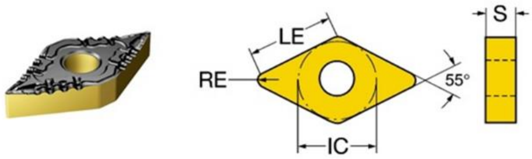

Figure 2. Sandvik DNMG 110408-PF 4315 cutting tool [20].

After the rough turning operation on the drive shaft surface, 0.1 mm chip removal is required to create the desired size and this is done as the final turning process. In the final turning operation, the part speed which is one of the parameters that will affect the surface roughness has been kept constant and the feed value of the cutting edge has been used as a variable parameter. A total of 54 samples have been processed, 27 of which are drive shafts made of 31CrMoV9 steel material and 27 of drive shafts made of 34CrAlMo5 steel materials. 3 different turning conditions were applied for every 27 drive shafts and the surface roughness of each experimental group was measured. The parameters used in turning process are given in Table 3.

Table 3. Last machining parameters used before heat treatment

	1.Group	2.Group	3.Group
Cutting Speed (m/min)	290	290	290
Cuttting Tool moving speed (mm/min)	0,05	0,38	0,55
Cooling liquid pressure (bar)	6	6	6

2.2.1. Nitriding

In the nitriding process, the samples have been washed to prevent the formation of areas that have not been subjected to partial nitriding, primarily due to the oil and wastes that may remain on the samples after turning. Ammonia gas is emitted in the furnace under vacuum when the temperature inside the furnace reaches approximately 400˚C - 450˚C. When the ambient temperature in the furnace reaches between 480 ˚C - 570 ˚C, diffusion process of nitrogen starts on the surface and after the diffusion step is completed, controlled cooling process is applied in the furnace. Nitriding process has taken 22 hours in total. Figure 3 shows the drive shaft before entering nitriding process.

Figure 3. Drive shaft before entering nitriding process.

2.2.2. Surface Roughness Measurement

In order to remove the impurities that may occur on the material after nitriding, the parts have been washed and left to cool. At ambient temperature, Ra (µm) and Rz (µm) surface roughness measurements have been made with the Mitutoyo SJ-410 device (Figure 4). As the measurement parameters, Measuring Speed = 0,2 mm / s, Measuring Force = 0.75 mN and Tip radius = 2 µm.

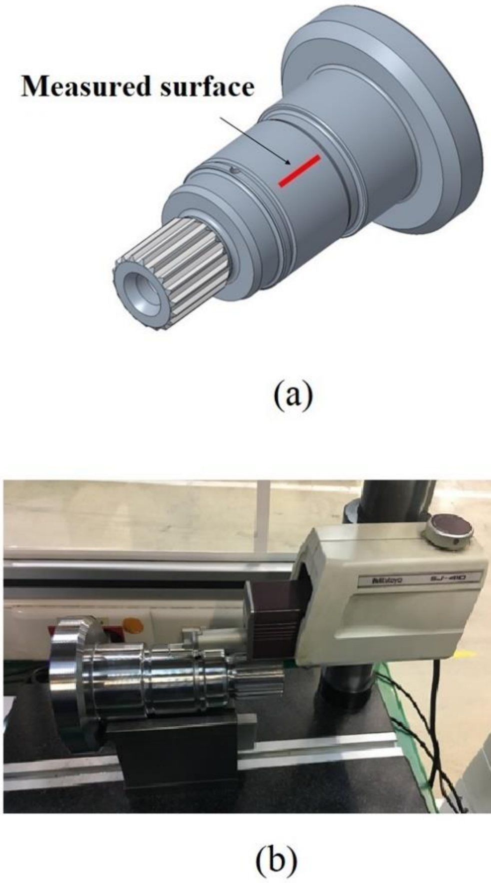

Figure 4. Measured surface (a) and Surface roughness measurement- Mitutoyo SJ-410 (b).

3. Results and Discussion

Average surface roughness measurement values which are found before and after nitriding process of drive shafts made of 31CrMoV9 and 34CrAlMo5 forged steel materials are given in figure 5. Surface roughness measurements have shown that the gas nitriding process increases the surface roughness (Ra and Rz) values of the workpiece, in other words, the gas nitriding process disrupt the surface roughness. In the machining parameters, when the cutting tool feed rate is increased, the surface roughness is negatively affected. After the nitriding process of the drive shafts made of 31CrMoV9 steel, the Ra value has increased by 42.95% in the 1st test samples, 5.45% in the 2nd test samples and 6.25% in the 3rd test samples. The value of Rz for this steel increased by 57.48%, 10.62% and 7.03% respectively for the 1st, 2nd and 3rd test samples. Likewise, after the nitriding process of the drive shafts made of 34CrAlMo5 steel, the Ra value has increased by 61.02% in the 1st test samples, 11.73% in the 2nd test samples and 7.56% in the third test samples. The increase in Rz values is 44.09%, 16.30% and 10.34%, respectively.

According to the measurement values, 31CrMoV9 and 34CrAlMo5 materials have different surface roughness even if they are shaped in machining with the same parameters. However, it is observed that the deformation caused by the nitriding process has less effect on the surface roughness of the piece produced from 31CrMoV9 material compared to the piece made from 34CrAlMo5 material. According to the results obtained, in the 1st test group samples where the cutting tool feed rate is chosen the lowest, the surface roughness has the lowest values and In terms of Ra (µm) value, these test samples have N6 surface quality according to TS 2040 EN ISO 1302 standard. This value is within the tolerance of the surface quality that can be achieved with the grinding process, and has shown that in the production of hydraulic motor drive shafts; only the surface roughness values that can be achieved by grinding can be obtained.

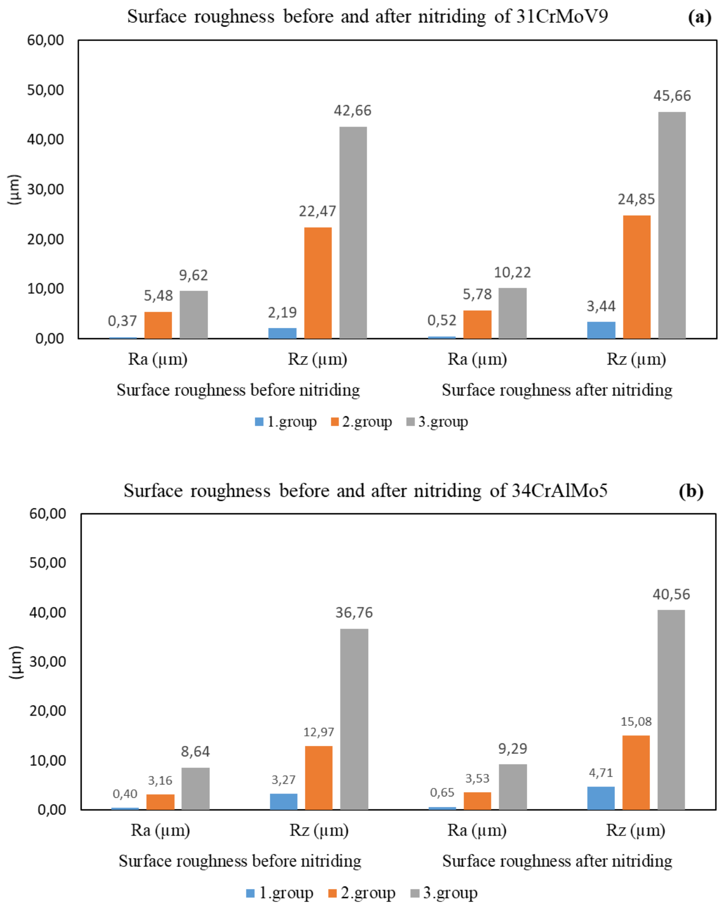

Figure 5. The effect of nitriding on average surface roughness of drive shafts made from 31CrMoV9 (a) and 34CrAlMo5 (b) steels

With the elimination of the grinding process, an important cost item will be removed, however, it can be said that the extension of the turning process will also bring an additional cost. The cost analysis has been made for a facility that is supposed to produce 125.000 drive shafts annually considering production, labor and inventory costs on average of corporate companies in Turkey. The data has been recorded in 2019. In the employee cost account, it is accepted that the grinding machine operates over 3 shifts per day, but the maintenance, repair and calibration costs of the machine are not taken into account. While calculating inventory cost, the number of parts stocked by three incumbent companies in Turkey and invertory costs has been averaged. Table 4 shows the labor costs in part production.

Table 4. Labor costs in part production

Labor Cost	
Monthly cost of a minimum wage worker	₺ 2.558,00*
Monthly cost of 3 minimum wage workers	₺ 7.674,00
Total cost over 12 months working period	₺ 92.088,00
Labor cost per piece for the production of	0,74 ₺/pcs.

*Minimum wage cost for 2019

Considering that the cost of the stones used in grinding is 18 thousand TL per piece and 3 pieces of stone are used for 125 thousand pieces annually, the annual stone cost is 54 thousand TL and the stone cost per piece is 0.43 TL. The total cost of grinding operator, stock and stone is 1.85 TL per piece.Stock cost in part production is given in table 5.

Table 5. Stock cost in part production

Stock Cost	
Average stock cost of 1 piece	₺ 170,00
Average number of parts waiting before and after machining	500 pcs.
Total stock cost	₺ 85.000,00
Cost per piece of stock for 125,000	0,68 ₺/pcs.

The turning plates used have 4 corners and the performance capacity of each corner is limited to about 80 pieces. In the turning process, as a result of decreasing the feed rate of the cutting tool, the contact time between the plate and the part has increased and the number of parts produced in the plates has decreased approximately by half according to the workflow where the grinding process is applied. Considering that 40 pieces are produced with one side of the plate instead of 80 and the cost of the cutting edge is 26 TL, there is a cost increase of 0.08 TL per piece. The total cost increase during turning has been calculated as 0.56 TL per piece. The reflection of the increase in time in the turning process on the labor cost has been neglected. Table 6 shows Effect of time increase of machining on cost.

Table 6. Effect of time increase of machining on cost

Time Increase Cost in Turning process	
Machining time with grinding process	14,90 min.
Machining time without grinding process (with 1st exp. group parameters)	15,23 min.
Lathe Machine Hourly Cost	86,80 ₺/h.
Manufacturing time cost per piece	-0,48 ₺/pcs.

4. Conclusions and Recommendations

The grinding process accounts for approximately 25-30 percent of the cost in all machining steps [21,22]. Because of this, eliminating this step is very advantageous in terms of cost. The removal of the grinding process from the workflow by applying the appropriate turning conditions in the scope of this research brings a total cost advantage of 1.29 TL per piece. Accordingly, the overall gain in the annual production of 125,000 pieces is 161,250 TL, considering the accepted data. This result shows that manufacturing by using suitable turning parameters can provide a significant cost advantage by eliminating the grinding process.

References

1. Farokhzadeh, K., Edrisy, A. Surface Hardening by Gas Nitriding. Comprehensive Materials Finishing, ed.;Hashmi S.; Elsevier: Oxford, GB, 2017; Volume 2, pp. 107-136.
2. Wang, N. and Liu, J. Effect of Process Parameters on Gas Nitriding of Grey Cast Iron. Advances in Materials Science and Engineering: 2013; Volume 2013, Article ID 217848.
3. Pye, D. Practical Nitriding and Ferritic Nitrocarburizing, ASM International: Materials Park, Ohio, USA, 2003.
4. Machlet, A. U.S. Patent 1,092,925, 24 June 1913.
5. Surface Hardening of Steels: Understanding the Basics, First edition; ed.; Davis, J.R.; ASM International: Materials Park, Ohio, USA, 2003.
6. Yang, M., “Nitriding-Fundamentals, Modeling and Process Optimization”, Ph.D Thesis, Worcester Polytechnic University Materials Science & Engineering, Worchester, 2012.
7. Oltean, S.E., Modeling the Workpiece Heating on a Plasma Nitriding Equipment Using Neural Networks. Procedia Technology, ed.; Moldovan L.; Elsevier: Oxford, GB, 2015; Volume 19, pp. 562-568.
8. Schneider, M.J., Chatterjee, M.S. Introduction to Surface Hardening of Steels. Steel Heat Treating Fundamentals and Processes: ed. Dossett J., Totten E.; ASM Handbook: USA, 2013; Volume 4A, pp. 389-398.
9. Güllü, Abdulkadir, “Silindirik Taşlamada İstenen Yüzey Pürüzlüğünü Elde Etmek İçin Taşlama Parametrelerinin Bilgisayar Yardımıyla Optimizasyonu”, Ph.D. Thesis, Gazi University Graduate School of Natural and Applied Sciences, Ankara, 1995.
10. Bayrak, Mustafa, “Ç1020, Ç1040 ve 9SMnPb28 Çeliklerinin Talaşlı İşlenmesinde Yüzey Pürüzlülüğün Uzman Sistemle Hesaplanan Değerlerinin Deneysel Değerlerle Karşılaştırılması”, M.S. Thesis, Gazi University Graduate School of Natural and Applied Sciences, Ankara, 2002.
11. TS 2040 EN ISO 1302, Geometrik mamul özellikleri (GMÖ) - Teknik mamul dokümantasyonunda yüzey durumlarının gösterilişi, 2005.
12. Black J. T., Kohser R. A. DeGarmo's Materials and Processes in Manufacturing, 10th Edition; Wiley: New York, USA, 2007.
13. Ratnam, M.M. Factors Affecting Surface Roughness in Finish Turning. Comprehensive Materials Finishing, ed.;Hashmi S.; Elsevier: Oxford, GB, 2017; Volume 1, pp. 1-25.
14. Groover, M. P. Fundamentals of Modern Manufacturing: Materials, Processes, and Systems 4th Edition, Wiley: New York, USA, 2010.
15. Aydın, İ., Çolakoğlu, G. Odun yüzeylerinde pürüzlülük ve pürüzlülük ölçüm yöntemleri. Artvin Orman Fakültesi Dergisi, 2003, 1(2), pp. 92-102.
16. TS 6956 EN ISO 4287, Geometrik Mamul Özellikleri (GMÖ) – Yüzey Yapısı: Profil Metodu - Terimler, Tarifler ve Yüzey Yapısı Parametreleri, Ankara: Türk Standartları Enstitüsü, 2004.
17. Bosch Rexroth, Ürün grupları. Available online: www.boschrexroth.com/en/xc/products/product-groups/mobile-hydraulics/index (accessed on 11 January 2019).
18. Steel Grades, Datasheet for Steel Grades Structure Steel EN 31CrMoV9 Available online: www.steel-grades.com (accessed on 29 October 2018).
19. Steel Grades, Datasheet for Steel Grades Structure Steel EN 34CrAlMo5 Available online: www.steel-grades.com (accessed on 19 November 2018).
20. Sandvik Coromant, Ürünler, Available online: https://www.sandvik.coromant.com/tr-tr/products (accessed on 15 January 2019).
21. V.N. Pi et al. An optimization of exchanged grinding wheel diameter whensurface grinding alloy tool steel 9CrSi. Materials Today: Proceedings, ed.; Singh S.K., Davim J.P., Kumar K.; Elsevier: Oxford, GB, 2019; Volume 18, Part 7, pp. 2225-2233.
22. Alagumurthi, N., Palaniradja, K., Soundararajan, V. Optimization of Grinding Process Through Design of Experiment (DOE)—A Comparative Study. Materials and Manufacturing Processes: 2006, Volume 21, pp. 19-21.