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RESEARCH ARTICLE / ARAŞTIRMA MAKALESİ

The Effect of Processing on the Surface and Subsurface Characteristic of Plastic Injection Mold Steel

İşleme Yönteminin Plastik Enjeksiyon Kalıp Çeliğinin Yüzey ve Yüzey Altı Özelliği Üzerine Etkisi

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Abstract

AISI P20 is prehardened mold steel that is commonly used to manufacture plastic injection molding. The surface characteristics of molds play crucial role to control plastic injected molds parts. Besides, the characteristic of molds is mainly influenced by machining process, the manufacturing process to produce molds. This study presents the extensive experimental work focusing on the machining processing conditions on the surface characteristics of Plastic Injection mold steels. The input parameters are cutting speeds, feed rates and cutting inserts' geometry (wiper and non-wiper). The measured output parameters are subsurface hardness of machined parts and phase transformation induced from cutting process. Experimental results show that wiper insert significantly helps to improve surface quality of components. Besides, microhardness measurement shows that thermal softening occurs resulting from machining of this alloy. However, cutting speed has limited effect on the thermal softening response of this work material. XRD data illustrates peak broadening and increased intensity with machined samples.

Keywords: AISI P20, Wiper, Microhardness, XRD

Öz

AISI P20, plastik enjeksiyon kalıbı üretiminde yaygın olarak kullanılan sertleştirilmiş kalıp çeliğidir. Kalıbın yüzey karakteristikleri, plastik enjeksiyon kalıp parçalarını kontrol etmede önemli rol oynar. İlaveten kalıbın özellikleri büyük ölçüde talaşlı imalat prosesi tarafından etkilenir. Bu çalışma plastik enjeksiyon kalıp çeliklerinin yüzey özellikleri üzerindeki işleme süreci koşullarına odaklanan kapsamlı deneysel çalışmayı sunmaktadır. Giriş parametreleri, kesme hızları, ilerleme oranları ve kesici uçların geometrisidir(silici uç ve normal uç). Ölçülen çıktı parametreleri, işlenmiş parçaların yüzey altı sertliği ve kesme işleminden kaynaklanan faz dönüşümüdür. Deneysel sonuçlar, silici ucun parçaların yüzey kalitesini artırmaya önemli ölçüde katkıda bulunduğu göstermektedir. Ayrıca mikrosertlik ölçümü, bu alaşımın işlenmesinden kaynaklanan ısıl yumuşamanın gerçekleştiğini göstermektedir. XRD verileri işlenmiş numunelerde pik genişlemesi ve şiddet artışını göstermektedir.

Anahtar Kelimeler: AISI P20, Plastik enjeksiyon, Mikrosertlik, Silici uç

I. INTRODUCTION

AISI P20 steels are widely used in industries to manufacture die and mold that are used for the plastic injection molding. Plastic injection molds and dies should have some properties such as high durability, resistance to plastic deformation in use, etc. For forming processes of dies and molds, machining is the one of the significant and required processes main processes. For this reason, machinability for Impax Supreme Steel should be carefully investigated. In addition to machinability, the effects of machining on surface and subsurface quality of machined dies and molds should be carefully examined. In the literature, researchers investigated machinability of plastic injection mold.

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Gupta et al. **[1]** investigated the machining of this die and mold steels. They conducted experiments to find optimum cutting conditions so that they reduce cutting power, and surface roughness. They also concluded that under cryogenic cooling conditions, optimum outputs can be obtained. Khan et al . **[2]** also investigated dies and mold steel, and found that under the minimum quantity lubrication, machinability of this material increases by reducing forces, and surface roughness. Optimization studies to increase machinability of this materials have been conducted in the open literature, and majority of these studies were able to find optimum conditions to control surface roughness, cutting forces including main cutting forces, tangential forces and feed forces **[1, 3]**. But this material is used in dies and molds, and more work is needed for the main output of workpiece so that reliability of dies and molds can be increased. Some previously presented literature reported the surface roughness that is important but not enough to see the quality of machined dies and molds. But just surface roughness is found to be not enough to characterize surface aspects of machined components **[4, 5]**. If surface integrity is not controlled appropriately, then some kind of problems might be seen during injection molding processes such as crack initiation, or failure of dies and molds. Because these components are dynamic components and during injection molding process, these components are subjected to stresses. But these stresses are not only mechanical stresses but also thermal stresses as temperature of dies and molds are changing during molding processes. Thus, just investigation of surface roughness might not be enough to get reliable molds and die after machining processes. Compare to optimizing the cutting process for this dies and molds steel, there are not enough studies mentioning about the surface integrity after machining process in the literature.

Limited number of studies has focused on the surface integrity of this material. Zeilmann et al. **[6]** investigated surface integrity characteristics of this material when it is milling. They reported that on the surface and subsurface the machining affected layer takes place after machining process. Under optic microscopy, they observed that plastic deformation occurs within this layer. Besides, they measured hardness of these material showed that it does not show big increases.

But in the meantime, surface integrity studies of this dies and molds steel is widely investigated for the nonconventional machining processing **[6]**. In these studies, generally focused points are surface and subsurface layer. During cutting process, researchers investigated if white layer takes place, and they measured the thickness of white layer. In addition, surface crack was the main point to investigate **[7]**.

In addition, when the literature is carefully examined, it is observed that the wiper insert had a positive effect on the surface roughness**[8, 9].** Wiper configuration has made it possible to employ higher feed rates in turning, at the same time keeping surface roughness as small as possible **[10]**.

As literature review shows, there is not enough study showing surface integrity of this material after machining process. Thus, the effect of cutting speed, feed rate and cutting insert on surface integrity characteristics is investigated and presented in this study. These surface integrity characteristics are surface roughness, microhardness and phase transformation.

II. EXPERIMENTAL PROCEDURE

In this study, AISI P20 work material with 20 mm diameter and 110 mm long were used. In each experiment, new work material was used. As-received hardness of work material was found as 270 Vickers hardness. Its ultimate tensile stress is 1020 MPa at 20 ºC, it is 930 MPa at 200 ºC; its yield stress is 900 MPa at 20 ºC, it is 800 MPa at 200 ºC. Thermal conductivity of work material is 28 W/m ºC. In this study, two different cutting insert were used. One of them was CNMG 120408-WMX wiper carbide insert (Sandvik), another one was CNMG 120408-FF2 conventional carbide insert. Wiper insert has some advantages like generating much better surface **[11]**, therefore it is considered to be useful for surface integrity.

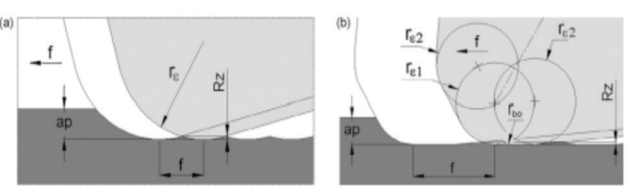

Figure 1. Demonstration of conventional insert (a) vs wiper insert (b)

In this study, three different cutting speeds (60,120, and 180 m/min) are used. In addition, three different feed rates (0.075 ; 0.15 ; 0.225 mm/rev) are used. Depth of cut was 0.8 mm. Dry cutting was employed during machining tests. The cutting conditions are depicted in Table 1.

Table 1. Cutting parameters

Insert	CNMG 120408-WMX Wiper CNMG 120408-FF2 Non-wiper
V (m/min)	60 ,120 , 180
f(mm/rev)	0,075 , 0,15 , 0,225
a_p (mm)	0.8
Cooling	Dry

After machining process, surface roughness for each samples were measured by using surface roughness measurement device. For surface roughness measurement, arithmetic average surface roughness (Ra) was considered. After surface roughness measurement, each workpiece were cut to prepare metallographic specimen. Precision blade was used to cut the specimen. After cutting the specimen, each specimen was mounted. For the molding process, cold mounting was preferred so that the possible effect of hot mounting on the microstructural characteristics of sample were avoided. After that polishing and grinding machine were used to grind and polish the specimen. After this process, the hardness of each specimen was measured by using vickers hardness measurement device. In addition to hardness, each specimen's phase was measured by using XRD analysis.

III. RESULTS AND DISCUSSION

The surface roughness is very important for die and mold applications. After machining process, it is desired to have lower surface roughness so that the surface quality of machined parts can be improved **[12, 13]**. During plastic injection molding, having rough roughness on the surface of dies and mold can negatively affect the product quality. Thus, it is always desired to have surface roughness as low as possible. It also affects the fatigue life and failure of machined dies and molds components.

Fig. 2a shows the measured surface roughness of machined workpiece. In these tests, feed rates varied and wiper and non-wiper (conventional) inserts were used. Surface roughness is high when non-wiper is insert is used at all feed rates. The difference is small at low feed rate, but when we increase feed rate, the difference becomes bigger. The effect of feed rate on surface roughness is also presented in this result. When feed rate increases, both wiper and non-wiper insert increases surface roughness.

Fig. 2b shows the effects of feed rate and cutting insert geometry on surface roughness. In this figure, the measured results are obtained at higher cutting speed. At higher cutting, wiper insert increases the surface roughness and produce data that is close to conventional insert. But at the highest feed rate, wiper insert still produces the better surface. This shows that when cutting speed is changed, the effect of wiper insert on surface roughness shows variations. At the very high cutting speed, the surface roughness changes with feed rates is depicted. Similar data is obtained at very high cutting speed (180 m/min). At high cutting speed, and low feed rate, wiper insert does not help and conventional insert can be used. But at high cutting speed, and high feed rate, wiper insert reduces surface roughness, but non-wiper insert produces very high surface roughness. As shown in Fig. 2, the wiper geometry of the cutting tool reduced the surface roughness. The measured surface roughness at the

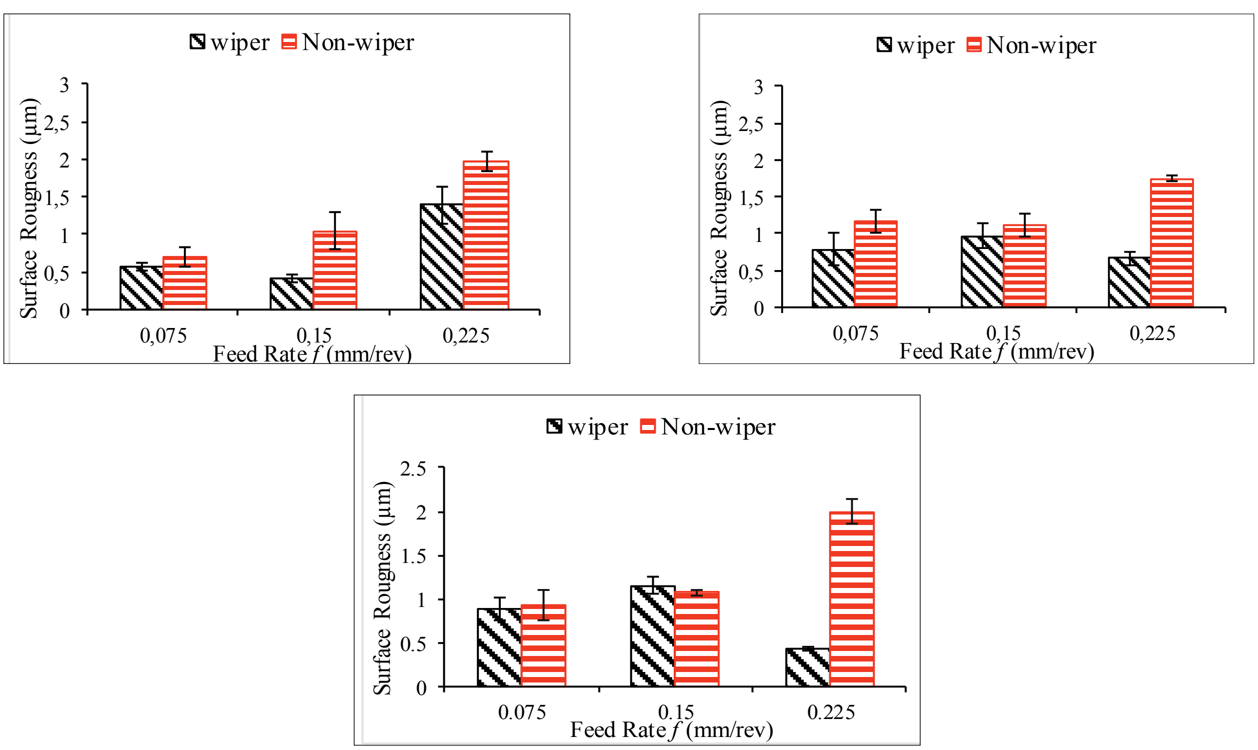

Figure 2. Surface roughness measurement at various feed rates and at various cutting speed a) 60 m/min, b) 120 m/min, c) 180 m/min.

highest feed rate is close to 2 μm that cannot be acceptable for die and molds application. For this reason, either selecting lower feed rate or higher feed rate with wiper insert can be possible. This shows the contribution of wiper insert to increase productivity and surface quality simultaneously.

The effects of cutting tool geometry and cutting speed on subsurface hardness of machined workpiece after machining process at 0.075 mm/rev feed rate is presented in Fig. 3. In this figure, two different cutting speeds are depicted. One is 60 m/min and another one is 180 m/min.

Microhardness measurement starts from 10 μm distance of depth below machined surface. It shows that machining process affects the microhardness at subsurface of machined parts. Fig. 3 shows that michrohardness is low close to surface in all three conditions. For example, as received part's microhardness is 270 HV, but machined parts microhardness at the surface is changing between 245 to 254 HV. This shows that in these conditions, thermal softening takes place. This mechanism called thermal softening and happens due to heat generation **[13]** as temperature increases during cutting that results in thermal softening. The most soften conditions is non-wiper at 180 m/min among all four conditions. The second one is again non-wiper at 60 m/min cutting speed. Wiper insert reduces thermal softening. Another important result of this experimental study is that cutting speed does not affect the softening response of the surface and subsurface of machined parts. The effect of wiper is much clear as we consider the effect of cutting speed.

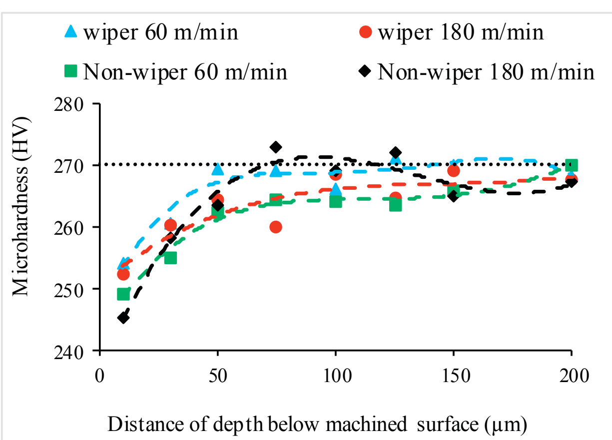

Figure 3. The effects of cutting speeds and cutting insert geometry on microhardness at 0.075 mm/rev

When the feed rate is increased from 0.075 mm/rev to 0.225 mm/rev, the measured micro hardness is presented at Fig. 4. Again, in these conditions thermal softening occurs in all four conditions. At this feed rate, the difference between wiper and non-wiper insert is very clear. Wiper insert at small cutting speed generates highest microhardness. Its value is 264 HV close to as received material's hardness. At high cutting speed (180 m/min), wiper insert again helps to not reduce microhardness compare to conventional cutting insert.

Overall trend in hardness measurement is that thermal softening occur. This is because of cutting high temperature during machining process. But the point is with conventional cutting inserts, bigger thermal softening is observed in almost all measurement indicates that with conventional cutting insert, the cutting temperature is much higher. The effects of cutting speed on subsurface microhardness changes is not very clear, but as cutting speed increase, we can say that microhardness is getting reduces.

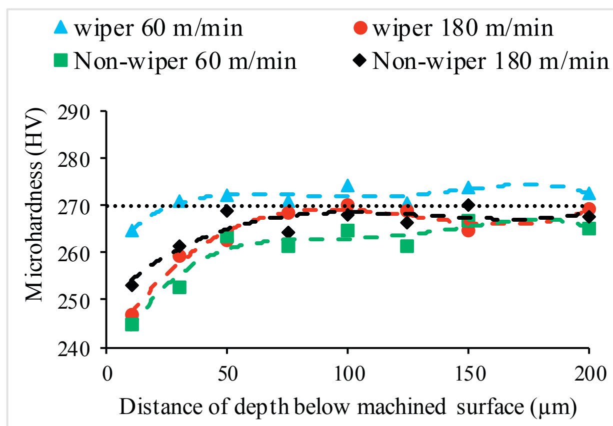

Figure 4. The effects of cutting speeds and cutting insert geometry on microhardness at 0.225 mm/rev

XRD analysis is an important measurement to understand if machining process is affecting crystal structure and phase transformation of machined samples. Phase transformation is an important parameter for surface integrity study. In this study the effects of feed rates and cutting insert geometries on XRD analysis is presented in Fig. 5. At main peak around 44.7 degree, clear phase is seen for as-received material. All machined samples have this phase but wider peaks are shown compare with as-received samples. Wider peaks mean peak broadening happens. According to Kaynak **[14]**, peak broadening indicates increased dislocation density due to stress induced by cutting process. In this case, biggest broadening occurs with non-wiper insert at 0.225 mm/rev feed rate. Wiper insert at the same feed rate generated less broadening. Another result with this measurement is that at small feed rate, broadening is less than larger feed rate. Another important data this figure shows the relative intensity. Relative intensity is smaller at small feed rate. This result shows machining process affects crystal structure of machined specimen. In literature, peak broadening also reported for different steels **[15]**.

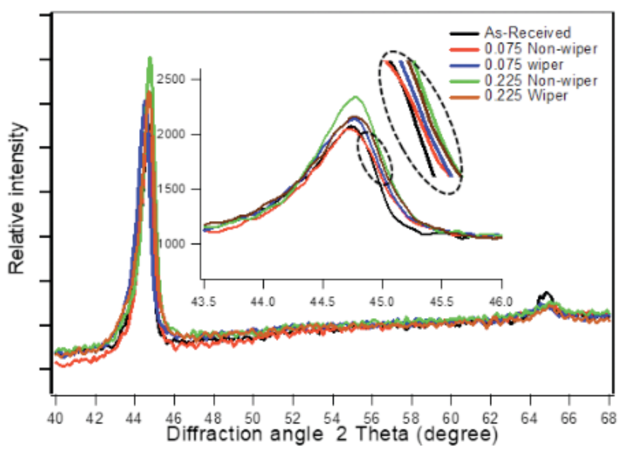

Figure 5. XRD measurement at 60 m/min cutting speed

At higher cutting speed, XRD analysis for different insert geometry and feed rates is depicted at Fig. 6. Similar results with small cutting speed are obtained. Peak broadening and increased intensity with machining process is depicted. Again higher feed rates increased relative intensity, as shown in Fig. 6. At 65 degree diffraction angle, peak broadening at all machining is observed. But intensity at this angle is smaller at machined.

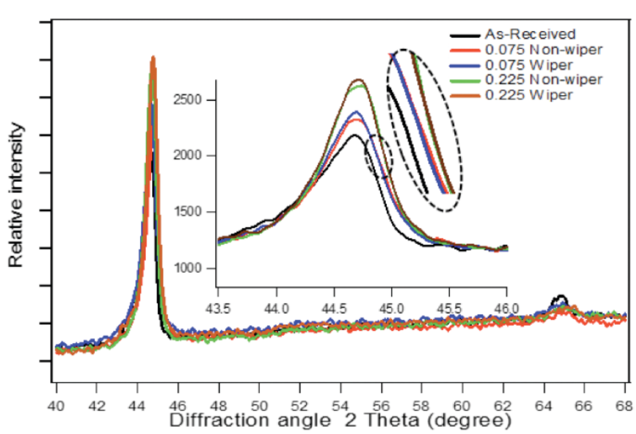

Figure 6. XRD measurement at 180 m/min cutting speed

IV. CONCLUSIONS

In this study the effects of wiper and non-wiper(conventional) inserts, feed rates and cutting speed on machining and surface integrity of dies and mold steel is investigated.

The following conclusion can be drawn from this work:

- Wiper insert helps to generate better surface quality in all cases. Compare to wiper insert, conventional insert does not help much to make surface quality better.
- Wiper insert causes less thermal softening compare with conventional insert. But in all conditions, thermal softening took place.
- Cutting speed does not make considerable influence on the microhardness variation on the surface and subsurface of machined parts.
- XRD analysis shows that peak broadening and increased relative intensity takes place with machined samples. Much bigger broadening with wiper inserts is observed. But not clear phase transformation occurs after machining process.

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