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Abrasive Flow Machining of Asymmetric Spur Gear Forging Die

Asimetrik Dişli Dövme Kalıbının Aşındırıcı Akışkan ile İşlenmesi

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Yüzey parlatma
Dişli dövme kalıbı
Elektro erozyon
Asimetrik dişli

Öz

Aşındırıcı Akışkanla İşleme (AAİ) hassas parçaların yüzey işlemesinde kullanılmaktadır. Bu çalışmada, asimetrik düz dişli dövme kalıbının parlatılmasında AAİ işlemi uygulanmıştır. AISI H13'ten yapılmış kalıp bir stok olarak sertleştirilmiş ve temperlenmiş ve asimetrik dişli profili tel elektro erozyon ile kesilmiştir. Kalıbın yüzey kalitesi, (AAİ) çevrim sayısına göre belirlenmiştir. Sonuçlar, asimetrik düz dişli kalıbında, tel elektro erozyon sırasında oluşan beyaz tabakanın AAİ kullanılarak başarıyla kaldırıldığını göstermektedir. Beyaz tabakanın kürecikleri ilk AFM çevriminde kaldırılmış ve beyaz tabakanın ortalama kalınlığı azaltılmıştır. Dördüncü çevrim sonunda beyaz tabaka tamamen kaldırılmıştır. Yüzey pürüzlülük değeri, çevrim sayısıyla azalmıştır. Yüzey iyileştirmesi ilk AAİ çevriminde daha iyidir ve kademeli olarak belli bir seviyeye kadar azalmaktadır. Yüzeyin diş kalınlığı yönündeki son yüzey pürüzlülüğü, aşındırıcı ortamın akışının, akış yönüne paralel olması nedeniyle, evolvent profili yönünden daha iyidir.

Abrasive Flow Machining of Asymmetric Spur Gear Forging Die

Abstract

Abrasive Flow Machining (AFM) is utilized for surface finishing of the precision parts. In the present study, AFM process is applied to finishing of an asymmetric spur gear forging die. The die made of AISI H13 was hardened and tempered as a stock and the asymmetric gear profile was cut by wire electrical discharge machine (WEDM). The surface quality of the die was determined with respect to the number of AFM cycles. The results show that the white layer formed during WEDM is successfully removed by using AFM for asymmetric spur gear forging die. The globules of the white layer were removed in the first AFM cycle and the average thickness of the white layer was reduced. The layer was totally eliminated after four cycles. The surface roughness value decreased with increasing in number of cycles. The surface improvement is better in the first AFM cycle and gradually saturated to a certain level. The final surface roughness along facewidth is better than involute profile direction because the flow of abrasive media is parallel to the facewidth direction.

Keywords

Abrasive flow machining
Surface Finishing
Gear Forging Die
Electro Erosion
Asymmetric gear

1. INTRODUCTION

Abrasive flow machining (AFM) is a specialized non-conventional finishing process which uses abrasive media to improve the surface quality of the surfaces. The AFM process can be successfully applied to the aerospace, aircraft, medical, and other precision manufacturing areas. In AFM process, the pressurized abrasive media passes inner surfaces of the die to reach the desired surface quality. AFM method can be used in different types of materials.

In the AFM, there are parameters to define the process which are classified as AFM process parameters, abrasive media parameters and workpiece parameters. Number of passes, media pressure, media flow speed, and machining time are named as AFM process parameters. Media viscosity, abrasive material type, abrasive mesh size and its concentration are abrasive media parameters. The type of material (metallic and

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non-metallic etc.), the shape, the hardness and the pre-machining process of the workpiece are named as workpiece parameters for AFM process.

Rhodes et al. carried out an experimental study on AFM process and described the process parameters as extrusion pressure, speed of the abrasive media, volume of the abrasive media, types of abrasive, which affects the finishing of workpiece [1]. Jain et al. applied a detailed experimental study which effects on performance parameters to explore the main AFM parameters such as number of passes, pressure, velocity, mesh sizes, abrasive concentrations and work-piece materials [2]. These researches show that effective AFM process parameters are abrasive concentration in media, abrasive mesh size, number of passes and media flow speed in the order of high level to lower. From to the study of Jain et al. suggested a theoretical model for AFM process which has acceptable differences with the experimental results [3]. In another research by Jain et al., which is about AFM media parameters, they showed that media viscosity is dependent on the abrasive concentration, the abrasive mesh size and temperature. Viscosity is directly proportional to the abrasive concentration and inversely proportional to the abrasive mesh and temperature. They also found that high viscosity provides higher material removal rate (MRR) and better surface quality, i. e., less roughness [4].

Polyborosiloxane is used as polymeric carrier for abrasive media in a study Flether and Fioravanti who studied the rheology of the abrasive media. They proved that the abrasive concentration is more effective parameter than mesh size and polymeric carrier. The temperature of the process is very effective on machining efficiency of abrasive media. They concluded that when abrasive concentration is increased, the media thermal conductivity is increased. The surface heat transfer coefficient is directly related to the abrasive media concentration [5]. Agrawal et al. studied with the polyborosiloxane as polymeric carrier for abrasive media. The properties were predicted as viscosity, creep compliance and bulk modulus [6]. Gorana et al. experienced with silly-putty and silicon carbide (SiC) as abrasive media. The forces acting on the surfaces were measured during the finishing process. The results show the effect of the abrasive media parameters on the surface roughness [7]. Loveless et al. performed an experimentation which the AFM process on the various machined surfaces obtained from grinding, milling, turning, and WEDM operations. The results show that the best improvement in the surface quality was obtained on the WEDMed surfaces [8]. Eyercioglu et al. designed a simple set up on a turning machine to perform abrasive flow machining [9]. Gov K, studied on the abrasive flow machining of EDMed surfaces and showed that the white layer on the EDM cut surfaces were successfully eliminated after few cycles [10]. Gov et al. carried out a work on Ti-6Al -4V alloy to show the effect of AFM parameters [11]. The effects of material hardness on the AFM process was shown by Gov et al. and they found that AFM process has better performance on the hardest work-piece which three level hardened AISI D2 tool steel [12]. The effects of abrasive types on the surface integrity of abrasive flow machined surfaces were also shown by Gov et al. [13].

Precision forging gives form to an initial billet, which can be used directly as a part needs little or no further finishing processes. Orientation of the grains or fibers, which form the outline of the product during the forging process, helps improve the mechanical properties of the final forged part, imparting increased strength, ductility, and resistance to the impact and fatigue of the metal [14]. Gear fabrication with precision forging has started with relatively easy bevel gears and has been successfully applied in recent years to spur and helical gears. There are many studies that show the superiority of gears manufactured with precision forging in terms of strength and cost [15-17]. It is predicted that if asymmetric gears are used in helicopter gearboxes and gear pumps, significant advantages can be obtained compared to standard gears. The load shearing ratio and pressure angle of asymmetric gears are achieved at higher levels than standard gears and have very advantageous results in unidirectional rotating systems. However, due to the profile geometry of the asymmetric gears, the production with the conventional thread cutting method limits the design of the profile. Recent studies in this area have shown that asymmetric profiles designed independently from the cutting tool are more efficient. The precision forging method enables manufacturing of complex profiles and therefore the flexibility of the gear profile to be produced would be advantageous in the use of precision forging in asymmetric gear manufacturing. However, there is a need to improve forging die and process design so that precision forging technology can be applied to asymmetric gears [18].

In the present study, AFM process is applied to finishing of an asymmetric spur gear forging die. The die was hardened and tempered as a stock and the asymmetric gear profile was cut by wire electrical discharge machine (WEDM). The surface quality of the die was determined with respect to the number of AFM cycles.

2. EXPERIMENTAL WORKS

2.1 Experimental set-up

In this study, a two-way AF machine that has two vertically opposed chambers was used (shown in Figure 1). The machine consists of a main frame, hydraulic unit, electronic control unit and heating-cooling unit. The specifications of the machine are given in Table 1. The hydraulic unit ensures adequate movement and media pressure that can be automatically configured. The control system is designed to control the volume of abrasive media and the number of cycles. One cycle in two-way AFM is composed of reciprocating motion of forward and backward of the piston ram in the media cylinder. Thus, cycle time depends on the piston speed and one cycle in the experimental study takes 2 minutes.

Table 1. Abrasive flow machine

Machine Specifications	
Hydraulic pressure	10-400 bar
Media capacity	6 liters
Stroke	400 mm
Bore diameter	140 mm

Figure 1. *Two-way abrasive flow machine*

2.2 Workpiece material

The experiments were performed on an asymmetric gear forging die. The die material is AISI H13 hot work tool steel and the chemical composition and the EDX spectrum are given in Table 2 and figure 2, respectively. The cylindrical die block is 90 mm in diameter and 50 mm in height. The asymmetric gear profile has 330 pressure angles for drive side and 220 pressure angles for coast side was designed (see figure 3). The die block was oil quenched and tempered at 675°C to obtain HRC 35. The asymmetric gear tooth profile was cut by using wire electro discharge machine (WEDM). Four die set were produced and they were cut after experiments to observe the surfaces. The surface roughness values of the gear surfaces of the dies were measured before and after AFM.

***Table 2.** Chemical composition of die material*

Element	Weight %
Carbon C	0.4
Chromium Cr	5.2
Iron Fe	91
Molybdenum Mo	1.4
Silicon Si	1.0
Vanadium V	1.0

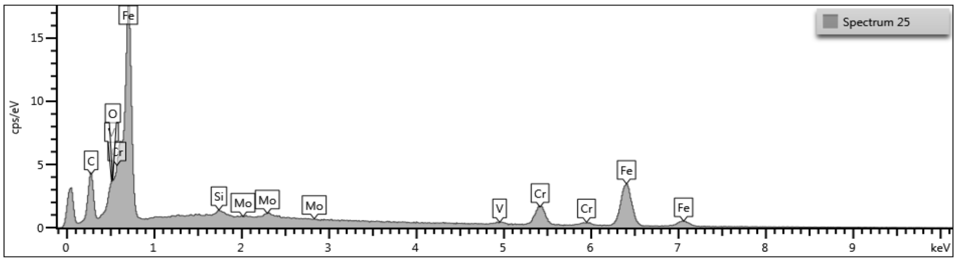


***Figure 2.** EDX Spectrum of the die material*

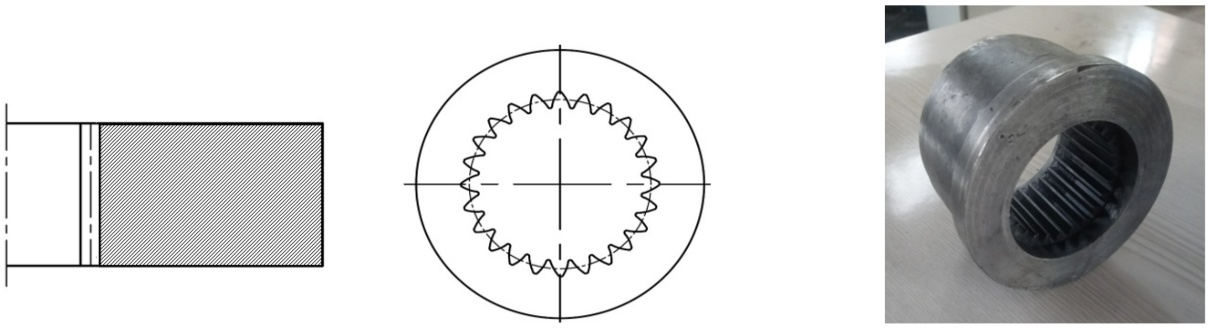


***Figure 3.** The asymmetric gear forging die*

2.3 Abrasive media

The abrasive media that were prepared for the present study is a mixture of polymeric carrier, silicon carbide (SiC) abrasive particles, and 10% of hydraulic oil. The polymeric carrier has specific gravity of 1.0 (at 250 C) and viscosity about 60 Pas. 240 mesh size silicon carbide (SiC) abrasives of 60% ratio by weight were used. However, the common definition of the percentage abrasive concentration is given by: weight of abrasive particles x 100/ (weight of abrasive media). Before performing the experiments, the abrasive media is run for 3–5 cycles with a trial workpiece, so as to get uniform mixing.

2.4 Experimental procedure

The WEDM cut asymmetric gear forging dies were machined by using the abrasive media described in Section 2.3 on the AFM machine (see Figure 1). The die is placed between the pistons by clamping unit of the machine. The experiments were carried out for 1, 4 and 9 cycles. The AFM pressure was 10 MPa and flow rate was 3 litres/min. Number of cycles, abrasive mesh size and abrasive concentration were taken as AFM parameters as given in Table 3. The surface roughness values were measured after 1, 4 and 9 cycles were measured along the facewidth and involute profile of the gear die by using Mitutoyo SJ 401 surface measuring machine, with the cut off length 0.8 mm. The measurements are repeated for three times in each condition and the averages of them were taken. The metallographic observations were carried out to evaluate the white layer which was formed during WEDM cutting. The SEM views of the surfaces were also taken by Zeiss Gemini SEM 300.

Table 3. *Experimental Parameters*

Variable Parameters	
Number of Passes	1, 4, 9
Constant Parameters	
Abrasive Mesh Size	240
Abrasive Type	SiC
Abrasive Concentration	60 %wt.
Abrasive Media Speed	400 mm/min

3. RESULTS AND DISCUSSION

3.1 Measurements of surface roughness

As seen from the Figure 4, the surface roughness value decreased with increasing in number of cycles. The surface improvement is better in the first AFM cycles and gradually saturated to a certain level. The initial surface roughness values along the facewidth of the gear surface are Ra = 3.9 µm and Rz = 18.8 µm respectively. The Ra values are gradually reduced to 1.1 µm, 0.3 µm and 0.13 µm after 1, 4 and 9 cycles, respectively. Similarly, the Rz values are reduced to 7.0 µm, 1.2 µm and 0.7 µm after 1, 4 and 9 cycles, respectively. The measurements along the involute profile (perpendicular to facewidth) have similar trends. The initial surface roughness values along the facewidth of the gear surface are Ra = 3.9 µm and Rz = 21.0 µm respectively. The Ra values are gradually reduced to 2.5 µm, 1.8 µm and 1.5 µm after 1, 4 and 9 cycles, respectively. Similarly, the Rz values are reduced to 12 µm, 8 µm and 6.5 µm after 1, 4 and 9 cycles, respectively. The final surface roughness along facewidth is better than involute profile direction because the flow of abrasive media is parallel to the facewidth direction.

3.2 Evaluation of White layer

Due to the nature of the WEDM process, the EDMed surface is unlike that produced by any traditional machining process; it is characterized by globules and random debris of re-deposited and recast material. The high temperature changes the metallurgy of the material. The region affected by these thermal changes is referred to as the heat-affected zone (HAZ). The HAZ is included of a recast layer (white layer) of material that has been melted and re-solidified at the surface, white layer that is harder than the original material; contains micro cracks(Rhoades 1996). The white layer thickness formed on the gear die surface after WEDM cutting is shown in figure 5. The recast layer contains holes and the globules which are quenched and sticked on the cut surface. The average thickness of the white layer was measured as 8 µm on the die surface after WEDM cutting. The peek points (the globules) of the white layer was removed in the first AFM cycle ant the average thickness of it reduced to 2 µm. The layer was totally eliminated after 4 cycles as seen in figure 5.

The SEM images were taken from the involute surfaces of the gear die and shown in figure 6. The removal of the globules and debris is observed and the ploughing of the surface is clear. The stretch marks are along the facewidth direction which is parallel to the AFM media flow.

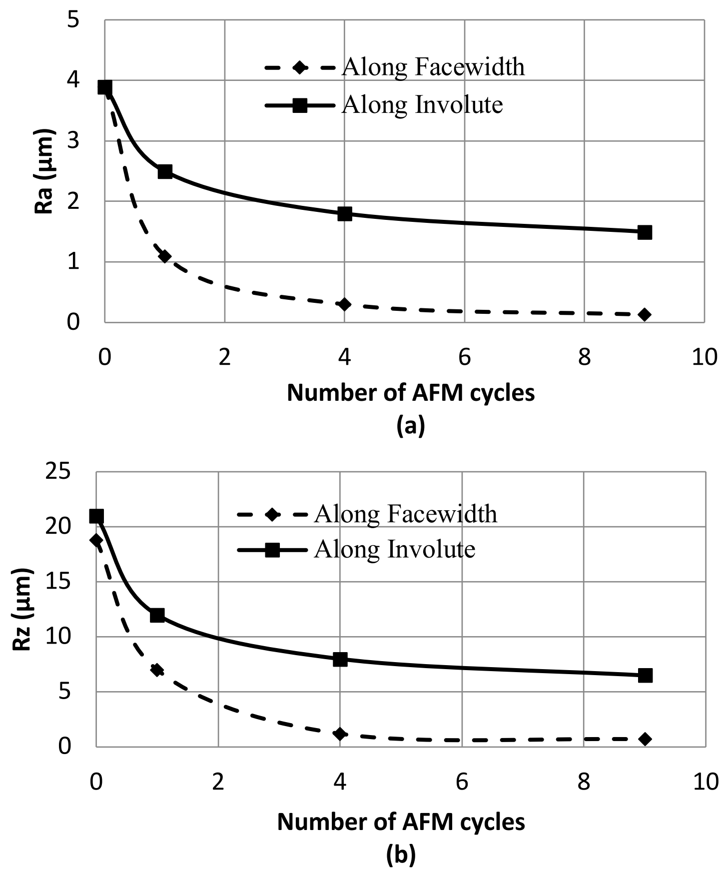


Figure 4. *Surface roughness values on gear die tooth a) Ra (µm) and b) Rz (µm)*

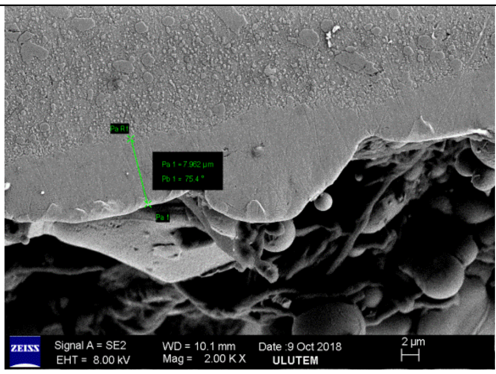
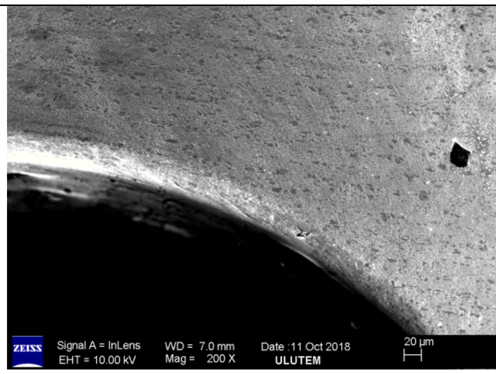
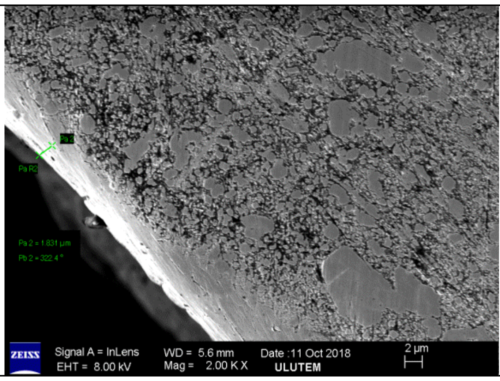
Cycle	WLT	Cycle	WLT
0		4	
1		9	

Figure 5. *Removing of white layer during AFM*

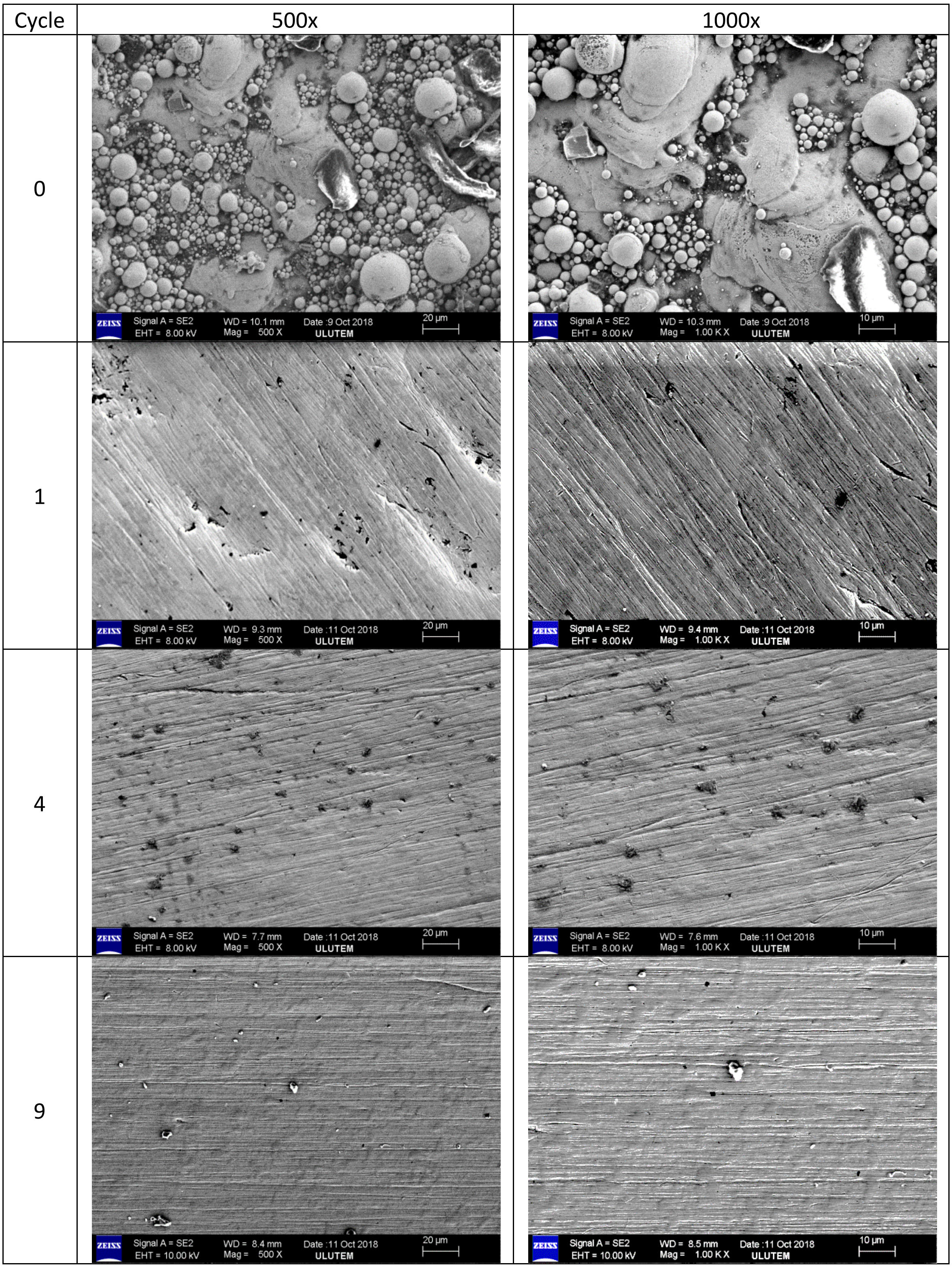


Figure 6. *SEM images of AFM process of surface*

4. CONCLUSIONS

The effect of the AFM process on asymmetric spur gear forging die were investigated. From the experimental results, the following conclusions can be made:

- The white layer formed during WEDM is successfully removed by using AFM for asymmetric spur gear forging die. The results of SEM images of surface and the sectional views are in well agreement. The peek points (the globules) of the white layer was removed in the first AFM cycle and the average thickness of it reduced to 2 µm. The layer was totally eliminated after 4 cycles.
- The surface roughness value decreased with increasing in number of cycles. The surface improvement is better in the first AFM cycle and gradually saturated to a certain level. The final surface roughness along facewidth is better than involute profile direction because the flow of abrasive media is parallel to the facewidth direction.

5. ACKNOWLEDGEMENTS

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