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ABRASIVE FLOW MACHINING OF AEROSPACE MATERIALS

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IN

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OSMAN SOYDAN

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Supervisor

Assoc. Prof. Dr. Kürşad GÖV

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Osman SOYDAN

ABSTRACT

ABRASIVE FLOW MACHINING OF AEROSPACE MATERIALS

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An advanced surface treatment method, abrasive flow machining (AFM), is an economical technique for high precision machining of hard and complex parts that are difficult to reach. With the AFM method, surface quality is improved by removing the low mechanical properties on the surface of the parts for increasing surface quality demands in the aviation industry. In this study, the effect of the parameters which is obtained from the AFM such as; workpiece materials, abrasive mesh size, abrasive concentration, number of cycles, is investigated on workpiece surfaces of materials machined by using an Electrical Discharge Machining (EDM) in aviation. A two-way Abrasive Flow Machine was used in the experimental studies. Semi-fluid media containing, polymer-based abrasive particles were developed at different ratios to improve surface quality. Experimental studies were carried out using high-strength and low-corrosion Inconel 718 and Titanium (Ti-6Al-4V) alloys used extensively in the aviation industry. Silicon carbide was used as an abrasive material in different grain sizes and proportions in the experiments. The results showed that the quality of the surface to which AFM was applied increased. It was concluded that the surface roughness values were reduced by increasing abrasive ratio, mesh size and number of cycles. At the same way, the material removal rate increases with the abrasive mesh size and concentration. The experiment results showed that better surface quality has been accomplished by using high cycle numbers.

Key Words: Surface Finishing, Abrasive Flow Machining, Inconel 718, Ti-6Al-4V

ÖZET

AŞINDIRICI MACUN İLE HAVACILIK MALZEMELERİNİN İŞLENMESİ

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Yüksek Lisans Tezi, Uçak ve Uzay Mühendisliği
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İleri düzeyde bir yüzey işleme metodu olan aşındırıcı macunla yüzey işleme (AMİ), ulaşılması zor, sert ve karmaşık parçaların yüzeylerinin yüksek hassasiyetle işlenmesinde kullanılan ekonomik bir tekniktir. AMİ metodu ile havacılık sektöründe giderek artan yüksek yüzey kalitesi taleplerine karşı, parça yüzeylerindeki düşük mekanik özelliklere sahip katman yüzeyden kaldırılarak yüzey kalitesi iyileştirilmektedir. Bu çalışmada, AMİ metodundaki parametrelerin; iş parçası, aşındırıcı tane büyüklüğü, aşındırıcı oranı, döngü sayısı, elektro erozyonla işleme (EEİ) yöntemi kullanılarak hazırlanmış, havacılıkta kullanılan malzemelerin yüzeylerine etkisi araştırılmıştır. Deneysel çalışmalarda iki yönlü AMİ makinesi kullanılmıştır ve yüzey kalitesini iyileştirmek için farklı oranlarda polimer esaslı aşındırıcı partiküller içeren ve yarı akışkan macunlar geliştirilmiştir. Deneysel çalışmalar, havacılık sektöründe çokça kullanılan yüksek mukavemetli ve düşük korozyona sahip İnkonel 718 ve Titanyum (Ti-6Al-4V) alaşımları kullanılarak gerçekleştirilmiştir. Deneylerde aşındırıcı malzeme olarak değişik tane boyutlarında ve oranlarında SiC kullanılmıştır. Deney sonuçlarında, AMİ işleminin uygulandığı yüzeyin kalitesinin arttığı gösterilmiştir. Yüzey pürüzlülük değerlerinin artan aşındırıcı oranı, tane büyüklüğü ve döngü sayısıyla azaltıldığı sonucuna ulaşılmıştır. Aynı şekilde malzeme kaldırma oranı da aşındırıcı tane büyüklüğü ve oranı ile artmaktadır. Yüksek döngü sayısı kullanılarak daha iyi yüzey kalitelerine ulaşılmıştır.

Anahtar Kelimeler: Yüzey Bitirme, Aşındırıcı Macunla İşleme, İnkonel 718, Ti-6Al-4V

''Dedicated to my precious family''

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LIST OF ABBREVIATIONS

AFM	Abrasive Flow Machining
EDM	Electric Discharge Machining
WEDM	Wire Electric Discharge Machining
SLM	Selective Laser Melting
CFD	Computational Fluid Dynamics
GRA	Grey Relational Analysis
MR	Material Removal
MRR	Material Removal Rate
$\mathbf{R_a}$	Surface Roughness μm
SEM	Scanning Electron Microscope

CHAPTER 1

INTRODUCTION

1.1 Introduction

The advancement of today's technology, demands for better material use is increasing. In our lives, especially in the sectors requiring high efficiency and precision such as aviation and automotive, complex-shaped surfaces are widely used [1]. Traditional methods are economically expensive and take a long time to machine. These methods are inadequate to get the desired results. In the context of these requirements, non-traditional manufacturing methods were performed. Abrasive Flow Machining (AFM) is a new technique of non-traditional finishing methods. The AFM method is used for the improvement of surface quality. In this way, the undesirable surface with low mechanical properties is removed by this process. A polymer-based abrasive media is used to remove the undesired layers from the surface.

AFM was developed by Extrude Hone Corporation in the 1960s and used for deburring, polishing, etc. [2]. This method has been applied by moving fluid consistency media pressure to remove the layers that are not accessible by conventional methods. This process is used for the improvement of the surface quality of workpieces where surface quality is poor by applying abrasive media under high pressure.

Upon ascending demands, it has become inevitable to use fast methods to produce parts in the manufacturing sector. For this reason, processes such as Electric Discharge Machine (EDM) has been used in recent years to produce utilizable materials.

When the pieces produced by the EDM method were examined under a microscope, it was observed that there was a white layer on the surface. The white layer is hard and has micro cracks on it [3]. In this study, a literature survey was conducted to increase the efficiency and applicability of the AFM and there was not much research on EDM surfaces in which the AFM method was applied. For this reason, it is necessary to investigate EDM surfaces to determine the parameters that can be applied for the desired surface quality in the parts.

The most appropriate parameters to be used in the experiments are determined by taking the limitations into consideration. Input parameters are selected depending on abrasive media pressure, abrasive media velocity, process time, number of cycles, abrasive media viscosity, abrasive type, abrasive concentration, abrasive mesh size, and workpiece type. As output parameters, the surface roughness value (R_a) and material removal rate (MRR) are selected. Scanning Electron Microscope (SEM) images are examined after the process.

1.2 Statement of the Problem

The main objective of Abrasive Flow Machining is to finish complex parts which are required to have good surface quality. Abrasive media is the most important factor in this process. Using abrasive media which is also vital in different abrasive flow machines, with the amount of material removal (MR), better surface quality results in new cost calculations [4]. In short, with the development of abrasive media, lower-cost processes can be made. It is difficult to choose the type of abrasive media, abrasive concentration and mesh size used in Abrasive Flow Machining. In order to make the most suitable combinations, the lack of sufficient data is the main challenge in the implementation of this technique [5]. Although some information about the AFM applicability is provided considering the parameters, there is a lack of literature on the subject. More research is needed in this process.

1.3 Organization of the Thesis

This thesis consists of 6 chapters. Introduction to the AFM process and objectives are described in Chapter 1. The literature review of the AFM process is also explained in Chapter 2. The process of Abrasive Flow is mentioned in Chapter 3. Chapter 4 consists of the experiments effectuated and gives general information about the materials to be used in the experiment. In Chapter 5, the results of the experimental studies are given and the effects of the AFM process on the workpiece are detailed. The main conclusions and recommendations issued are stated in Chapter 6.

CHAPTER 2

LITERATURE SURVEY

2.1 Introduction

At the desired media pressure, the surface of the workpieces is treated with abrasive media of liquid consistency is called AFM.

In the media used in Abrasive Flow Machining, silicon carbide (SiC) is preferred as abrasive type mostly.

The diversification of the results in the AFM operation depends on certain parameters. These parameters include abrasive media pressure, processing speed, process time, number of cycles, abrasive type, abrasive concentration, abrasive mesh size, the shape of the workpiece, surface of the workpiece, and hardness of the workpiece.

2.2 Literature Survey about Abrasive Flow Machining and Implementation

Abrasive Flow Machining was developed in the 1960s [6]. Abrasive Flow Machining which has been developed, is used frequently in the industry with mass production.

The AFM is a very useful process for surface finishing of difficult and complex parts [7]. The AFM is a method that can be used to remove burrs on the surfaces of hard-to-reach parts [8]. Rhoades [9] pointed out that the AFM process has reduced production costs by about 15% and said that surface quality improvement of approximately 90% after the AFM process has been accomplished.

Kumar and Hiremath [10] have conducted research on the AFM process, have touched on various the AFM application techniques, have specified different abrasive types and most commonly used abrasive types, as a result, have pointed out the successful application of the AFM process to complex parts.

Uhlmann and Roßkamp [11] have effectuated various studies to improve the applicability of the AFM method in the industrial sector, and in these studies they have connected the decline in surface roughness value to the previous surface of the workpiece, shape of the workpiece and the parameters used during the process.

Sato *et al.* [12] mentioned that the inner surface quality of Titanium alloy parts used in aviation industry are particularly important for fuel-saving, conducted experiments using Titanium alloy (Ti-6Al-4V), and said that surface roughness improved at high pressure, and also stated that the material removal rate was lower in parts with small internal diameter due to the decline in slip velocity.

Kenda *et al.* [13] applied the AFM process to hardened tool steel AISI D2 surface and pointed out that the AFM process will improve efficiency and also stated that the AFM process was useful for surface finishing procedure . Singh *et al.* [14] applied the AFM to pure Aluminum and Brass parts and examined the material removal and supported the results obtained by taking Scanning Electron Microscope (SEM) images. They stated that after the AFM, the amount of material removal from Aluminum is less than the amount of material removal from Brass. Lin *et al.* [15] applied the AFM process to micro holes on Ti-6Al-4V and Stainless Steel (SUS 304), mentioned the improvement in surface roughness and said that processing time was the most effective parameter in the material removal rate.

Han *et al.* [16] conducted tests at different abrasive mesh sizes and abrasive concentration, and observed differences in material removal rates, and also observed abrasive scars on the workpiece surface after processing. Duval-Chaneac *et al.* [17] conducted experiments on the heat-treated and non-heat treated selective laser melting (SLM) inner surface , depending on the viscosity and abrasive ratio of the media, and stated that the heat-treated part was harder than the non-heat treated part, and found significant deep abrasive scars on the non-heat treated part, the better material removal rate has been accomplished on the heat-treated surfaces by using the AFM process.

When the AFM process parameters were examined, the surface roughness value was reduced by increasing the parameters such as pressure and abrasive concentration [18]. Jain and Adsul [19] examined the effects of parameters used in the AFM operations on surface improvement and stated that abrasive concentration is the most effective parameter for surface improvement. Gorana *et al.* [20] studied the changes caused by the AFM process parameters on output parameters such as active grain density, cutting force and material removal.

Venkatesh *et al.* [21] applied the AFM method to EN-8 steel taper gear, made various analyses, mentioned that the surface improvement is more than 50%, and said that extrusion pressure is the most effective parameter, and the abrasive media flow rate is insignificant. Williams and Rajurkar [22] increased the flow rate of the abrasive media in their studies, indicating that they did not see a change in the amount of material removal.

The viscosity of the abrasive media in the AFM process is one of the important parameters [23]. The increase in the amount of material removal the increase in the media viscosity increasing media viscosity [24]. Davies and Fletcher [25] made studies on pressure and an increasing number of cycles, and stated that the media temperature increased with the increasing number of cycles and media temperature was an important parameter in the AFM process due to the effects of the temperature on viscosity.

Eyercioğlu *et al.* [26] applied the AFM technique to the surface of the ground homogeneous workpiece and used silicon carbide as an abrasive type in practice, as a result, they mentioned that the surface roughness value declined by increasing abrasive concentration. Sankar *et al.* [27] applied the AFM process on aluminum alloy (Al) and Al/SiC metal matrix composites, abrasive media was prepared with silicon carbide for use in the experiments, stated that as the percentage of abrasive in the media increased, the radial force increased and so did the scratches on the surface of the workpiece.

Good results from the AFM process depend on the workability status of the material, the shape of the workpiece and the processing parameters [28]. During the electric discharge machining process, a surface is formed on the surface which is inefficient and reduces the strength of the material [13]. This surface is called a white layer. This white layer is hard and poor quality, and also causes a negative change in the value of surface roughness [29].

Surface roughness values of the EDM surfaces vary according to the amount of material that is re-adhered to the surface of the material removed during the process

[30]. Lee and Yur [31] stated that the pulse current and duration of the EDM process is the most important factor in the formation of white layer, indicating that the thickness of the white layer depends on these parameters.

Göv [32] worked on developing the EDM surfaces of Ti-6Al-4V and Inconel 718 alloys using cooling water types and concluded that de-ionized water for Ti-6Al-4V gives the best results and that tap water and kerosene for Inconel 718 gives the best results, thus indicating a decline in surface roughness values.

Loveless *et al.* [33] applied the AFM process to the surfaces of the parts obtained by different methods, showed SEM images, stated that the initial surface quality was important in the amount of material removal and indicated that wire electric discharge machining (WEDM) surfaces were successfully improved. Tzeng *et al.* [34] applied the AFM process to micro-slits which have been manufactured by the WEDM. They studied the AFM parameters and the parameters required to obtain micro-slit by WEDM process. They took the images from the workpiece and showed the surfaces using a scanning electron microscope.

Göv *et al.* [35] applied the AFM process to WEDM surface with the media which was prepared using different abrasive mesh size and concentration. They stated that the change in the surface roughness value is not linear and suggested that AFM be applied after the WEDM process instead of performing more procedures to correct surface roughness by using WEDM process. Göv and Eyercioğlu [36] improved surface roughness of Ti-6Al-4V by applying the AFM process, used silicon carbide as an abrasive type in the experiments, the samples used in the experiments were obtained by the EDM method, and observed that the white layer was removed in several cycles by applying the AFM method. Göv and Eyercioğlu [37] applied the AFM process to the WEDM surface using different abrasive types (Boron carbide (B_4C), silicon carbide (SiC), Aluminum oxide (Al_2O_3), garnet) and after the AFM, they concluded that during the WEDM, the white layer formed on the surface of the workpiece was removed using the media prepared separately with all abrasive types and also stated that the best surface quality in abrasive types is accomplished using B_4C and SiC abrasive types.

Experimental design can be used to determine the parameters to be set on process. Butola *et al.* [38] applied Taguchi method to the parameters to be used in the AFM operation and stated that the surface roughness after Abrasive Flow Machining declined by 26.42% in combination of the most appropriate values, mentioned that using Taguchi method would result in more efficient results in a shorter time. Raj *et al.* [39] used the Grey Relational Analysis (GRA) and Taguchi method, performed the AFM process on satellite components and indicated that the burrs on the workpiece were removed.

Jain and Jain [40] have developed a model for determining the AFM input parameters and stated that the most appropriate parameters could be determined.

Results can be obtained more efficiently with fewer experiments using a finite element model in Abrasive Flow Machining process [41]. Jain and Jain [42] proposed a simulation program and stated that the effects of the AFM input parameters (e.g. abrasive grain size, abrasive concentration, number of cycles, etc.) in improving surface quality with this simulation would be predicted. Jain *et al.* [43] examined the AFM input parameters using neural network model and stated that the evaluation of the AFM process can be performed without physical experiments with this model. Rajeshwar *et al.* [44] developed a simulation model to determine the properties of abrasive media during the AFM process.

In the AFM process, it is difficult to estimate the amount of material removal. Wei *et al.* [45] has developed a new material removal model to be used in the AFM process. In this new model, material removal behaviors of single abrasive and active abrasives have taken into account and demonstrated the accuracy and applicability of the newly developed model by doing four different experiments. Active abrasives are abrasive particles which remove material on the workpiece surface during the AFM process. Seifu *et al.* [46] used ANSYS FLUENT software to investigate material removal in computational fluid dynamics (CFD) simulations related to the AFM process. In this way, the axial and radial forces were calculated, and the radial force which allows the material to be removed was smaller than the axial force.

Jain *et al.* [47] designed a finite element model that showed the flow of the media during the AFM, indicating the working principle of this model and its results. They have shown that the surface roughness value declines with the increase in parameters such as the number of cycles and the rate of abrasive, have pointed out that the amount of material removal increased because of increased parameters such as pressure and abrasive concentration in the media. According to these conclusions, it is possible to use this model to make theoretical analysis easily.

Ibrahim [48] prepared abrasive media using silicon carbide SiC abrasive type in the experiment. He used the Minitab program to predict the amount of material removal and said that extrusion pressure is the most important parameter for material removal.

New techniques are being tested for the Abrasive Flow Machining process. Drill bit assisted abrasive flow is one of these techniques and the amount of material removal has been increased with this technique [49]. Biing Hwa *et al.* [50] attempted to improve surface quality by passing the abrasive media through a screw rod. Sankar *et al.* [51] provided the movement of rotation to the workpiece for the development of parameters such as the amount of material removal.

Walia *et al.* [52] applied centrifugal force to abrasive media when applying the AFM process, providing this centrifugal force with a rotating centrifugal force generating rod (CFG) and stated that productivity has increased significantly using this method. Walia *et al.* [53] developed finite elements modeling (FEM) for the media which used in the AFM process with CFG rod and performed the analyses using the ANSYS program.

Mohammadian *et al.* [54] developed a new technique to polish the IN625 interior surfaces used in the aviation industry, a newly developed chemical-abrasive fluid was used to improve surface quality, and the inner surface of the part was improved sufficiently and the processing time was shortened.

Singh *et al.* [55] conducted experiments using Magnetically Assisted Abrasive Flow Machining (Magnetically assisted AFM) which is a different type of the AFM, and as a result of these experiments, they said that the magnetic field generated during the process provided an increase in the amount of material removal.

2.3 Discussion

According to literature studies, abrasive type, abrasive concentration, abrasive mesh size, processing time, extrusion pressure are the most important process parameters.

Better results have been obtained on applications to hard workpieces. The surface roughness value is reduced on all applied workpieces. Material removal varies with the shape of the workpieces, abrasive mesh size, and abrasive concentration. The SEM images of the workpieces which are applied to the AFM are taken and more understandable findings are obtained.

Various methods have been developed to find the most appropriate parameters in terms of cost and time. Different modeling and simulation programs (GRA, ANSYS FLUENT, FEM) were used. In this way, the surface roughness values and the amount of material removal can be predicted in advance.

In this study, it was experimentally studied to improve surface quality by applying AFM method to workpieces prepared from Ti-6Al-4V and Inconel 718 materials which are widely used in aviation industry. The effects of AFM input parameters (abrasive type, abrasive mesh size, abrasive concentration, and varying number of cycles) on output parameters (material removal rate (MRR), surface roughness value (R_a), and surface images of workpieces (SEM)) were experimentally studied and their results were revealed.

CHAPTER 3

EDM SURFACES AND ABRASIVE FLOW MACHINING

3.1 Introduction

This chapter provides information about AFM methods. Application methods of the AFM, process parameters are specified. The information about EDM surfaces is also included in this chapter.

3.2 Electrical Discharge Machining

Electrical discharge machining method is the technique of forming electric arc and forming workpiece. Initially sparks and then erosion occur on the workpiece by removing very small parts from the workpiece.

3.2.1 EDM Surface

3.2.1.1 EDM Surface Layers

The EDM application differentiates the surface of the workpiece. During the process, some of the metals bounce back to the surface. In addition, the surface contains molten metal, so that a layer is formed on the surface after the process. This layer appears as a white layer in the examinations. The white layer which has a hard structure and cracks causes early deformation of the material.

3.2.1.2 Surface Deformation and Surface Roughness in EDM

Due to the application method in the EDM process, it is inevitable that high temperatures will occur. Due to the process and the thermal properties of the workpiece, capillary cracks are formed on the surface.

The changing structure of EDM surfaces reduces the strength of the material and reduces the corrosion resistance.

EDM surface roughness values generally depend on the energy and application time of the process.

3.3 Abrasive Flow Machining

In terms of cost and time, finishing by using classical methods is not enough to process complex workpieces. These negative situations and emerging technology have led to the research for new finishing processes. One of the non-traditional finishing procedure is Abrasive Flow Machining.

Various surface finishing methods were investigated and developed according to the needs of the industry. Abrasive Flow Machining method was developed by Extrude Hone Corporation in the 1960s [2]. It is very difficult to use traditional methods to finish surfaces of complex parts, especially in the aviation industry. This process can improve important parts of the aircraft, such as the airfoil surface condition and fuel control parts [56]. AFM method is not only used in the aviation industry, but also in different industries such as automobile and medical.

Suitable polymer-based abrasive media is prepared for the application of AFM method and this abrasive media moves back and forth on the workpiece under pressure and makes surface improvement.

The Abrasive Flow Machining method used to improve the surfaces of parts that are particularly difficult to reach is a method used for operations such as deburring and polishing.

The newly discovered AFM method has become an important application of finishing processes in many sectors with developing technology.

Even holes that are too small to be accessed can be completed by using the AFM method. Undesirable bad surfaces can be removed by using Abrasive Flow Machining process and improve surface quality.

A lot of parts can be finished in mass production by using the AFM process. Thus, the cost of labor can be reduced and time can be saved.

3.4 Abrasive Flow Machine Types

The general principle of abrasive flow machines is to accommodate abrasive media and to adjust processes such as pressure, processing speed and number of cycles.

Abrasive flow machines are available at different sizes, different pressures, and different processing speeds.

There are four different types of abrasive flow machines, one-way AFM, two-way AFM, orbital AFM and magnetically assisted AFM. The general parts of the machine are the hydraulic unit, machine body, and control unit.

3.4.1 One-way Abrasive Flow Machine

One-way abrasive flow machine is operated by a hydraulic piston. The operation is done with the help of the cylinder hosting the abrasive media. AFM process is applied with the help of the holder prepared for the workpiece. One end of the cylinder on the one-way abrasive flow machine is open. The one-way abrasive flow machine is shown in Figure 3.1. Abrasive media is thrown out of this opening. To continue the cycle, the piston comes to its former position and continues to apply by filling the abrasive media again.

Figure 3.1 One-way abrasive flow machine

3.4.2 Two-way Abrasive Flow Machine

The two-way abrasive flow machine is a widely used abrasive flow machine. The schematic diagram of a two-way abrasive flow machine is shown in Figure 3.2. The machine contains two reciprocating pistons and the abrasive media filled into the piston is moved by the progress of the two pistons [57]. As the length and width of the cylinder increases in the machine, the capacity of the machine increases. There is also a digital display for the control of the machine so that it can be processed under desired conditions. The screen allows you to adjust the pressure, speed, and number of cycles.

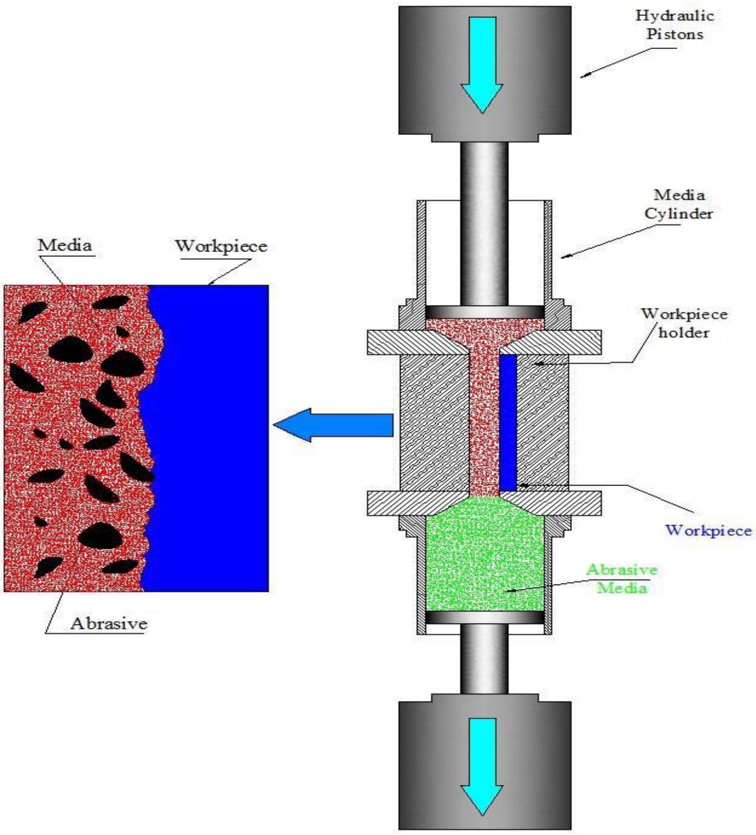


Figure 3.2 Schematic diagram of two-way abrasive flow machine [58]

3.4.3 Orbital Abrasive Flow Machine

Different types of machines are being developed because of developments in AFM process. This machine type is similar to typical AFM processing methods, but some changes have been made. The workpiece vibrates with oscillations while the abrasive media is flowing. The operating procedure of the orbital abrasive flow machine is shown in Figure 3.3.

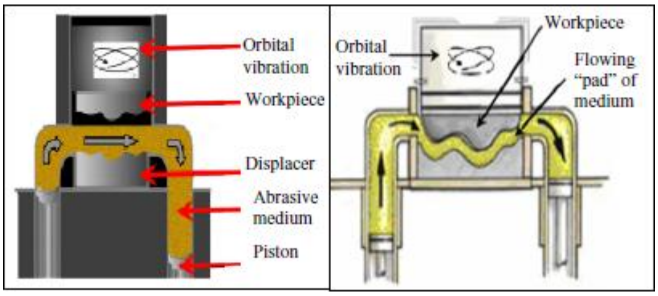


Figure 3.3 Operating procedure of orbital AFM [10]

3.4.4 Magnetically Assisted Abrasive Flow Machine

Magnetically assisted abrasive flow machine is another type of machine that was developed. It has the same logic as the general AFM application methods, but there are magnets around the workpiece. When applying abrasive media, abrasive grains are attracted to the material surface by means of a magnet, thus removing more materials and achieving better surface quality. The schematic diagram of the magnetically assisted AFM is shown in Figure 3.4.

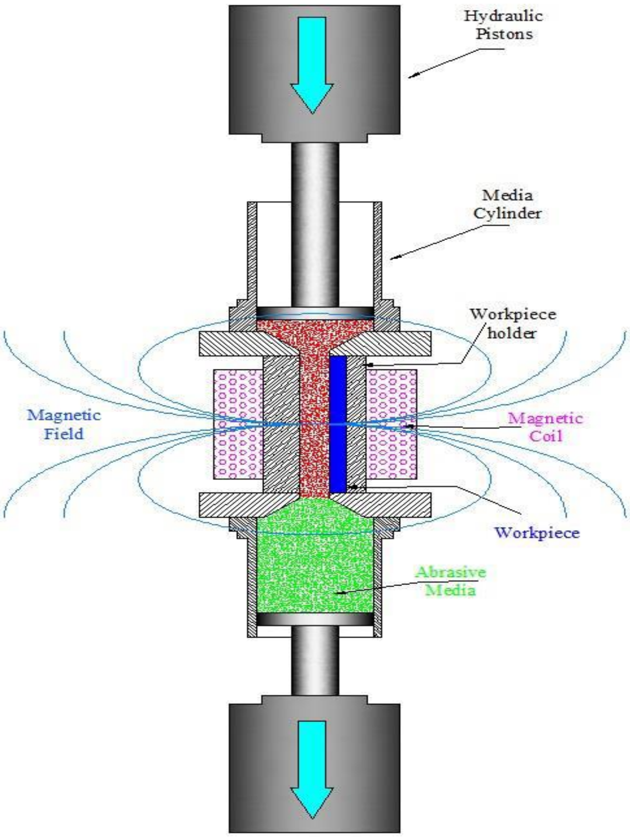


Figure 3.4 Schematic diagram of magnetically assisted AFM [58]

3.5 Workpiece Holder

Certain parts of a lot of workpieces are required to be corrected. Therefore, the surfaces that will not be processed should be protected. The workpiece holder, designed specifically for the workpiece, performs this task. It also ensures that the part to be treated is placed and removed.

Abrasive media affects the workpiece surface and passes through the holder surfaces. Therefore, the holder surface must be wear-resistant. Polyurethane elastomer is frequently used for durability [58]. Holders are usually made of steel because steel is cheaper than other materials. In addition, the holder shapes have an easy, non-complicated shape. At each end of the workpiece holder, dies are used to guide the flow of abrasive media while processing.

3.6 Polymer-based Abrasive Media

Polymer-based abrasive media is one of the master components of the AFM process. The media containing abrasive particles is pliable and semi-fluid [59]. According to the desired material removal and surface improvement ratio, abrasive type, size, and concentration are selected and abrasive media is prepared. Examples of abrasive types include silicon carbide (SiC), boron carbide (B_4C), aluminum oxide (Al_2O_3), and diamond. SiC is the most preferred type in abrasive types since it is easier to reach and cheaper than other abrasive types. The media prepared with SiC removes more burrs than the media prepared with Al_2O_3 [60].

3.7 Abrasive Flow Machining Procedure

As a starting stage, the abrasive media is filled in the lower chamber. In the two-way abrasive flow machine, the upper and lower pistons are adjusted from the control panel. When the process is started, the lower piston moves up by compressing it. Thus, abrasive media starts to move under pressure. As the media flows, on the surface of the workpiece, processes such as chip removal and polishing are started. The bottom and top pistons reach the maximum point and return to their initial positions. In this way, a loop is completed. At the end of the process, the abrasive media can be easily removed from the surfaces because the media is semi-liquid and takes a consistency that does not adhere too much to the lubricators. It can be easily removed from the material by air or some solvents.

3.8 Abrasive Flow Machining Process Parameters

As a result of the research, it is understood that the AFM parameters depend on:

- The material of the workpiece,
- The shape of the workpiece,
- The surface of the workpiece,
- The number of cycles,
- The pressure,
- The abrasive type,
- The abrasive mesh size,
- The concentration of abrasive,
- The viscosity.

In short, if the parameters are categorized; machine parameters, workpiece parameters, and abrasive media parameters can be classified.

The following is a brief overview of some of these parameters.

3.8.1 Machine Parameters

3.8.1.1 Media Flow Rate

The flow rate of abrasive media depends on the speed of pistons in the abrasive flow machines. If pistons move fast, the flow rate increases. This speed can be changed if desired.

3.8.1.2 Number of Cycles

In abrasive flow machines, a cycle is accomplished by the completion of the work, that is, the return of the elements to the starting position of the machine. In a simple one-way abrasive flow machine, a cycle is followed by the forward movement of the piston after the abrasive media is filled and then completed with the start position of the piston. In the two-way abrasive flow machine, abrasive media moves from bottom to top, then from top to bottom, and a cycle is completed.

3.8.2 Media Parameters

3.8.2.1 Abrasive Types

Abrasive type is selected according to the structure of the workpiece. Frequently used abrasive types to mention briefly; Silicon carbide (SiC) most commonly used abrasive type because it can be used in many types of materials. Aluminum oxide (Al_2O_3) is often used in applications such as aircraft engine blades and medical procedures. Boron carbide (B_4C) and diamond are very costly abrasive types. These two types are usually desired for very good surfaces and are preferred to use with very hard materials.

3.8.2.2 Abrasive Mesh Size

Abrasive mesh size is the grit size of abrasive particles. As grain sizes change, surface processing and material removal vary.

3.8.2.3 Abrasive Concentration

It is the parameter of how much abrasive is used in abrasive media. Concentration is found by comparing the weight of the total media and the abrasive weight used.

3.8.2.4 Viscosity

The fluidized abrasive media has a viscosity like all liquids. Viscosity of abrasive media varies depending on the type of polymer used and the amount of oil it contains.

3.8.3 Workpiece Parameters

3.8.3.1 Material Type

It is not a parameter that can be changed directly in AFM implementation, but studies have been conducted on different types of materials and results have shown diversification. This indicates that the material type should be evaluated before the process and the preferences should be made accordingly.

3.8.3.2 Initial Surface

The starting surface varies according to different production techniques. Scratches occur on surfaces when parts are produced. For instance, random lines are formed on the EDM surfaces to be used in this study.

3.8.3.3 Hardness of Material

The hardness of the material affects the rate of material removal in the AFM method. In connection with this situation, the surface quality also varies according to the material hardness.

3.9 Output Parameters

The surface roughness value and material removal rate can be considered as output parameters of the AFM process. In addition, SEM images are taken and surface changes are observed.

3.9.1 Surface Roughness

The changes in the surfaces of the workpieces that are made in the AFM process can be better understood by numerical values. In this way, it can be evaluated how efficient the AFM application is. For this reason, by taking horizontal and vertical values from the workpiece surface, numerical data about surface roughness is obtained.

3.9.2 Material Removal

Material removal is the amount of material removed from the workpiece. The material is removed when surface healing is performed by using the AFM method. The difference between the first and last weights of the workpiece is the material removal value.

CHAPTER 4

EXPERIMENTAL STUDY

4.1 Introduction

The studies about the experiments are given in this section. Various AFM parameters were applied to EDM surfaces of the materials frequently used in aviation. The instruments used in the experiment and the test procedure are explained.

4.2 Experimental Equipment

The major equipment used in the experiments is described in this section. Information about the prepared abrasive media is given. In addition, information is given about measuring instruments.

4.2.1 Two-way Abrasive Flow Machine

Basically, two-way abrasive flow machine consists of a main body, hydraulic unit and a control unit. The properties of the machine are shown in Table 4.1. The two-way abrasive flow machine is shown in Figure 4.1. Furthermore, this two-way AF machine can also be used as a one-way AF machine.

Table 4.1 Properties of two-way abrasive flow machine

Two-way Abrasive Flow Machine Properties	
Abrasive media capacity	6 / 10 / 23 liters
Pressure	2 – 40 MPa
Stroke	400 mm
Diameter of bore	140 – 180 – 280 mm

Figure 4.1 Two-way abrasive flow machine

4.2.2 Abrasive Media

New abrasive media was prepared for use in experiments. The media consists of polymer-based abrasive particles. The required amount of abrasive can be mixed with the desired amount of polymer and additives can be added when necessary.

Polymer gives semi-fluid consistency to the media. In addition, the polymer allows the media to exhibit elastic behavior. When the abrasive media is compressed under pressure, it becomes a dense consistency close to the solid. After the AFM process, it returns to its previous state, in other words, it becomes more fluidized. In addition, the workpiece has a full effect on its surface. Despite this effect, the tendency to adhere to the surface is low.

Silicon carbide is preferred as an abrasive type to be used in these studies. The properties of different types of abrasives in the same mesh sizes are given in Table 4.2. SiC is less expensive than other abrasive types and has a higher resistance, thus longer use. Especially used in metals other than hard castings and iron. The newly prepared polymer-based abrasive media is shown in Figure 4.2.

Figure 4.2 Polymer-based abrasive media

Table 4.2 Abrasive properties

	Mesh size	**Mohs' Hardness**	**Density (gr/cm^3)**
SiC	180	9	3.2
SiC	240	9	3.2
SiC	400	9	3.2

4.2.3 Design of Experiment

Taguchi method was used to determine experimental parameter combinations. The appropriate parameters were extracted using the Minitab. Abrasive mesh size, abrasive concentration, and the number of cycles were determined as parameters. The parameter combinations and the adjusted state of the parameters to be used are shown in Table 4.3.

Table 4.3 Determination of parameter combinations by using Taguchi method (A) number of experiments, (B) number of cycles, (C) abrasive mesh size, (D) abrasive concentration.

A	**B**	**C**	**D**
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	1
5	2	2	2
6	2	3	3
7	3	1	2
8	3	2	3
9	3	3	1
10	4	1	3
11	4	2	1
12	4	3	2
13	5	1	2
14	5	2	3
15	5	3	1
16	6	1	3
17	6	2	1
18	6	3	2

4.2.4 Material Removal Measurements

One of the output parameters of the AFM operation is material removal. The first weights and the last weights of workpieces are measured and the difference between them is the material removal value. Workpiece weights were measured by using a SHIMADZU AUX220 balance shown in Figure 4.3.

Figure 4.3 Shimadzu AUX220 balance

4.2.5 Surface Roughness Measurements

The surface roughness (R_a) value gives the numerical values to better understand the surface improvement. The workpieces operated in different cycle numbers were measured in the direction of the abrasive media flow and perpendicular to the flow. There is a 0.5 mm distance between each measurement. A total of six R_a values were taken from each sample in three values of flow directions and three values perpendicular to flow. Measurements were taken using a Mitutoyo SJ 401 surface roughness measuring machine shown in Figure 4.4.

Figure 4.4 Mitutoyo SJ 401 surface roughness measuring machine.

4.2.6 Scanning Electron Microscope Images

Since the AFM is a surface improvement process, the changes in the applied surfaces are better understood by taking SEM images. Images were taken from workpieces before and after the AFM operation. Thus, it is possible to see changes in workpiece surfaces. Zeiss GeminiSEM 300 was used to get the images. The SEM machine is shown in Figure 4.5.

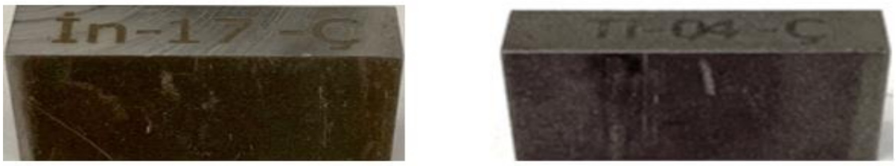
Figure 4.5 Scanning electron microscopy (SEM)

4.3 Experimental Information

This section describes the ways in which experiments are conducted. The number of cycles, abrasive mesh size, and abrasive concentration parameters were changed and the effects on the workpiece surface were investigated with the appropriate combinations. As the workpieces, Inconel 718 and Ti-6Al-4V alloys, used frequently in aviation, were selected. Workpieces are cut by wire electrical discharge machining. In the experiments, a two-way abrasive flow machine was used. Taguchi method was used to design experiments. Surface roughness was measured after the experiments were completed. The initial weights of the samples and the weights after processing were measured and the material removal value was determined.

4.3.1 The Workpiece Material

Inconel 718 and Ti-6Al-4V materials were used to use in experiments. Workpieces, 5x10x20 mm in size, are prepared by wire electrical discharge machining. The Ti-6Al-4V and Inconel 718 workpieces used in the experiments are shown in Figure 4.6.



(a) (b)

Figure 4.6 (a) Workpiece of Inconel 718 (b) Workpiece of Ti-6Al-4V

4.3.2 The Abrasive Media

For use in the experiment, a new media has been prepared to contain polymer, abrasive and hydraulic oil. Silicon carbide was selected as an abrasive type. Three different abrasive mesh sizes were used for the preparation of the different media. 400, 240 and 180 abrasive mesh sizes were used in the experiments. The abrasive ratio is calculated using the formula shown in Equation 4.1.

$$\text{Abrasive concentration} = \frac{\text{weight of abrasive particles}}{\text{weight of media}} \text{ x } 100 \qquad (4.1)$$

The media which has been prepared with an abrasive concentration of 20%, 40%, and 60% were processed separately. The media are run three or five cycles before processing the samples to be used in the experiments to make the media homogeny.

4.3.3 Design of Experiment

Taguchi method was used in the experiment. The number of cycles, abrasive mesh size, and abrasive concentration were determined as factors. Three levels of abrasive mesh size and abrasive concentration were studied. The number of cycles at six levels was processed. The appropriate parameters were extracted using the Minitab program. According to the Taguchi orthogonal array design, the L18 (6^1, 3^2) table was created. Table 4.4 shows the edited table.

Table 4.4 Edited representation of parameters according to Taguchi method.

Number of Experiments	Number of Cycles	Abrasive Mesh Size	Abrasive Concentration
1	1	400	20
2	1	240	40
3	1	180	60
4	3	400	20
5	3	240	40
6	3	180	60
7	5	400	40
8	5	240	60
9	5	180	20
10	10	400	60
11	10	240	20
12	10	180	40
13	20	400	40
14	20	240	60
15	20	180	20
16	50	400	60
17	50	240	20
18	50	180	40

4.3.4 The Experimental Procedure

There are three different variables used in experiments. These variables are the number of cycles, abrasive mesh size, and abrasive ratio. The parameters used in the experiments are given in Table 4.5.

Table 4.5 Experimental parameters

Parameters	**Value**
Abrasive mesh size	180 – 240 – 400
Abrasive concentration	20% – 40% – 60%
Number of cycles	1 – 3 – 5 – 10 – 20 – 50
Piston velocity	900 mm/min
Pressure	6 MPa
Volume of the media flowing in one cycle	3 liters

The holder has a gap that allows abrasive media to influence the surface. A total of eight samples can be placed in the mold. The picture of the workpiece holder is shown in Figure 4.7. The mold is suitable for the workpieces to be effectuated. In the mold, no samples were placed in the areas where abrasive media had the first effect. Six samples were placed at the same time. The samples placed in the mold for processing by using the AFM method, are removed from the mold when they come to the desired number of cycles. The surfaces of the samples removed from the mold are cleaned with air. In this way, the abrasive media is completely removed from the surfaces of samples.

Figure 4.7 The workpiece holder

The surfaces of the samples whose weights were measured before and were cleaned after the AFM process and the final weights of the samples were measured. Thus, the difference between the two measurements was taken and the amount of material removal was determined. Material removal rate is found with the formula from Equation 4.2.

$$\text{MRR}=\frac{\text{initial weight} - \text{final weight}}{\text{processing time}} \left(\frac{\text{mg}}{\text{min}}\right) \tag{4.2}$$

After the AFM operation, surface roughness values of Inconel 718 and Ti-6Al-4V surfaces were measured. The samples were removed from the holder and measurements were taken at 0.5 mm intervals in along to flow and perpendicular to flow. The average of the measurements was obtained and the surface roughness values were calculated.

After experimental operations, SEM images of samples were taken to observe the changes on the surface and to see the improvements. Changes in the surface quality of samples placed according to the number of cycles, abrasive mesh size, and abrasive ratio were displayed. Thus, the changes on the surface have become more meaningful.

CHAPTER 5

RESULT AND DISCUSSIONS

5.1 Introduction

This section discusses the implications of the experiments described in the previous section. Graphs and values of the results were shared. SEM images in this section are provided for better understanding.

5.2 Experimental Results

The results of the improvement of surface quality of Inconel 718 and Ti-6Al-4V alloys by the AFM treatment are stated. In different cycle numbers, different abrasive mesh sizes and concentration were applied to workpieces, surface roughness and material removal rate was concluded, SEM images of workpieces were observed.

5.2.1 Material Removal Rate

When material removal quantities are calculated, it is observed that there is an increase in nonlinear due to the effect of the number of cycles. The reason for this is that the particles adhered to the sample surfaces during the WEDM process form a rough surface. As the surface reaches a flatter structure, the amount of material removal declines gradually.

Another parameter that affects material removal is the abrasive mesh size. As the abrasive mesh size declines, the amount of material removal increases. This is because as the abrasive mesh size increases, the abrasive grain size declines. In short, larger grain abrasives remove more material. The material removal capacity of 180 abrasive mesh size is more than 240 abrasive mesh size. At the same time, the amount of material removal in 240 abrasive mesh size is more than 400 abrasive mesh size.

The concentration of abrasive in polymer-based abrasive media is important. 20% of abrasives showed no significant material removal. It has been observed that the media containing 40% abrasives removes more material than the media containing 20% abrasives. Maximum material removal rate is a media containing 60% abrasive at all mesh sizes.

MRR is low in experiments effectuated with media containing 400 abrasive mesh size. MRR in 20%, 40%, 60% abrasive concentrations, 400 mesh size and 1, 3, 5, 10, 20, 50 cycles numbers are shown in Figure 5.1 and Figure 5.2.

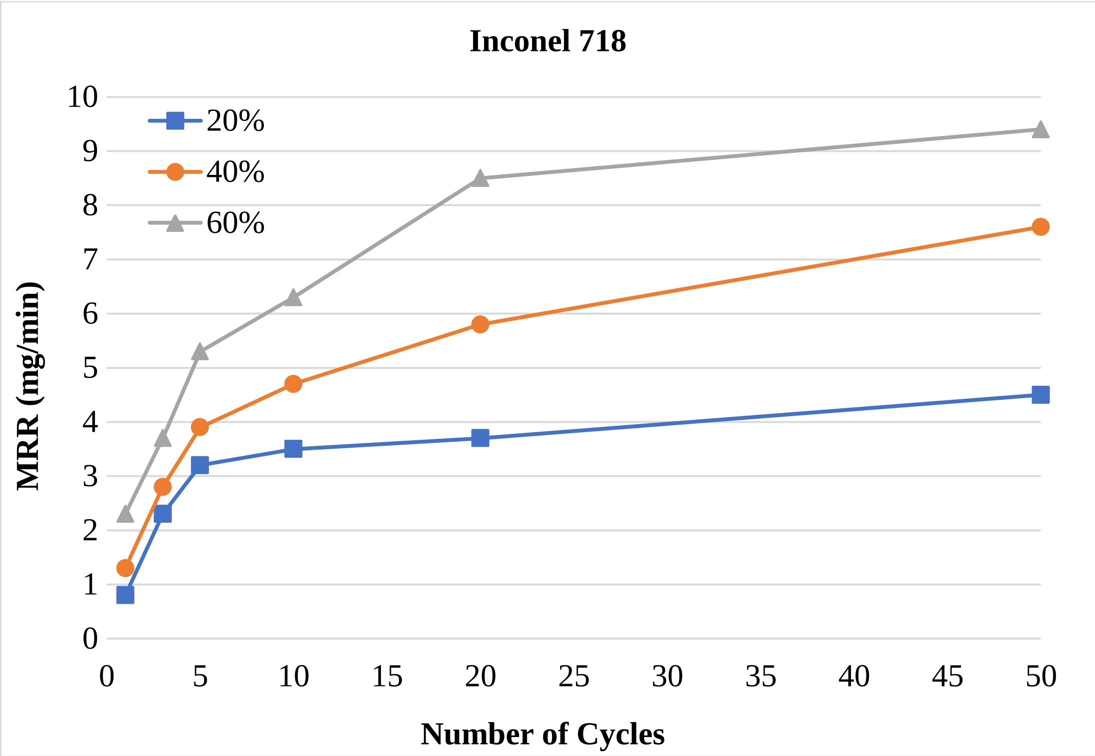


Figure 5.1 MRR measurements of Inconel 718 in 400 abrasive mesh size

A linear material removal rate of up to 5 cycles was observed in experiments with a 20% abrasive concentration. It continued to increase in a non-linear trend after 5 cycles. The MRR at a 40% abrasive concentration has increased to close to 50 cycles straight. The abrasive rate of 60% has the maximum MRR in this abrasive type.

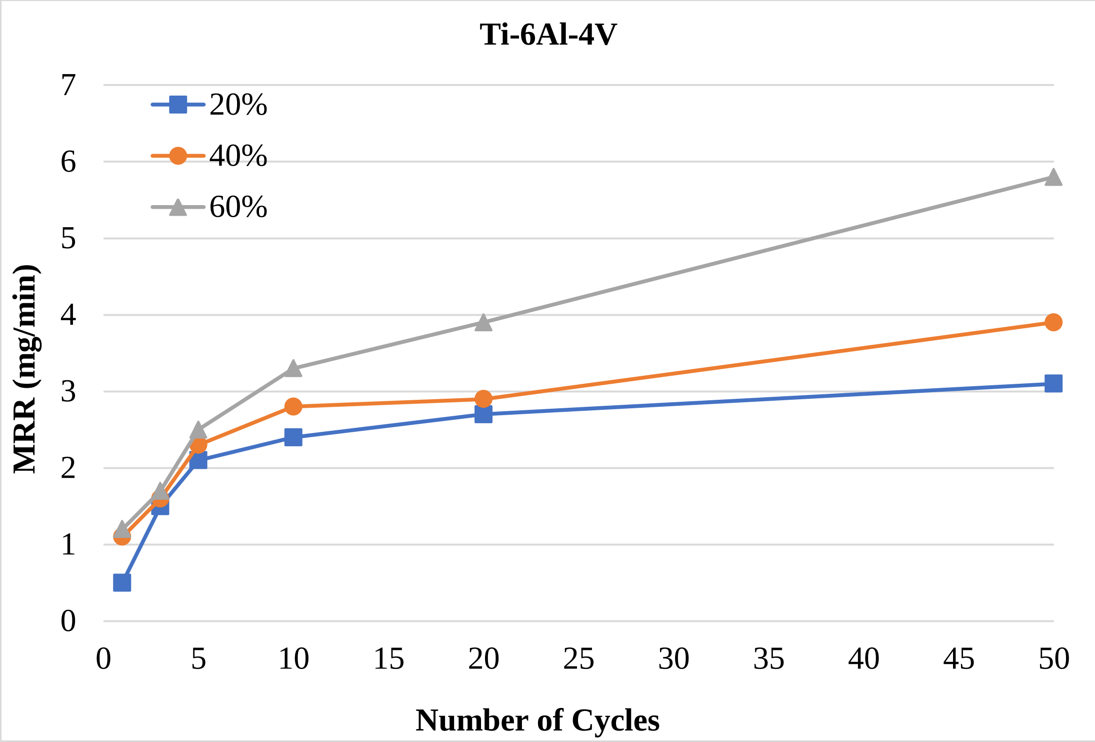


Figure 5.2 MRR measurements of Ti-6Al-4V in 400 abrasive mesh size

The MRR from the Ti-6Al-4V surfaces is less than the MRR from the Inconel 718 surfaces. A linear increase in the values measured after 5 cycles was observed at a 20% abrasive rate. After 20 cycles at a rate of 60% abrasive, the MRR rose rapidly.

Figure 5.3 and Figure 5.4 show the MRR from surfaces of Inconel 718 and Ti-6Al-4V alloys. The MRR in the 240 abrasive mesh size has increased steadily.

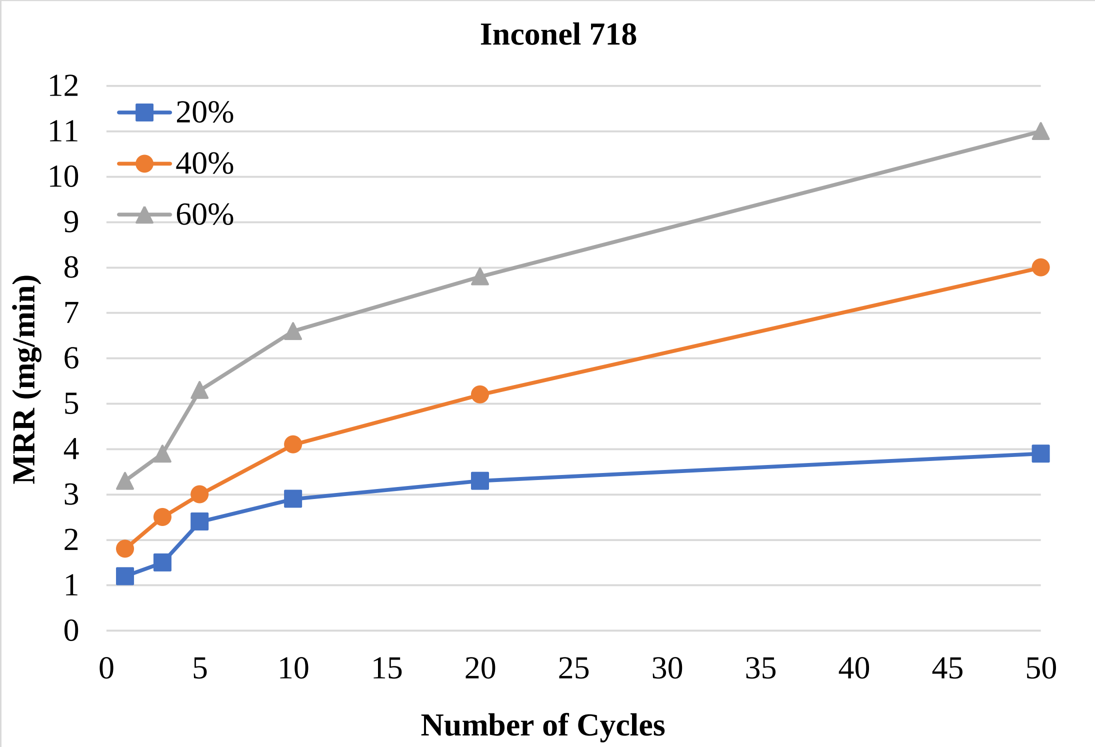


Figure 5.3 MRR measurements of Inconel 718 in 240 abrasive mesh size

In 240 abrasive mesh size, as in the 400 abrasive mesh size, the MRR increased as the number of cycles increased. A faster MRR was observed after 20 cycles from the surfaces of workpieces processed with 40% and 60% abrasive concentrations.

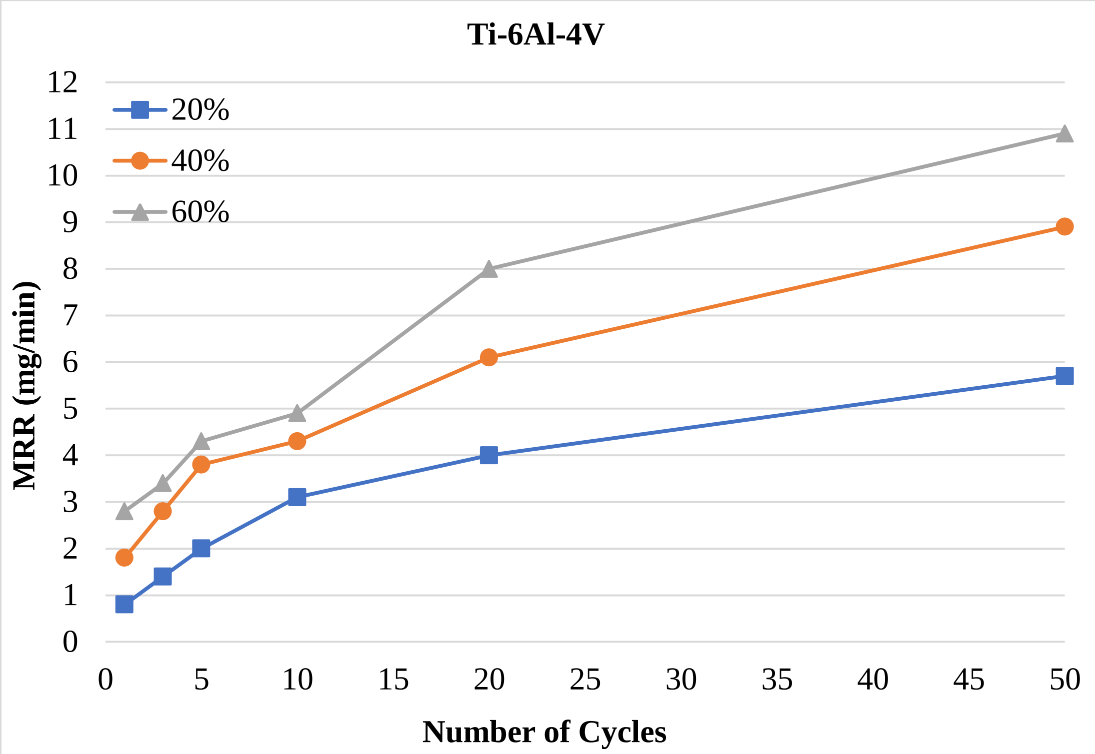


Figure 5.4 MRR measurements of Ti-6Al-4V in 240 abrasive mesh size

After 10 cycles in all abrasive concentration for Ti-6Al-4V, the material removal rate continued to increase rapidly. As with 400 abrasive mesh size, the MRR from the Inconel 718 surfaces is greater than the MRR from the Ti-6Al-4V surfaces. The MRR from Ti-6Al-4V surfaces at a rate of 60% abrasive and 50 cycles is very close to each other with the MRR from the Inconel 718 surfaces.

The 180 abrasive mesh size graphs with maximum MRR values are shown in Figure 5.5 and Figure 5.6.

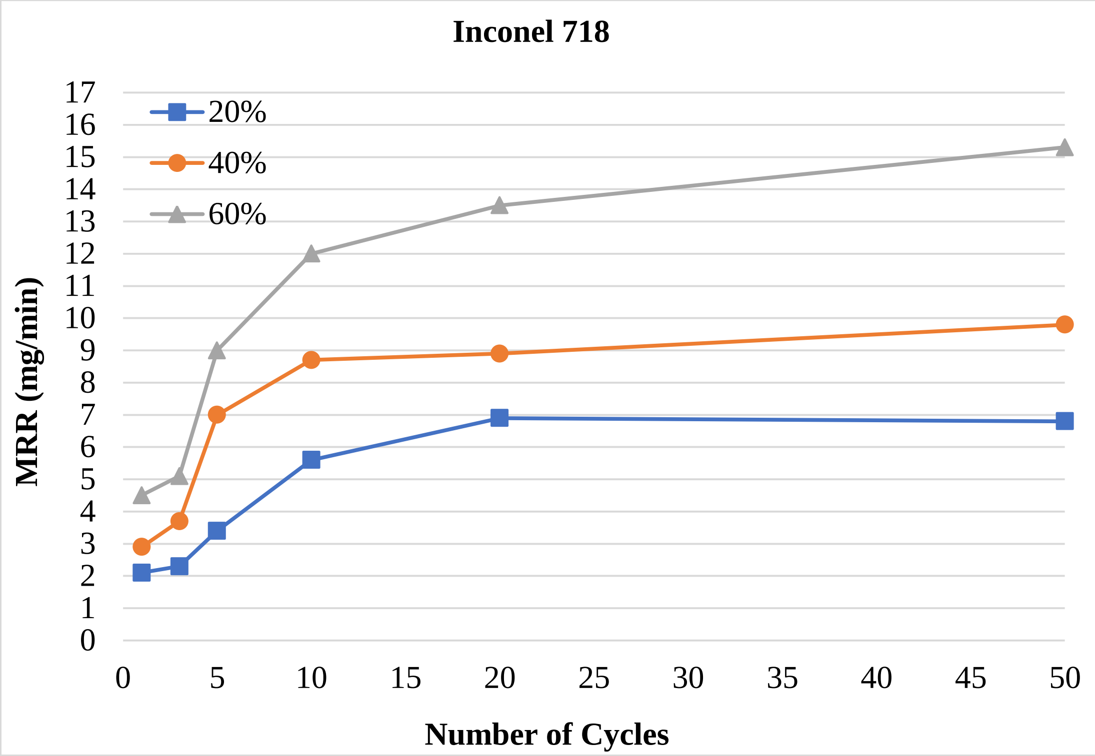


Figure 5.5 MRR measurements of Inconel 718 in 180 abrasive mesh size

There is a non-linear increase in the amount of material removal at 3 different abrasive concentrations. It has been observed that the amount of material removal increases rapidly after 3 cycles at 60% abrasive concentration. The maximum material removal rate was measured at 180 abrasive mesh size compared to other abrasive mesh sizes.

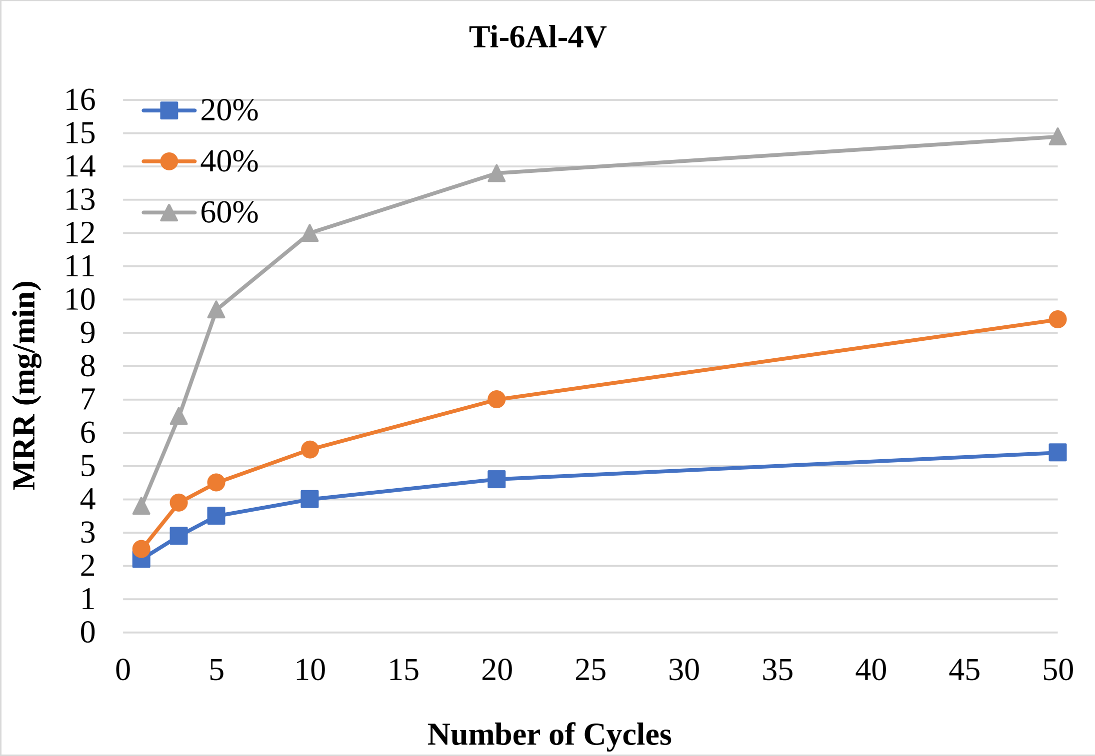


Figure 5.6 MRR measurements of Ti-6Al-4V in 180 abrasive mesh size

A slower increase in the MRR was observed at 20% and 40% abrasive rates, while a rapid material increase from the first cycle was observed at 60% abrasive concentration. Although this increase has continued rapidly, the MRR from the Inconel 718 surface is greater than the MRR from the Ti-6Al-4V surface.

When the three parameters for both materials used in the experiments were evaluated, the maximum MRR was effectuated in 50 cycles, 180 abrasive mesh size, 60% abrasive concentration was observed.

For a more clear understanding of the material removal rate, the graphics of all abrasive grain size and abrasive concentration are given separately for both material types in Figure 5.7 and Figure 5.8.

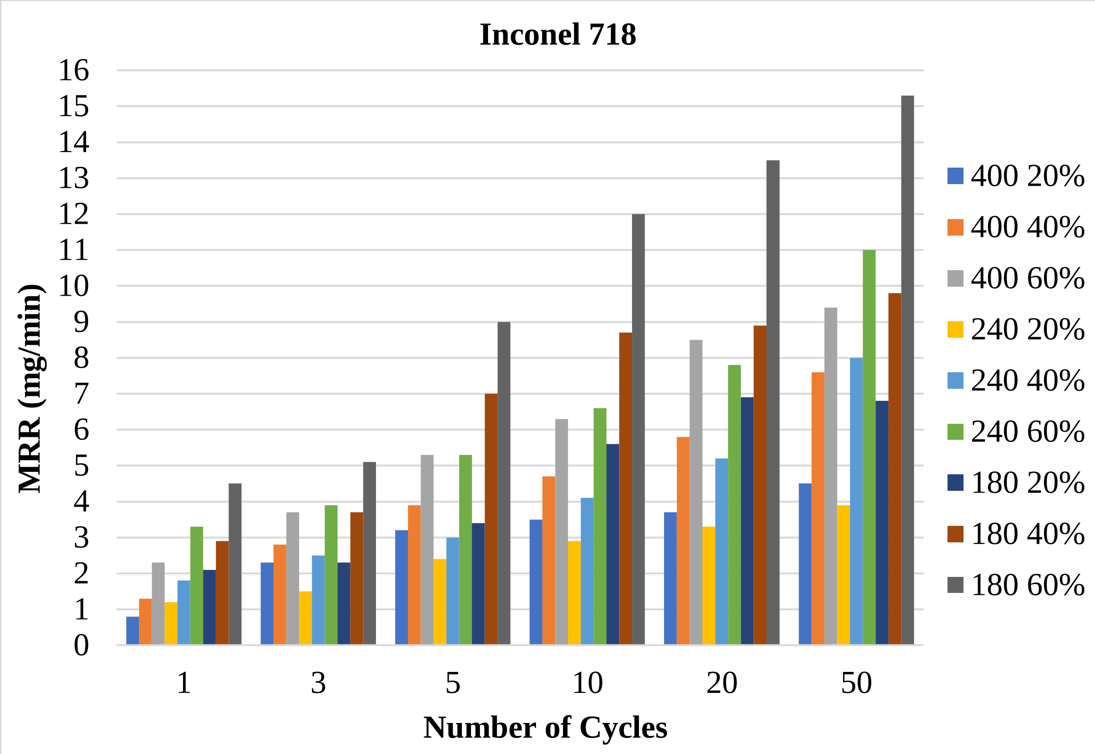


Figure 5.7 MRR graphics of Inconel 718 in all mesh size

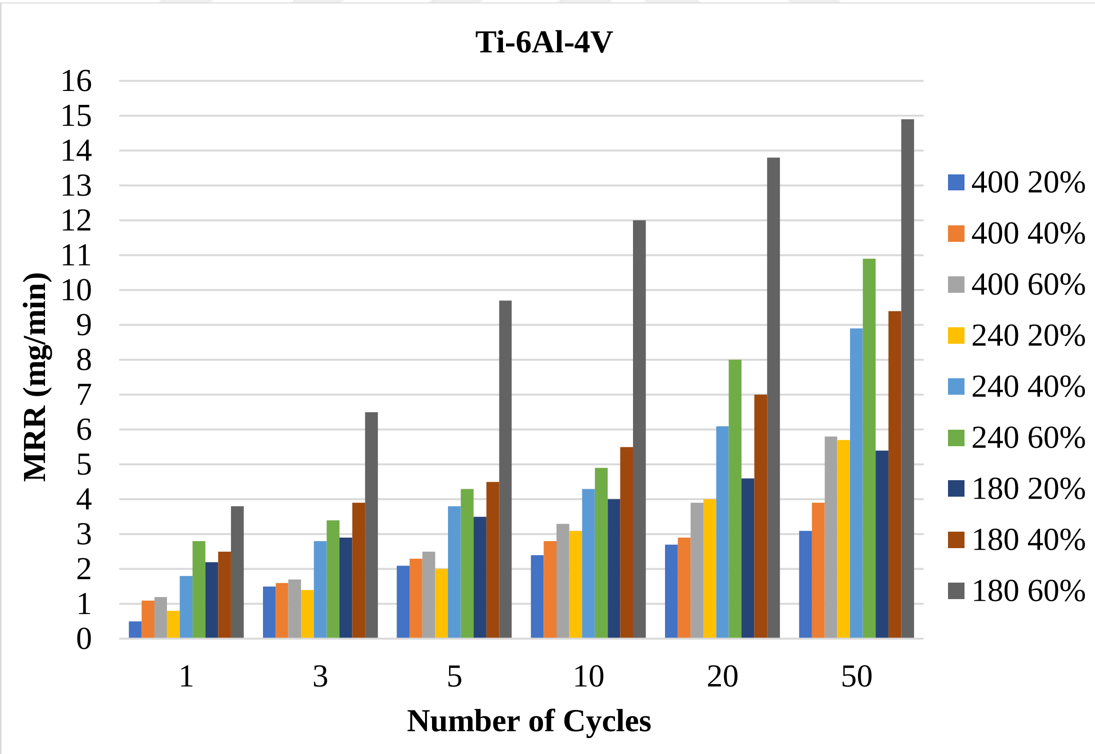


Figure 5.8 MRR graphics of Ti-6Al-4V in all mesh size

5.2.2 Surface Roughness Measurements

Surface roughness (R_a) values obtained in flow direction and perpendicular to flow direction have shown a decline in surface roughness values after the AFM operation. As the number of cycles increased, R_a values declined, that is, surface quality improved.

No significant reduction in R_a values of 400 abrasive mesh size was observed. The R_a values, further reduced to 240 abrasive mesh size, have reached the best R_a values with 180 abrasive mesh size.

Good surface quality is not accomplished in all abrasive mesh sizes, polymer-based media containing 20% abrasive. When working with a media containing 40% abrasive, surface quality was found to be better than the media containing 20% abrasive. When the abrasive ratio of the media was increased to 60%, it was observed that the surface roughness values declined considerably. Surface roughness measurements in 20%, 40%, 60% abrasive concentrations; 180, 240, 400 mesh sizes; 1, 3, 5, 10, 20, 50 cycles numbers are shown in from Figure 5.9 to Figure 5.20.

R_a values taken in the 400 abrasive mesh size were not observed much decline. The R_a values taken are shown between Figure 5.9 and Figure 5.12.

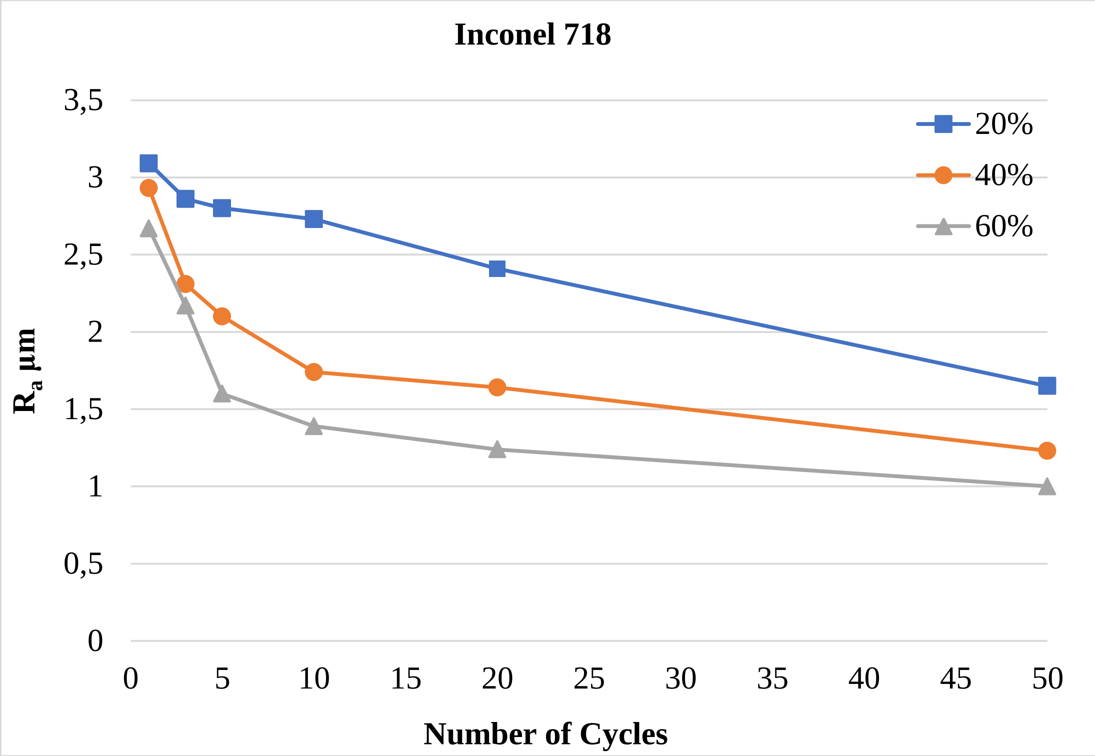


Figure 5.9 R_a measurements of Inconel in 400 abrasive mesh size (perpendicular to flow)

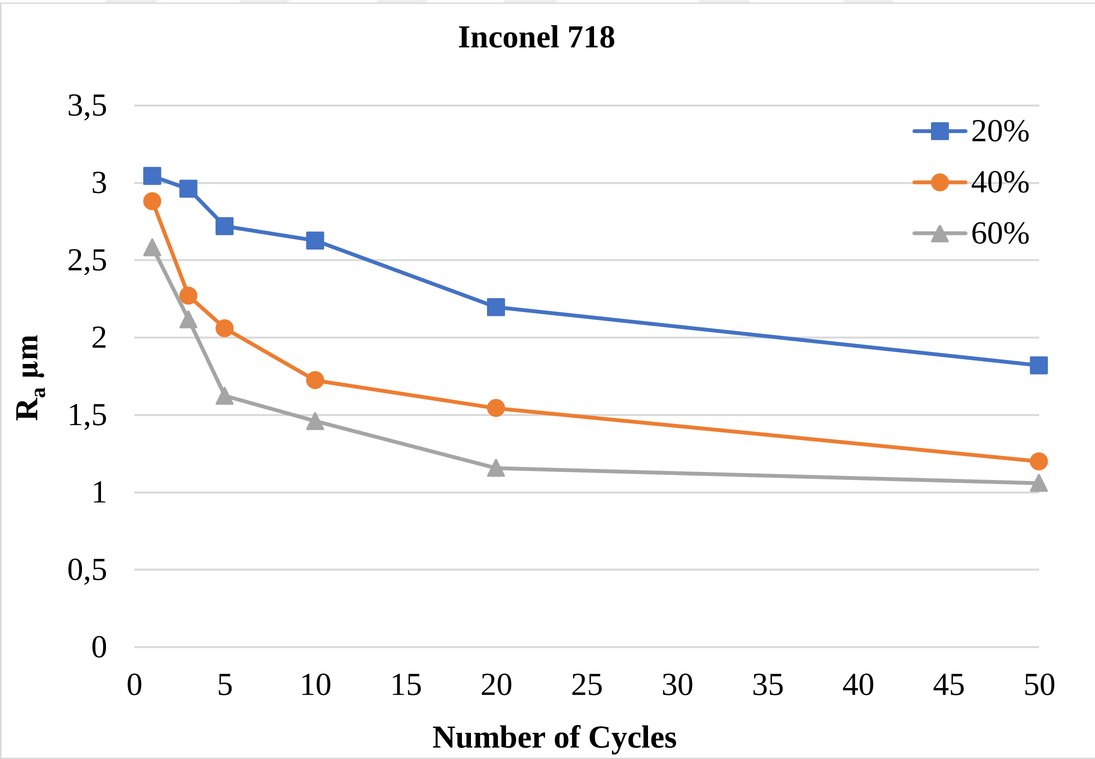


Figure 5.10 R_a measurements of Inconel in 400 abrasive mesh size (along to flow)

The surface roughness values taken in the direction of flow and perpendicular to the flow were similar to the decline in values in both types of measurements. The workpiece, processed with the media containing 20% abrasive, barely fell below 2µm in 50 cycles. Values below 2µm were taken after 5 cycles at 40% abrasive concentration. Measurements close to 1µm in 50 cycles with a 60% abrasive concentration were able to be taken.

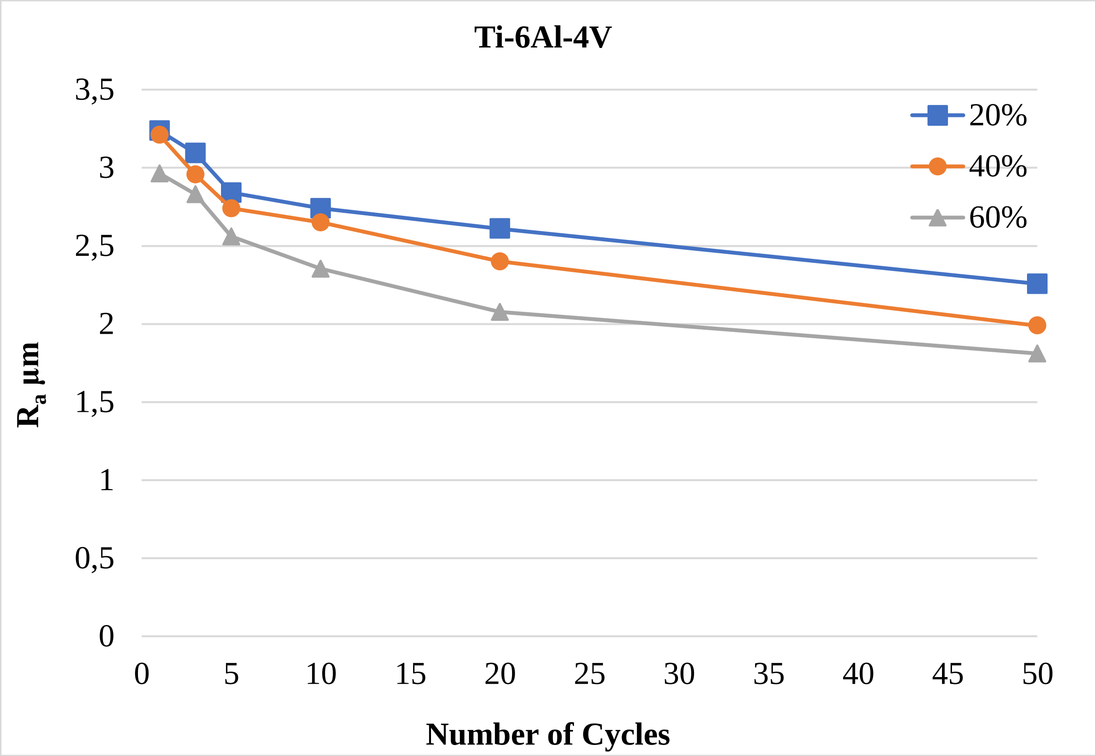


Figure 5.11 R_a measurements of Ti-6Al-4V in 400 abrasive mesh size (perpendicular to flow)

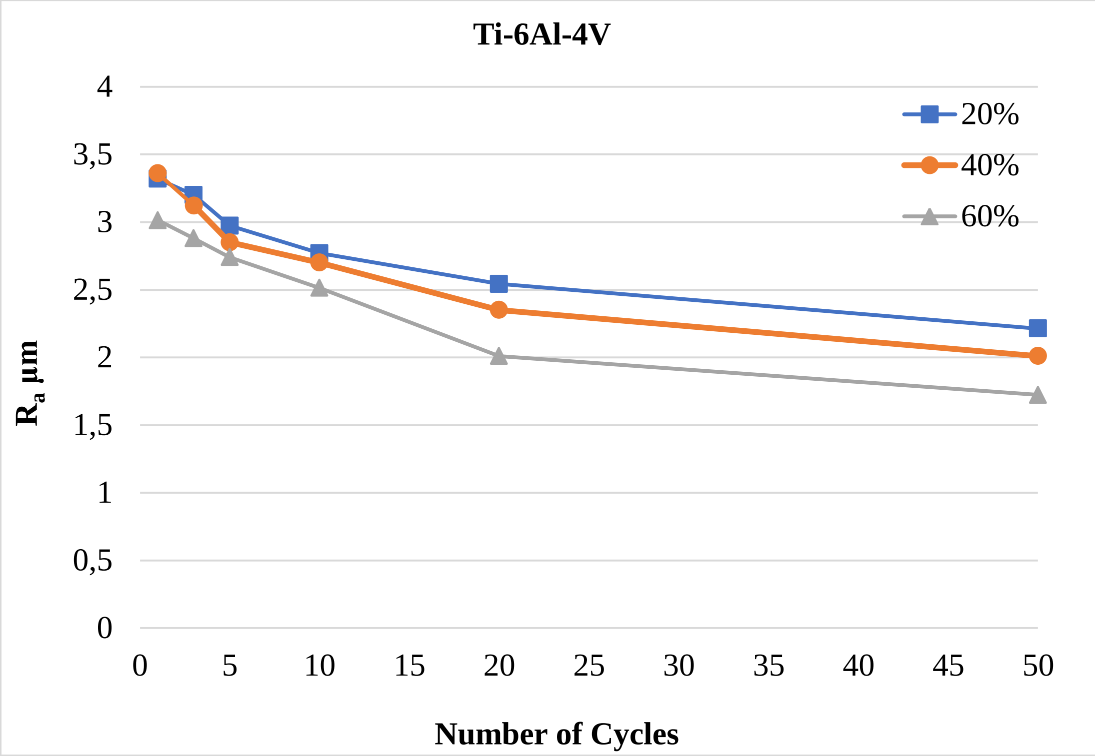


Figure 5.12 R_a measurements of Ti-6Al-4V in 400 abrasive mesh size (along to flow)

A linear decline was observed in the values taken from Ti-6Al-4V surfaces in the direction of flow at a rate of 20% abrasive, but there is a non-linear decrease in the values taken perpendicular to the flow. There is a similar reduction in values taken in both directions at 40% abrasive concentration. At 60% abrasive concentration, a linear decline after 3 cycles was observed in the values taken perpendicular to the flow.

The R_a values taken in the 240 abrasive mesh size are shown between Figure 5.13 and Figure 5.16. The values obtained from Inconel 718 declined to below 1µm at 60% abrasive concentration. The R_a values taken from Ti-6Al-4V in the same abrasive concentration (60%), were not observed to decline below 1µm.

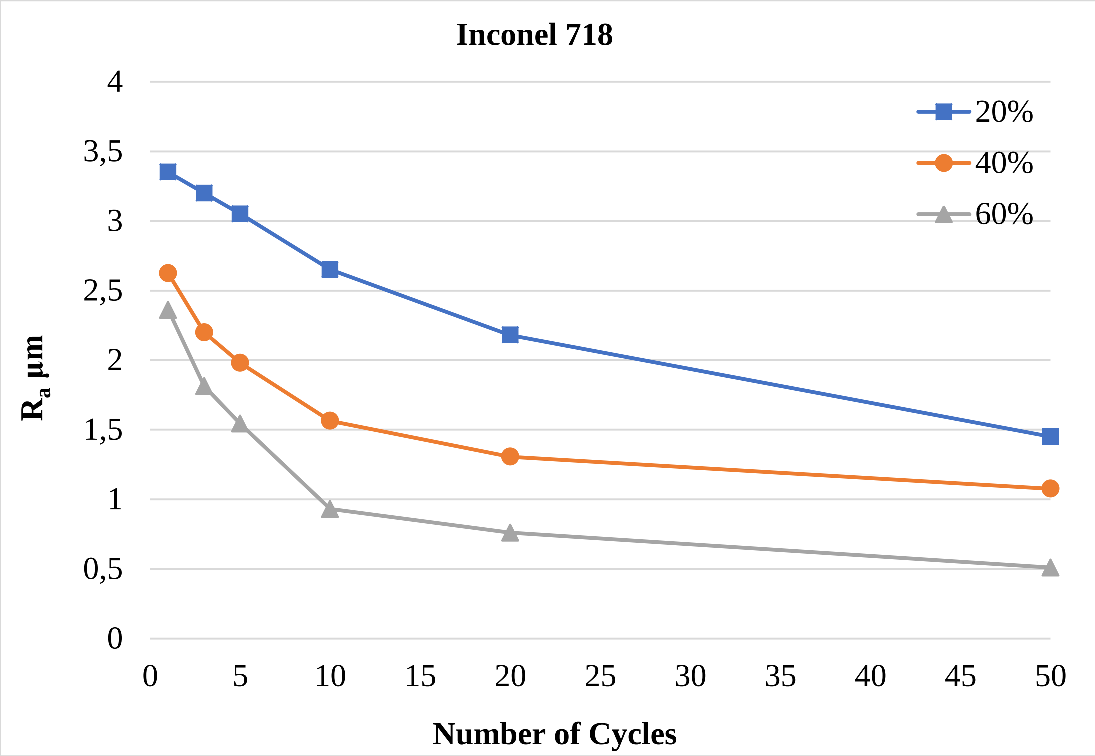


Figure 5.13 R_a measurements of Inconel in 240 abrasive mesh size (perpendicular to flow)

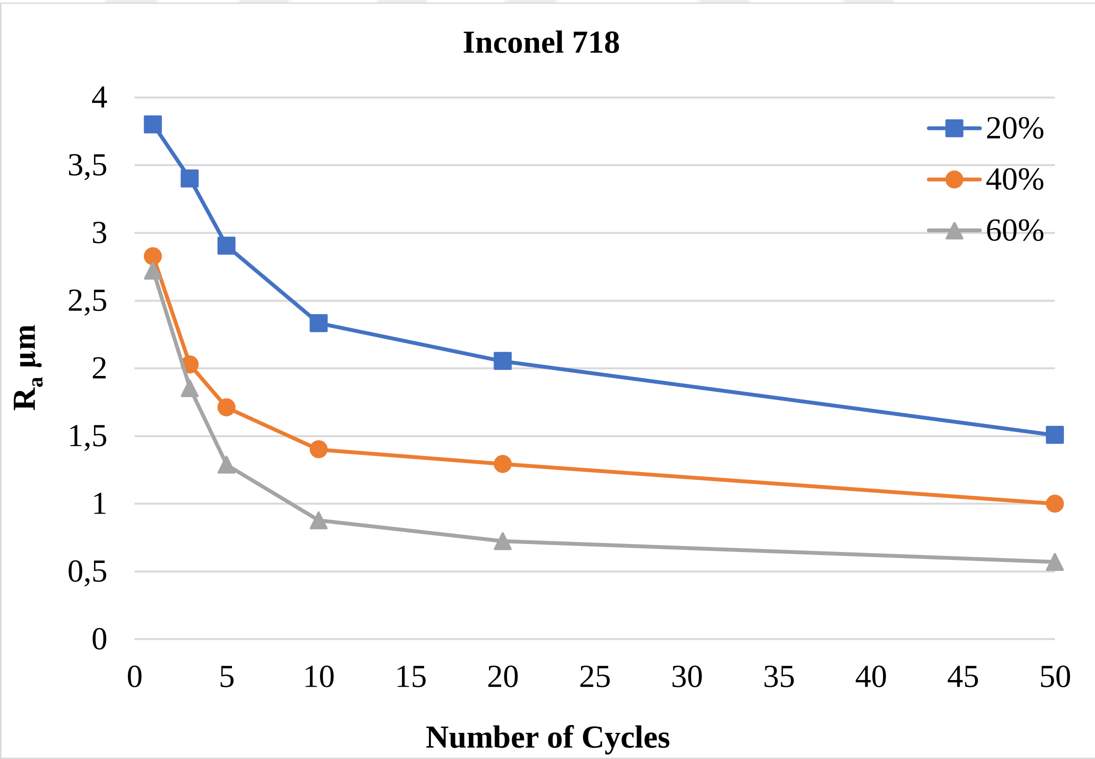


Figure 5.14 R_a measurements of Inconel in 240 abrasive mesh size (along to flow)

The surface roughness values taken after with the media containing 20% abrasive were below 2µm after 20 cycles. The values taken after 3 cycles at a 40% abrasive rate are below 2µm. In experiments with media containing 60% abrasive, values below 1µm were taken after 10 cycles. The best R_a values taken for this abrasive mesh size are 0.51µm in 60% abrasive concentration, the R_a value measured perpendicular to the flow in 50 cycles, while the R_a value measured in the direction of flow is 0.57µm.

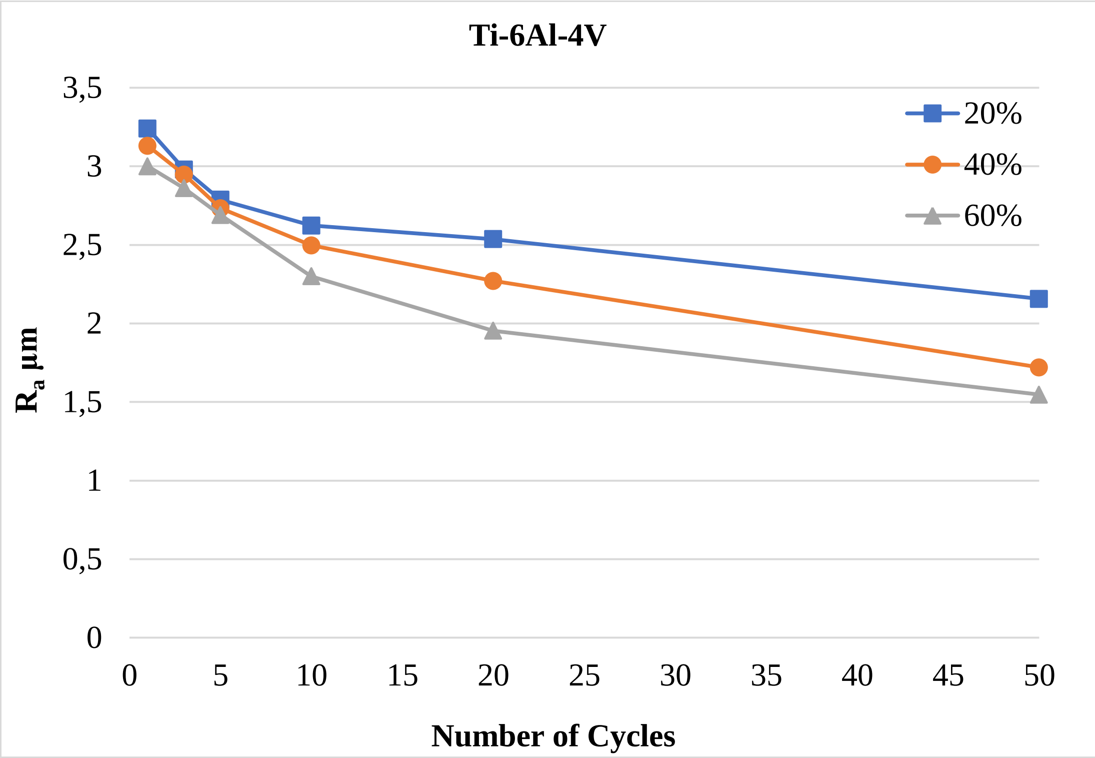


Figure 5.15 R_a measurements of Ti-6Al-4V in 240 abrasive mesh size (perpendicular to flow)

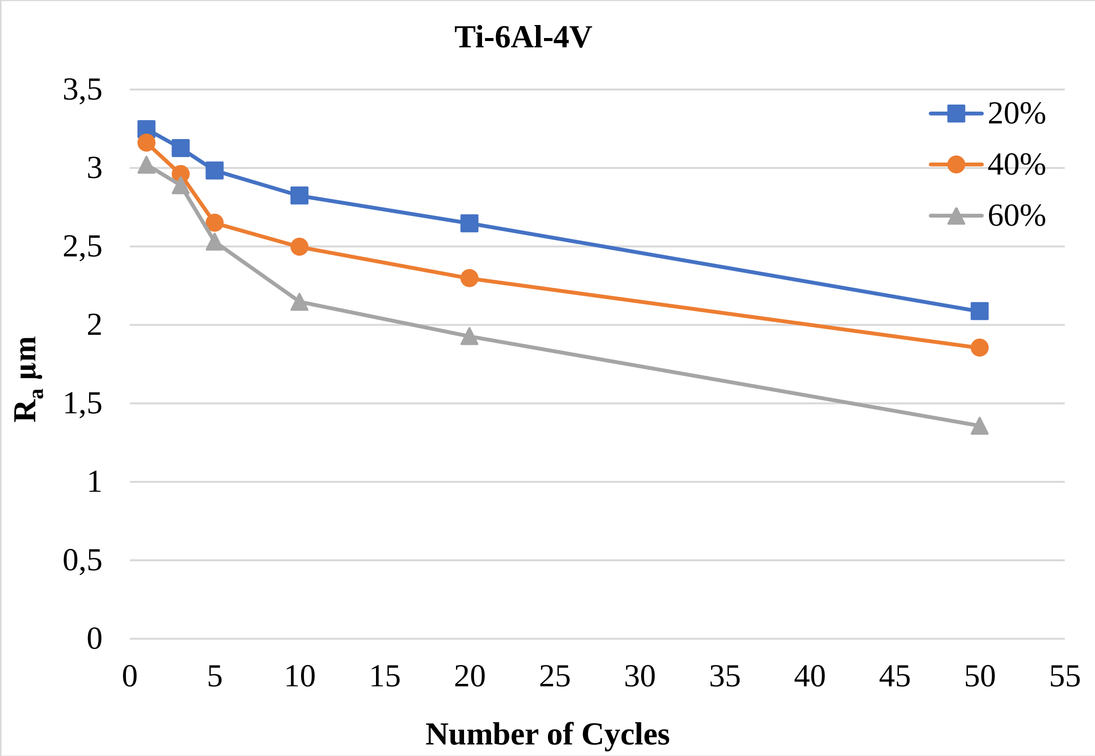


Figure 5.16 R_a measurements of Ti-6Al-4V in 240 abrasive mesh size (along to flow)

For Ti-6Al-4V, the R_a values taken perpendicular to the flow direction after the AFM were close to each other and followed a similar course up to 5 cycles. After 5 cycles, a nonlinear reduction was observed. The R_a values measured from the Ti-6Al-4V surface are higher than the values taken from the Inconel 718 surface.

The graphics of R_a values taken from samples with 180 abrasive mesh size were shown between Figure 5.17 and Figure 5.20. The lowest surface roughness values were reached in this abrasive mesh size. The lowest surface roughness values were obtained in 50 cycles, with 180 abrasive mesh size and 60% abrasive concentration.

It can be deduced that the surface roughness value declines as the material removal increases as a result of observing the maximum material removal in workpieces with 180 abrasive mesh size, 60% abrasive concentration and number 50 cycles.

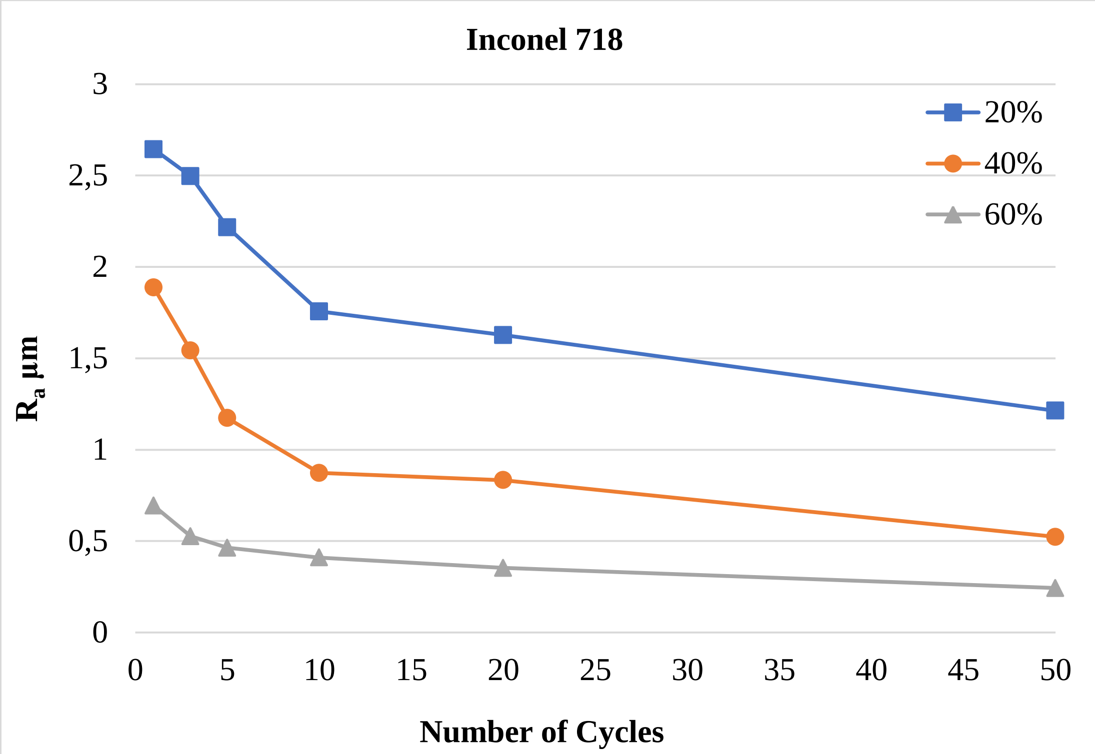


Figure 5.17 R_a measurements of Inconel in 180 abrasive mesh size (perpendicular to flow)

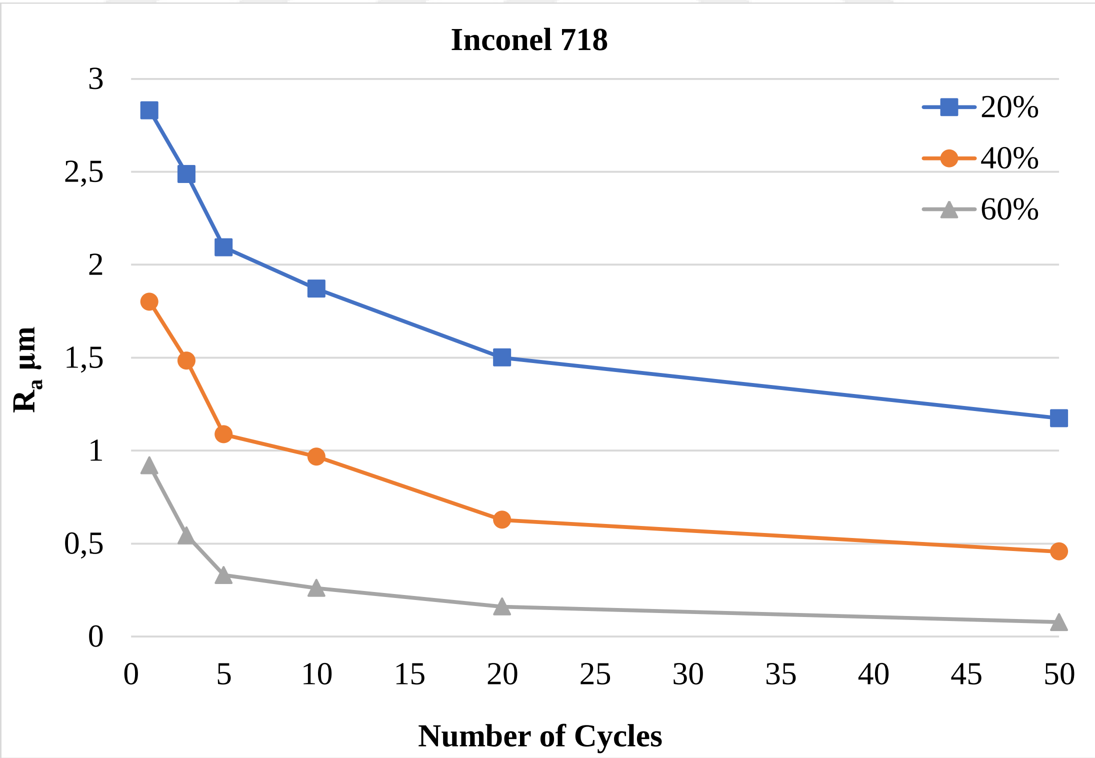


Figure 5.18 R_a measurements of Inconel in 180 abrasive mesh size (along to flow)

Compared to other abrasive mesh sizes, the difference is greater between the values taken at different abrasive concentrations. This difference is seen starting from the first cycle. In the experiments with the media containing 20% abrasive, values taken after 5 cycles fell below 2µm. Values below 2µm were taken from the first cycle at 40% abrasive concentration. Values taken after the first cycle at 60% abrasive concentration are below 1µm. In the number of 50 cycles, the best surface roughness values were taken. For each abrasive concentration, the R_a values taken in 180 abrasive mesh size, are less than the R_a values taken in 240 and 400 abrasive mesh sizes.

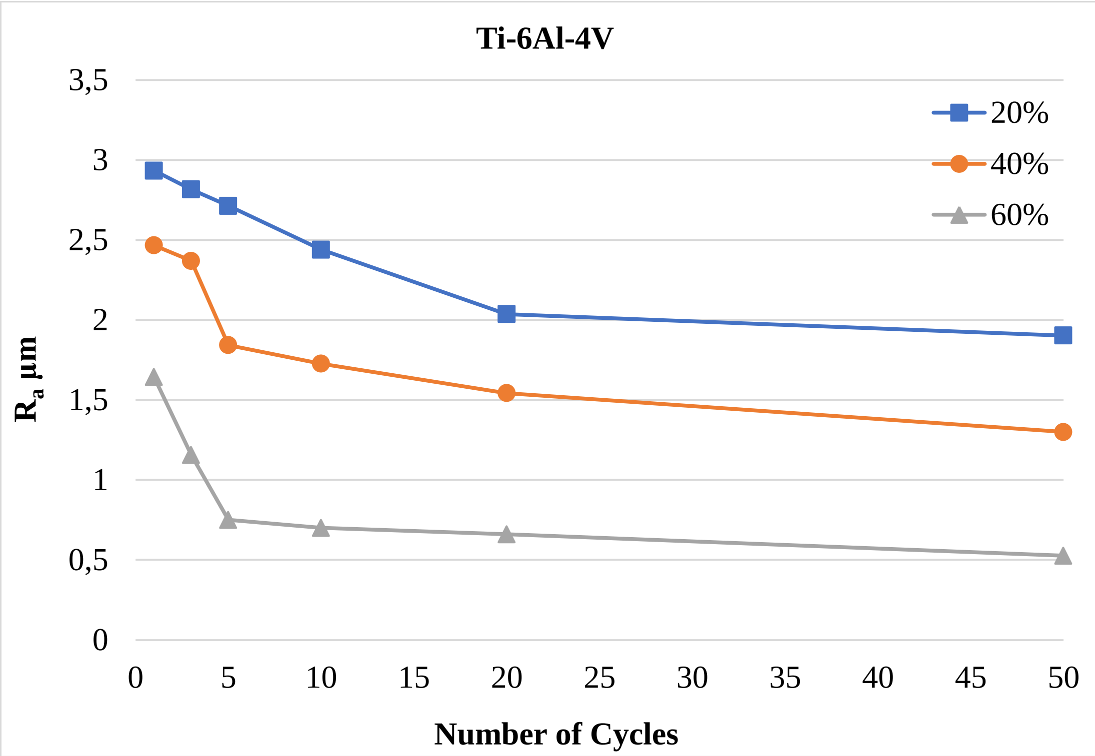


Figure 5.19 R_a measurements of Ti-6Al-4V in 180 abrasive mesh size (perpendicular to flow)

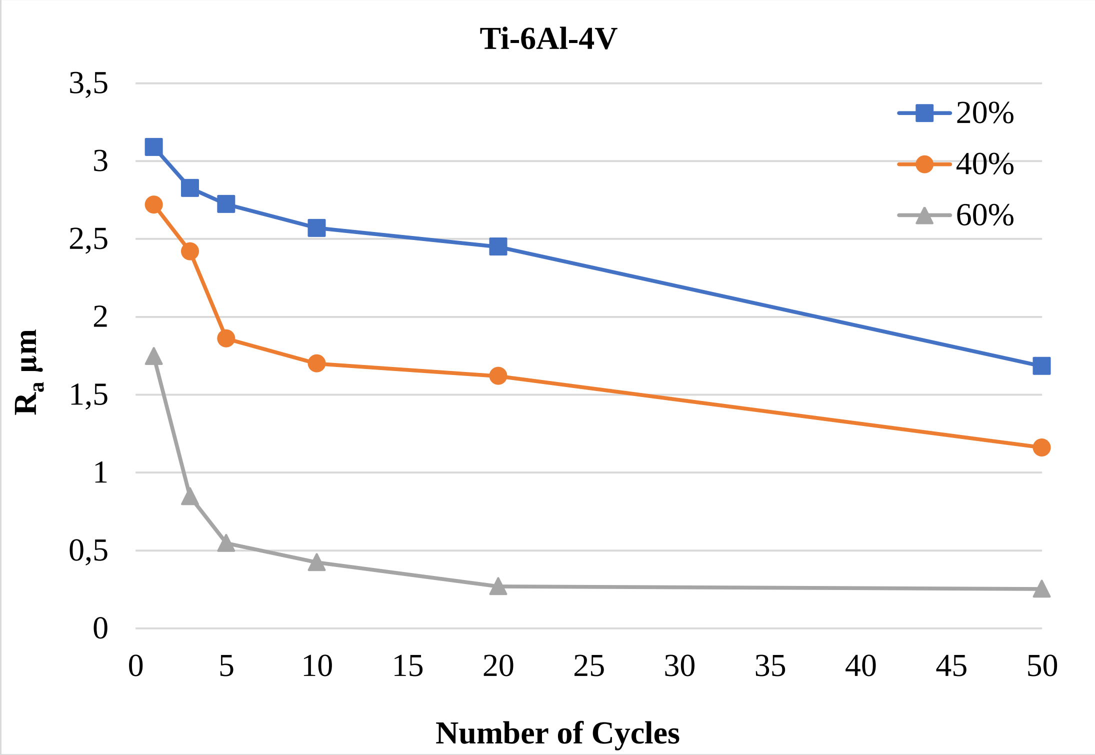


Figure 5.20 R_a measurements of Ti-6Al-4V in 180 abrasive mesh size (along to flow)

Although the values taken after the experiments on Ti-6Al-4V samples were more than the values taken from the surface of the Inconel 718 samples, the best results were taken at values made with 180 abrasive mesh size. After the experiments with the media containing 60% abrasive, a rapid decline was observed in the values taken up to 5 cycles. After 5 cycles, it continued to decline slowly.

If the surfaces of Inconel 718 and Ti-6Al-4V are compared, the best Inconel 718 surface roughness value was found to be lower than the best Ti-6Al-4V surface roughness value. It is clear that the surface quality has been improved with these values.

For a better understanding of the surface improvement after the AFM process, R_a graphics of all abrasive mesh sizes and concentrations are given in Figures 5.21 and Figure 5.22.

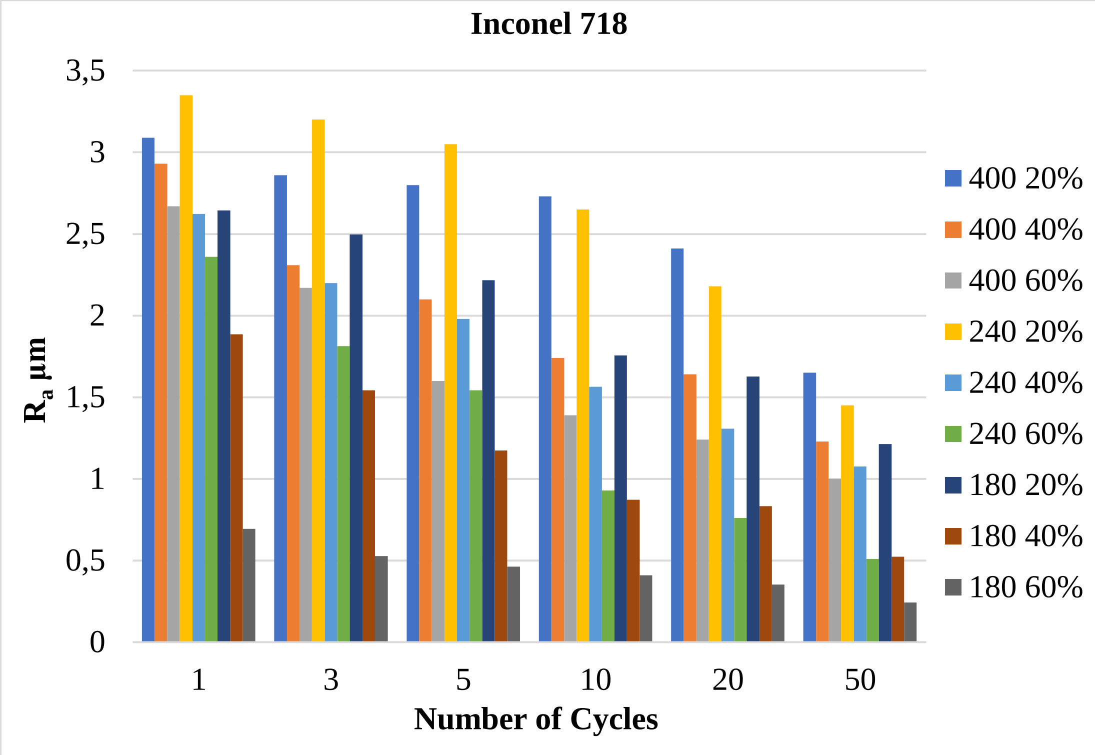


Figure 5.21 R_a measurements of Inconel 718 in all mesh size

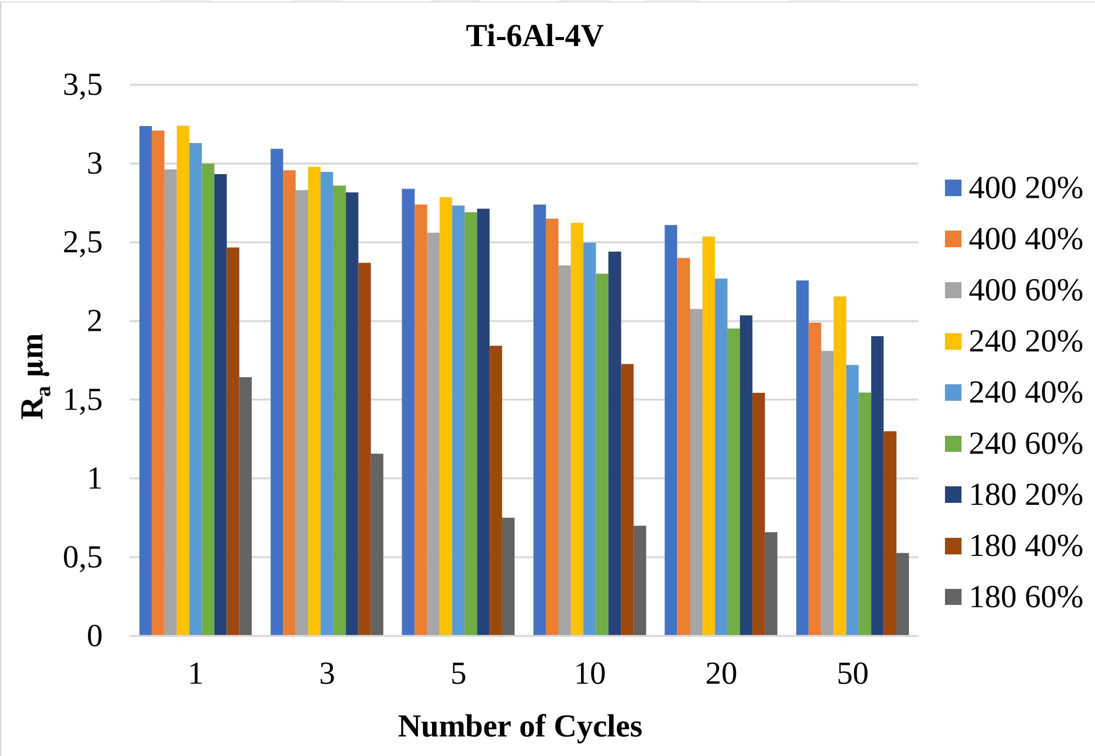


Figure 5.22 R_a measurements of Ti-6Al-4V in all mesh size

5.2.3 SEM Images

After the AFM operation, surface images of workpieces were taken. A white layer is seen on the untreated workpiece surface by using the AFM method. This layer is caused by the WEDM process. When the surface is viewed, it is seen that there is an indented, protruding layer. On the surfaces of Ti-6Al-4V alloy, cracks have been observed. This white layer does not contain the general characteristics of the workpiece. Briefly, it is a layer with bad features. It is necessary to get rid of this layer and this layer was corrected by the AFM treatment.

Images of workpieces are taken in different cycle numbers, abrasive mesh sizes and abrasive concentrations. Images of the workpieces were taken at a magnification of x200 and x1000. Thus, it is better observed whether the white layer has been removed and the condition of the workpiece surfaces.

The removal of the white layer in the size of 400 abrasive mesh was realized in an excess number of cycles. The white layer has been removed after the fifth cycle in the size of 240 abrasive mesh. When 180 abrasive mesh size is used, the white layer has been removed after the first cycle. The surface quality has increased. Abrasive scars were observed on the surface.

In the AFM process done, using the media with an abrasive rate of 20%, it has been observed that the white layer is not completely removed even when it is operated in 50 cycles in all abrasive mesh sizes. The reason for this is due to the low amount of abrasive in the media. Better surfaces were observed using the media with an abrasive rate of 40%. The best observed abrasive rate of the surfaces purified from the white layer is 60%. As the abrasive rate increased, the improvement on the surface was easier and quicker.

After the experiments with the media which were prepared using 400 abrasive mesh size, the SEM images taken from Ti-6Al-4V and Inconel 718 surfaces are given between Figure 5.23 and Figure 5.26. In the experiments with abrasive media which were prepared with 400 mesh size have shown that good surface quality is not accomplished and that white layer can be removed only at high abrasive concentrations. Thus, the importance of abrasive mesh size and abrasive concentration in surface treatment is understood.

In addition, improvement of surface quality of Inconel 718 is more than the improvement of surface quality of Ti-6Al-4V.

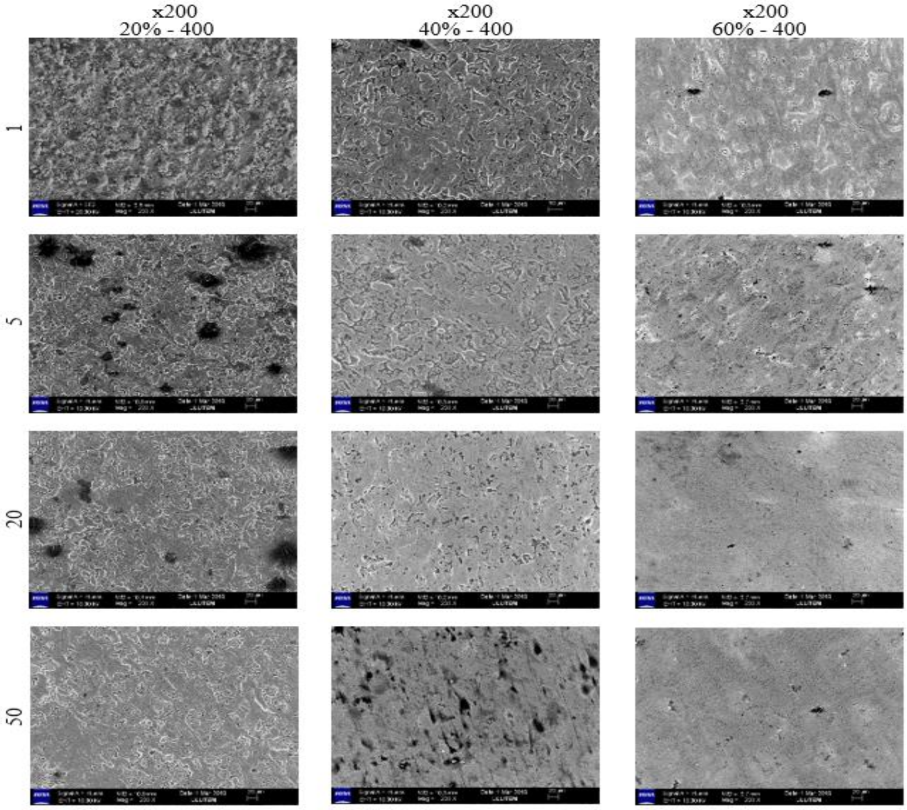


Figure 5.23 400 mesh; 20%, 40%, 60% abrasive; SEM images of Inconel (x200)

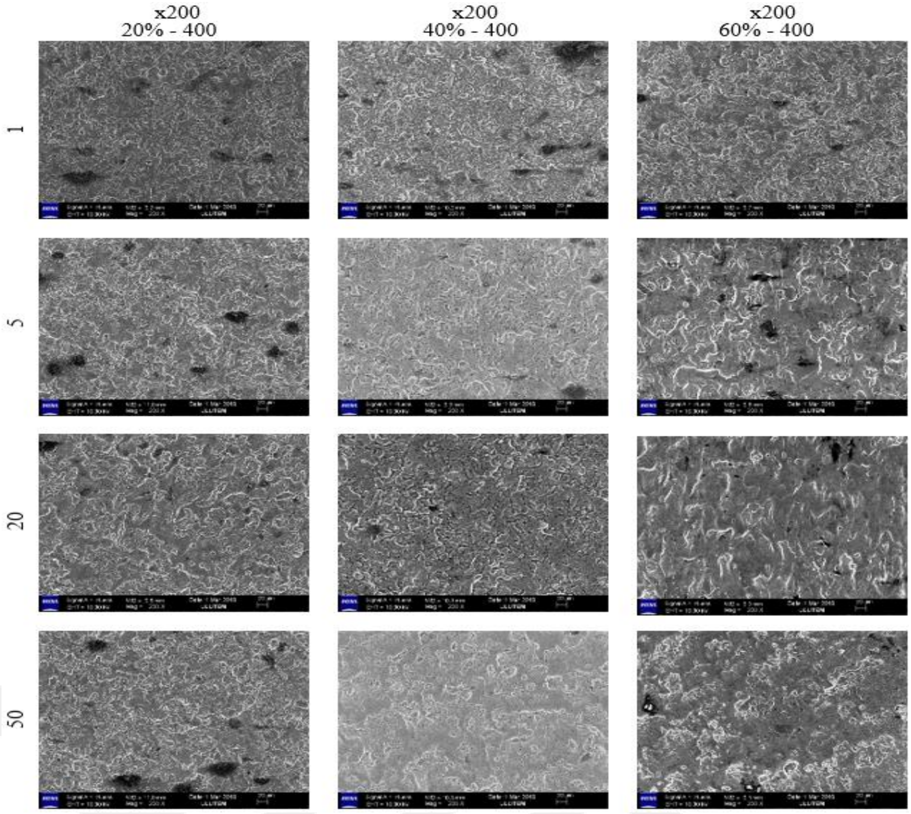


Figure 5.24 400 mesh; 20%, 40%, 60% abrasive; SEM images of Ti-6Al-4V (x200)

In the Inconel 718 SEM images taken with x200 magnification, experiments with the media containing 20% abrasive, showed that the inefficient layer called white layer could not be removed even in 50 cycles. However, with the increasing number of cycles, bubbles on the surface have been seen to decline. In experiments with media containing 40% abrasive, it is observed that bubbles are removed in later cycles, while in studies with media containing 60% abrasive, bubbles are completely removed after the fifth cycle.

SEM images taken from the Ti-6Al-4V surface showed that the white layer was not removed at all abrasive concentrations. But with increasing cycle numbers, bubbles on the surface have gradually declined.

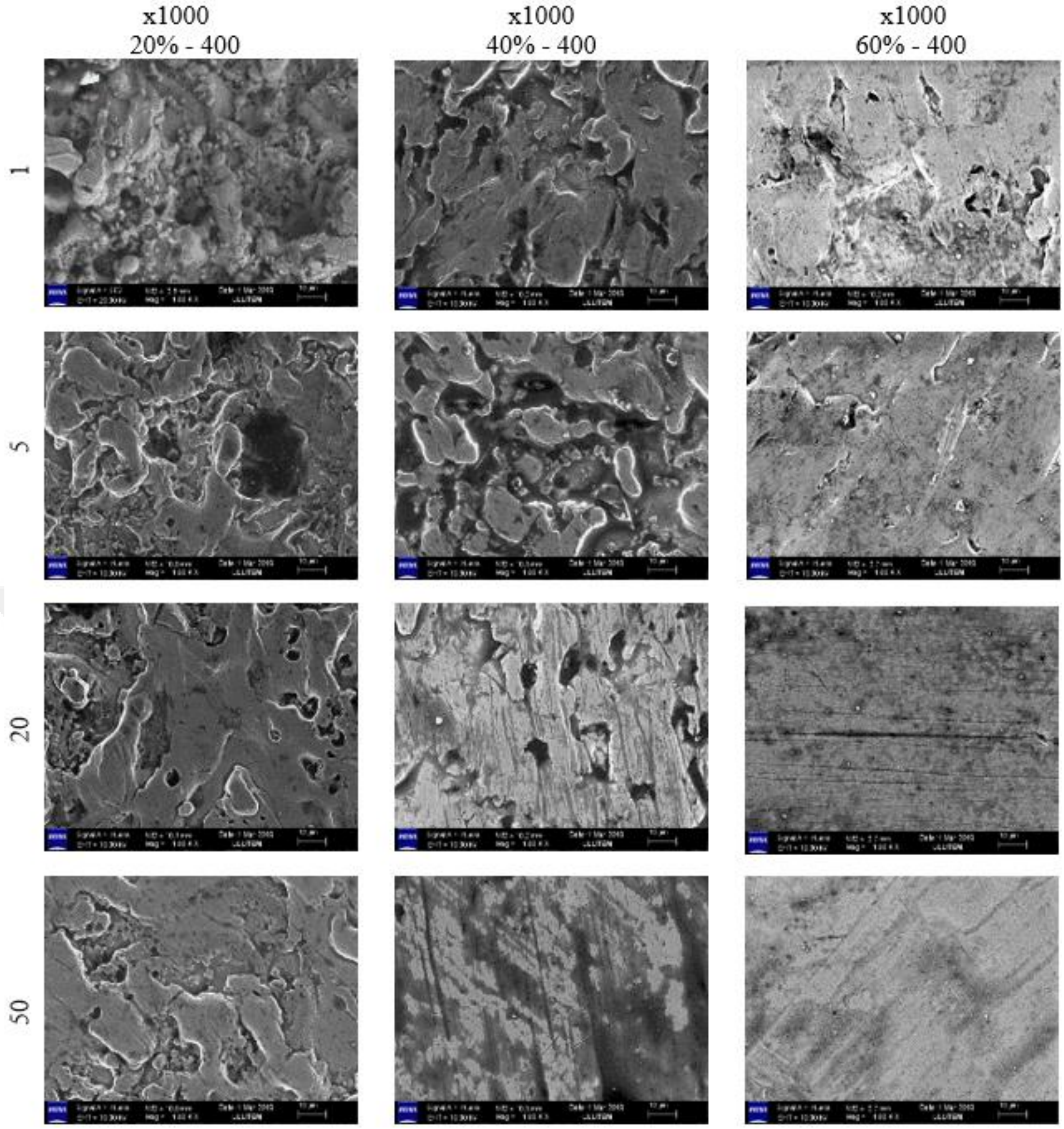


Figure 5.25 400 mesh; 20%, 40%, 60% abrasive; SEM images of Inconel (x1000)

In SEM images taken with x1000 magnification, it is more apparent that the white layer on the Inconel 718 surface has been removed in studies with media containing 60% abrasive. On the other hand, in studies with media containing 60% abrasive, non-very deep abrasive marks were observed on the surface of samples which run at 20 and 50 cycles.

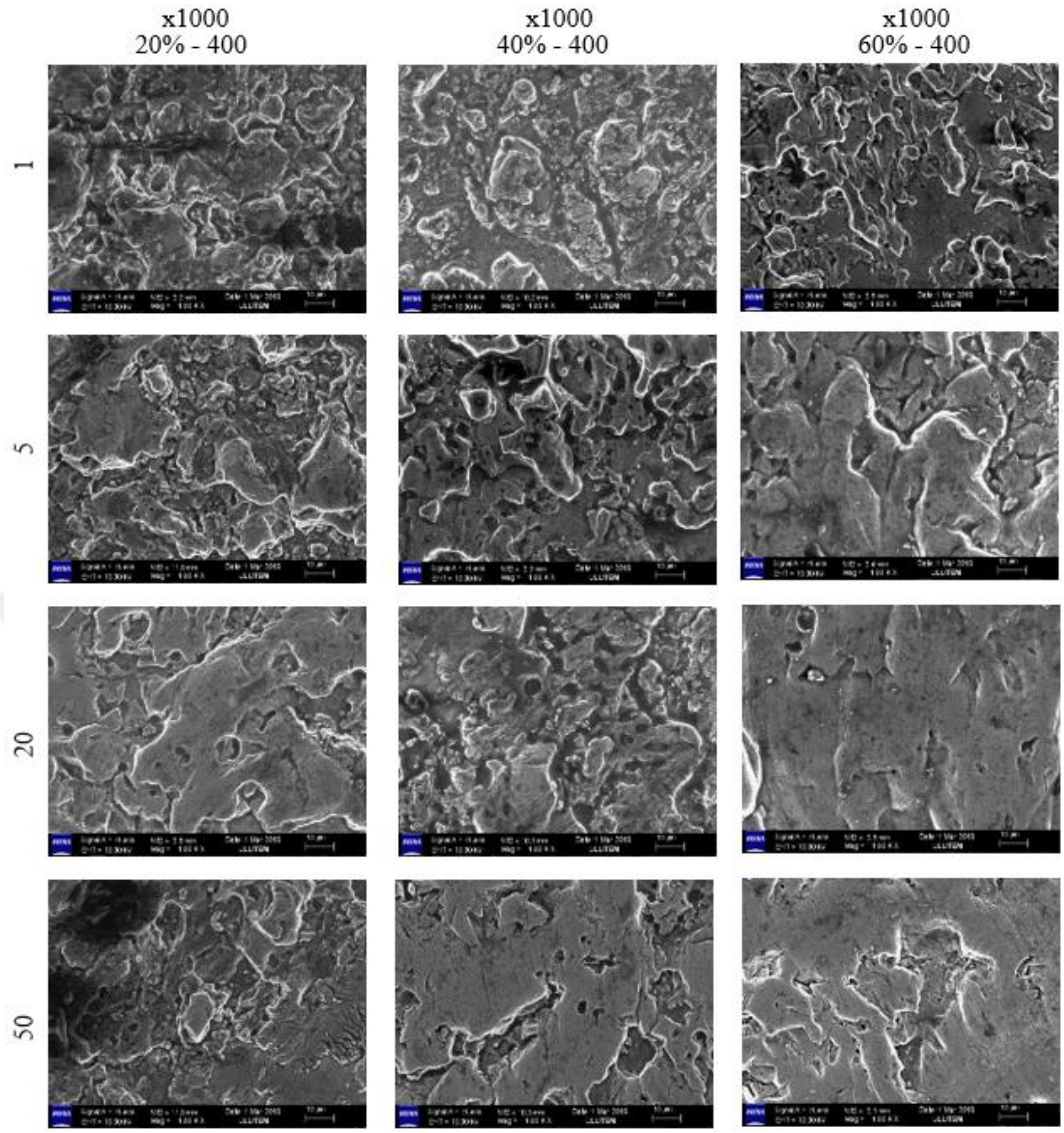


Figure 5.26 400 mesh; 20%, 40%, 60% abrasive; SEM images of Ti-6Al-4V (x1000)

After the experiments with the media which were prepared using 240 abrasive mesh size, the SEM images taken from Ti-6Al-4V and Inconel 718 surfaces are given between Figure 5.27 and Figure 5.30. In the AFM operations made using media which prepared with 240 abrasive mesh size, as the abrasive concentration increased, the white layer was removed in fewer cycles. According to the samples used in the experiments effectuated with 400 abrasive mesh size, better surface quality was obtained than the samples used in this mesh size.

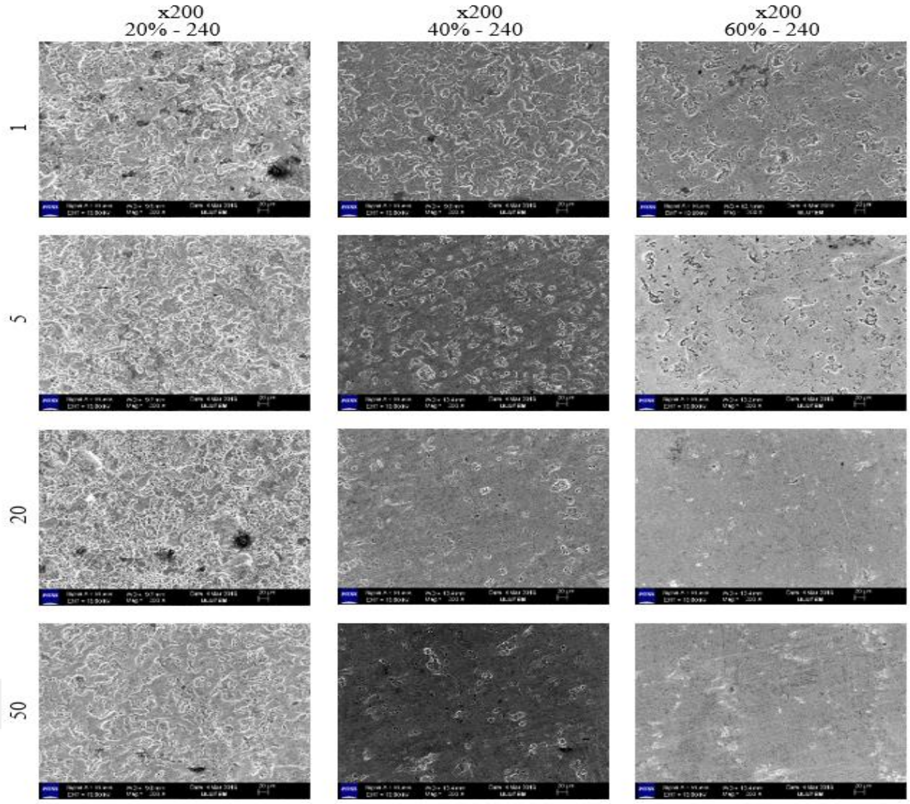


Figure 5.27 240 mesh; 20%, 40%, 60% abrasive; SEM images of Inconel (x200)

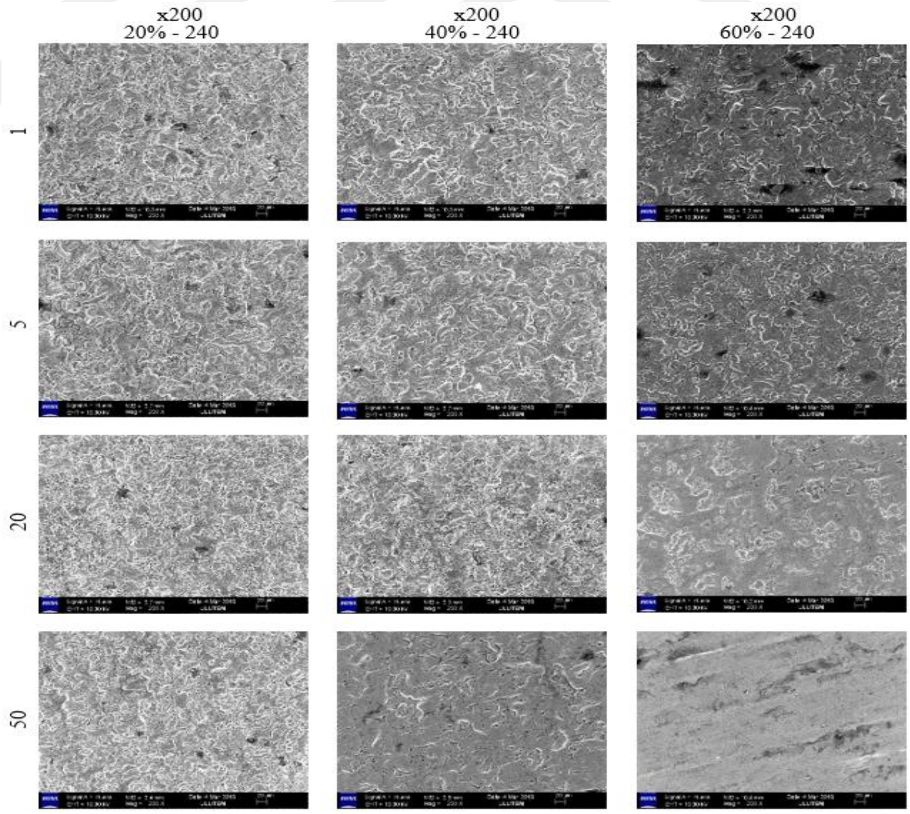


Figure 5.28 240 mesh; 20%, 40%, 60% abrasive; SEM images of Ti-6Al-4V (x200)

Compared to experiments with media containing 400 abrasive mesh size, better surface quality was accomplished in fewer cycle numbers in studies with media 240 abrasive mesh size, as shown in Figure 5.29. The media which 20% abrasive ratio 240 abrasive mesh size has also not been effective despite the increasing number of cycles in removing the white layer.

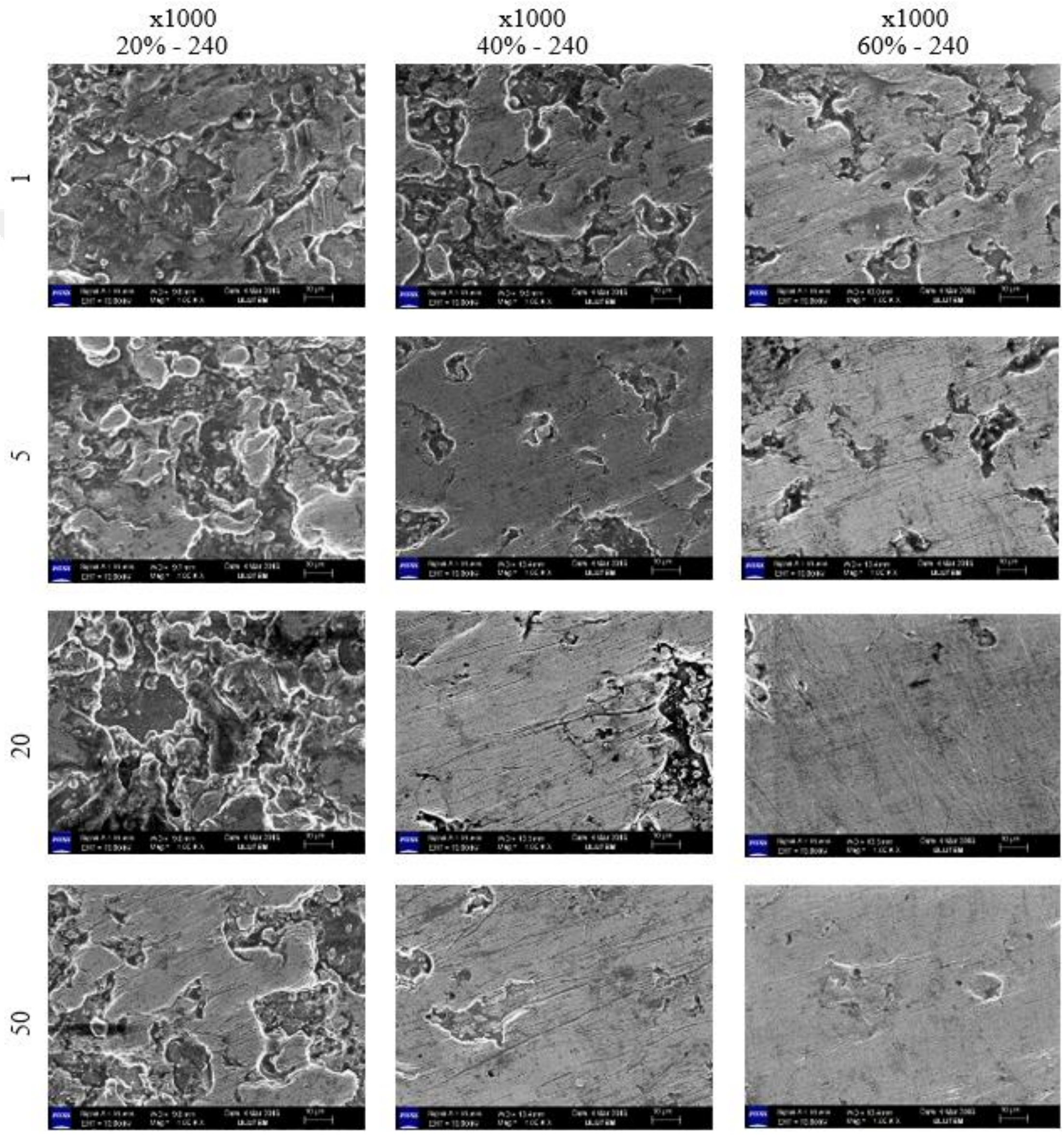


Figure 5.29 240 mesh; 20%, 40%, 60% abrasive; SEM images of Inconel (x1000)

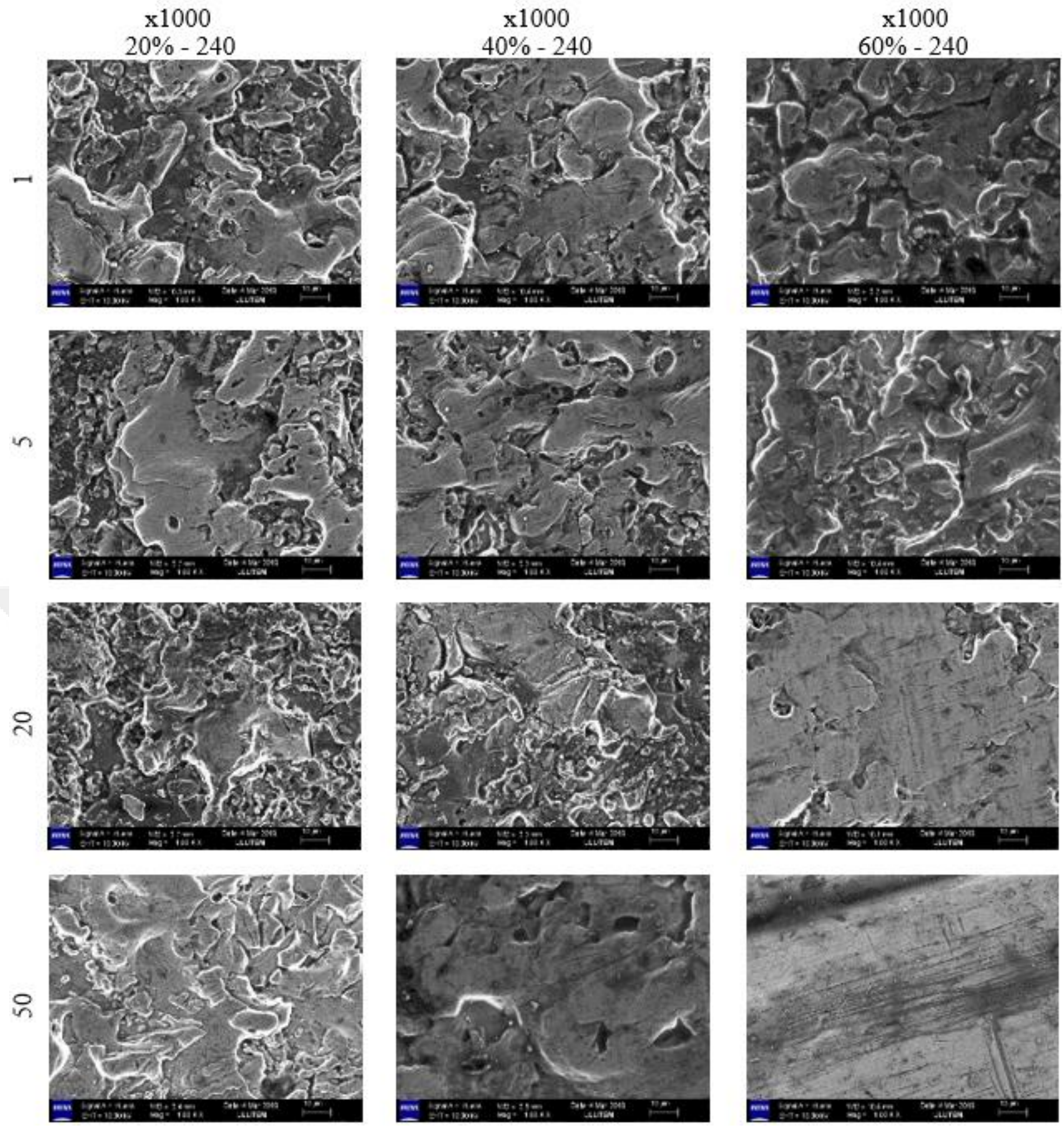


Figure 5.30 240 mesh; 20%, 40%, 60% abrasive; SEM images of Ti-6Al-4V (x1000)

The best results were obtained in experiments with media prepared with 180 mesh size. In the experiments effectuated with low abrasive concentration, such as in other abrasive mesh sizes, the desired results could be obtained with more cycle numbers, the white layer has been removed in less time with the increase in abrasive concentration. Especially in the experiments with media containing 60% abrasive concentration, traces of abrasive were observed. After the experiments with the media which were prepared using 180 abrasive mesh size, the SEM images taken from Ti-6Al-4V and Inconel 718 surfaces are given between Figure 5.31 and Figure 5.34.

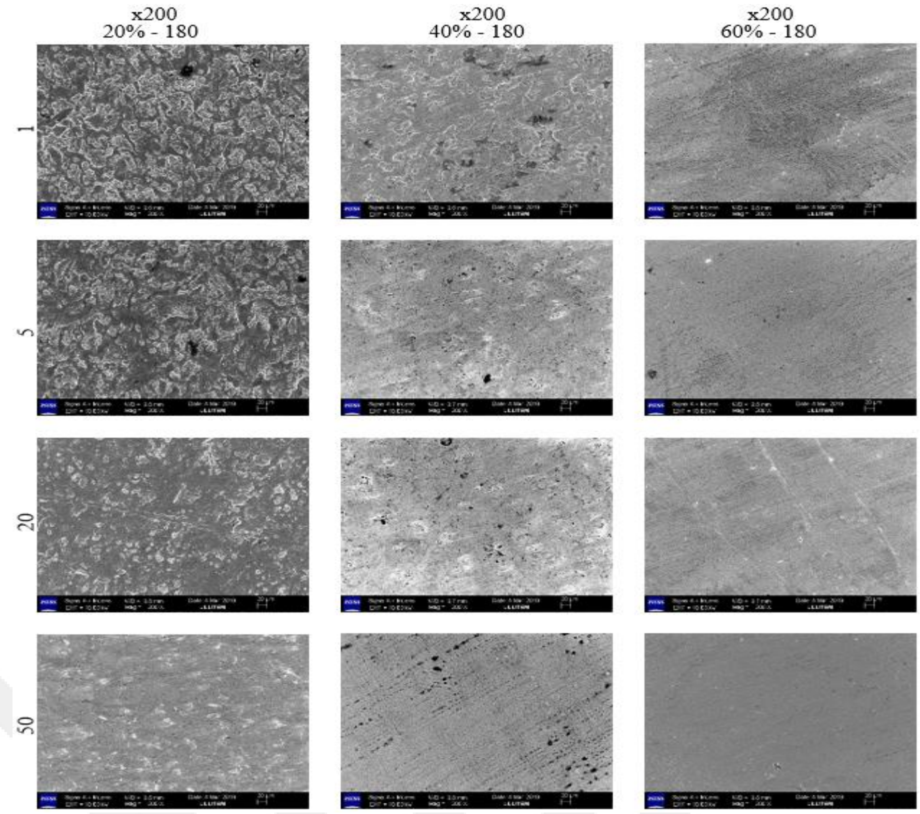


Figure 5.31 180 mesh; 20%, 40%, 60% abrasive; SEM images of Inconel (x200)

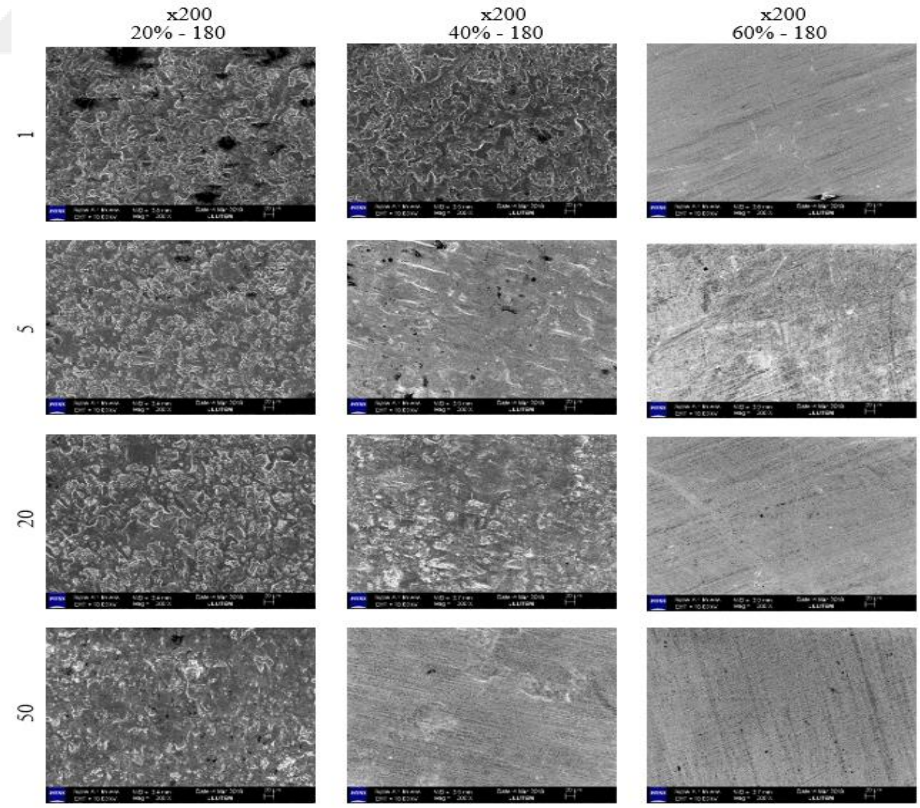


Figure 5.32 180 mesh; 20%, 40%, 60% abrasive; SEM images of Ti-6Al-4V (x200)

Studies with media containing 180 abrasive mesh size showed that white layer was quickly removed even at 20% abrasive concentration. In experiments with 40% abrasive media, abrasive marks were found in later cycles. In studies with a 60% abrasive concentration, it was observed that the white layer was removed from the first cycle and the abrasive marks were observed more prominently.

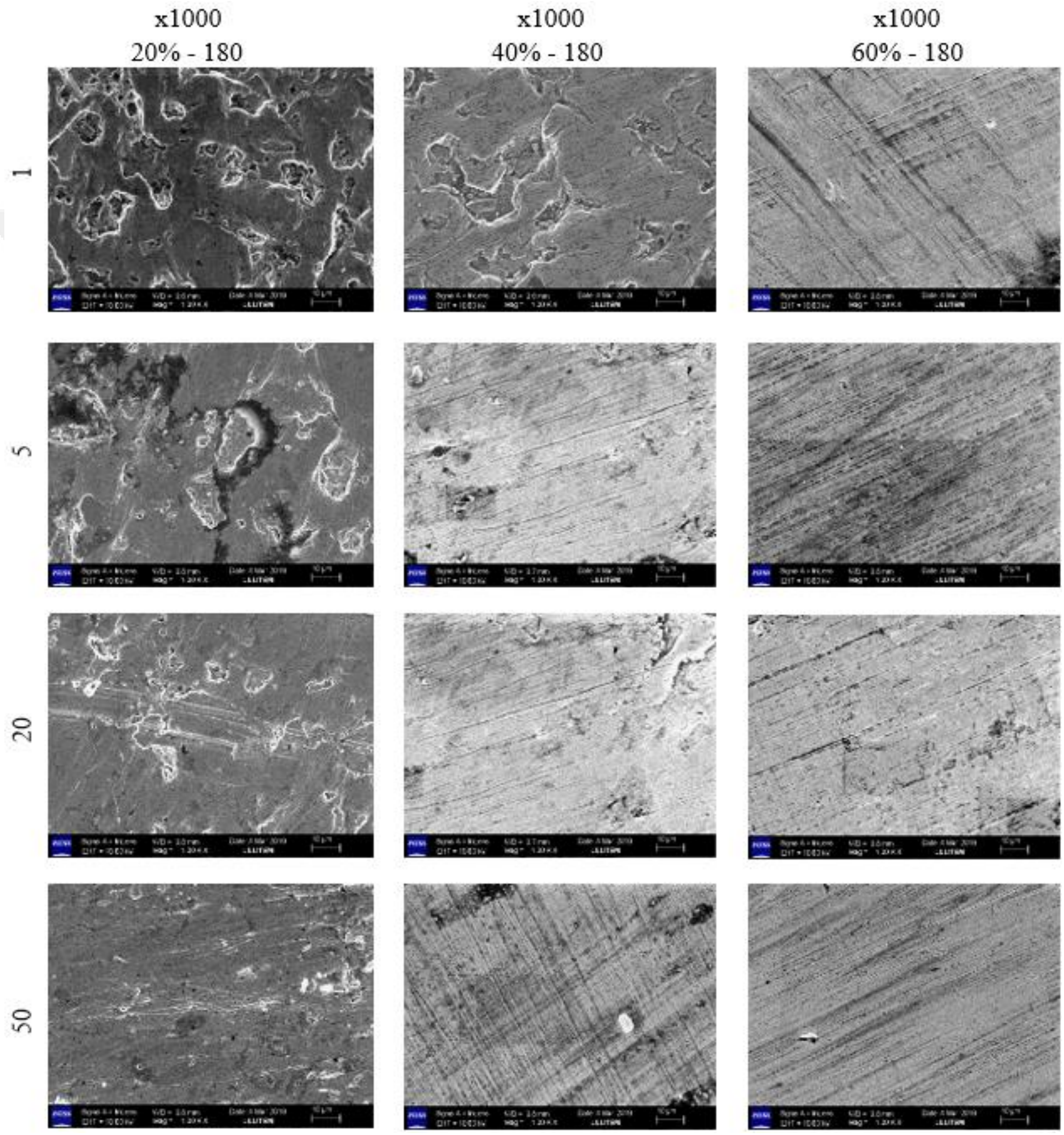


Figure 5.33 180 mesh; 20%, 40%, 60% abrasive; SEM images of Inconel (x1000)

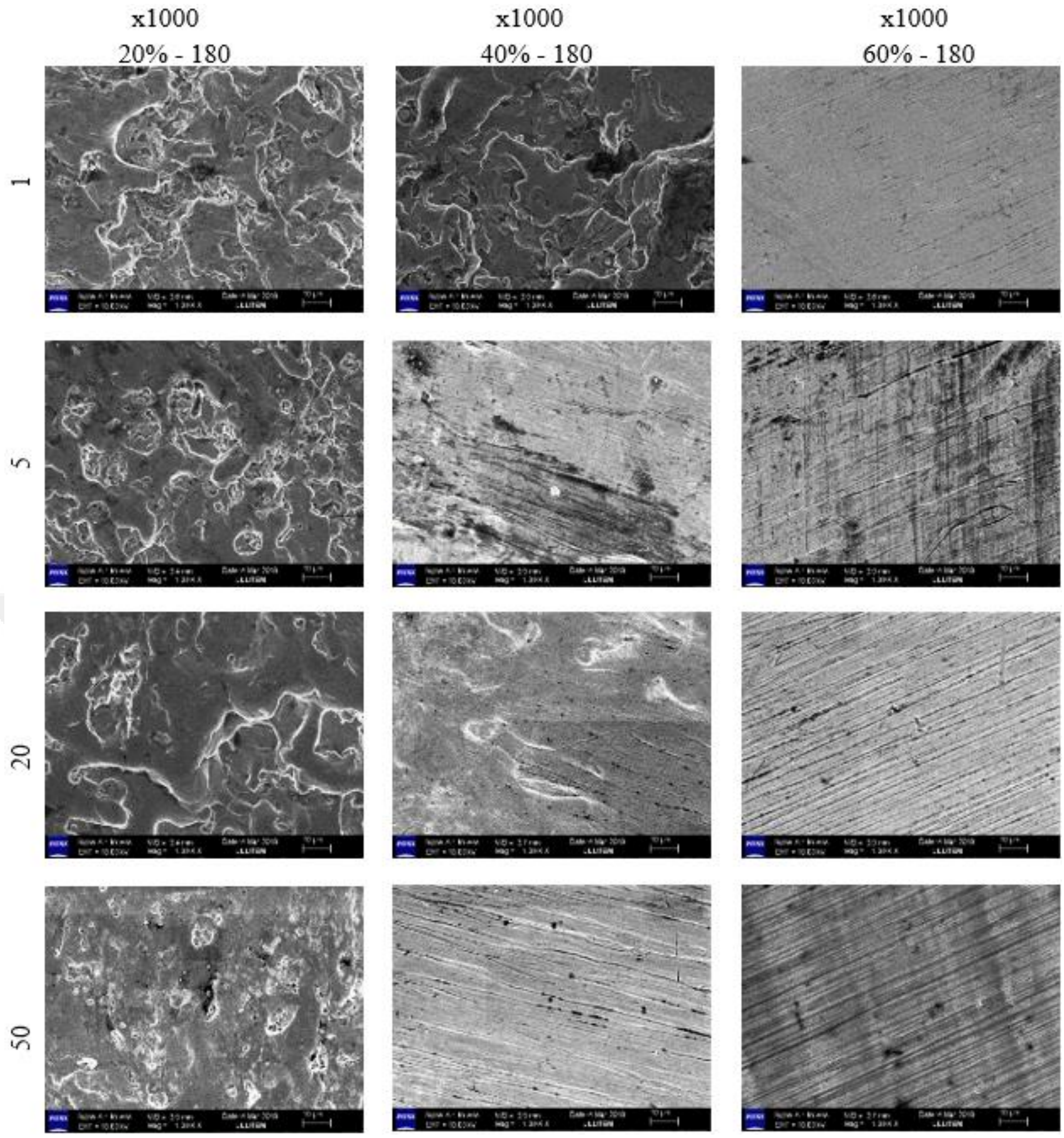


Figure 5.34 180 mesh; 20%, 40%, 60% abrasive; SEM images of Ti-6Al-4V (x1000)

As with the Inconel 718 surfaces, abrasive marks were found in SEM images taken from Ti-6Al-4V samples. These abrasive marks were found to be more on the Ti-6Al-4V surfaces.

Compared to abrasive mesh sizes, the best result is 180 abrasive mesh size. In experiments with media containing 60% abrasive, more successful results were obtained in a shorter time compared to all other mesh sizes.

Figure 5.35 shows that there are deep scratches on the surface of Ti-6Al-4V in 180 abrasive mesh size and 60% abrasive concentration. The formation of these scratches causes abrasive particles in the media.

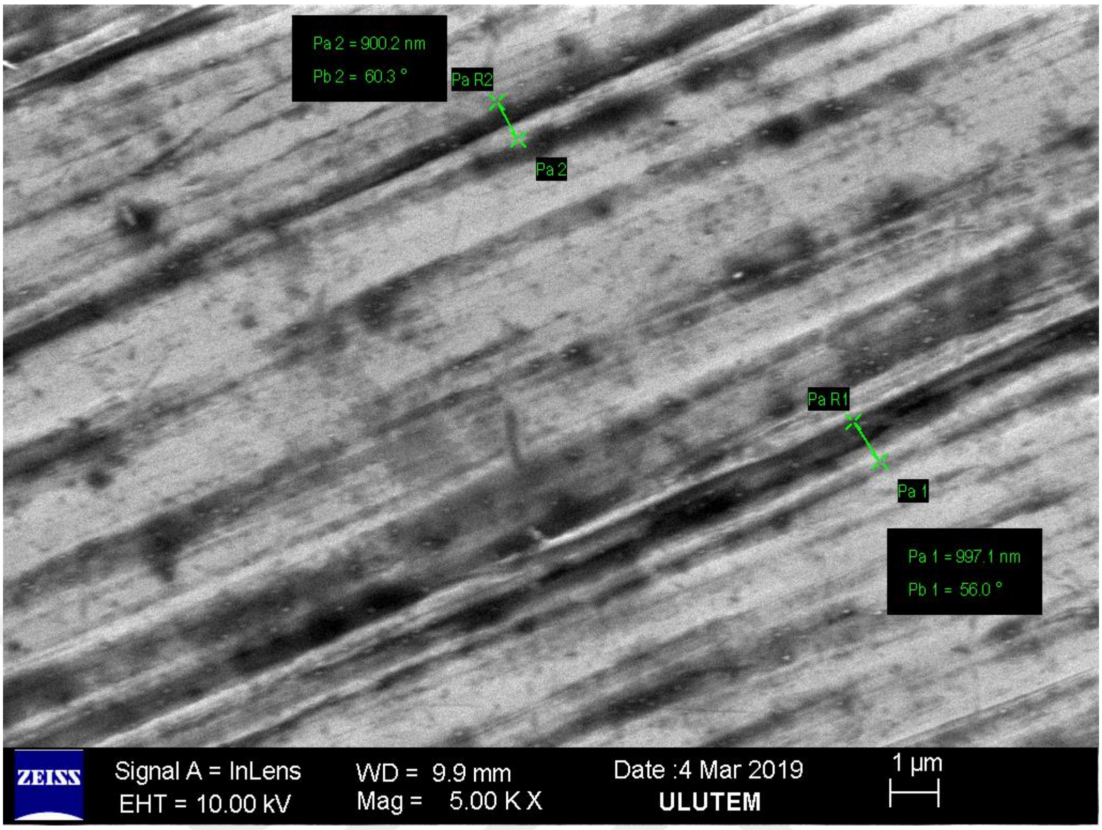


Figure 5.35 Scratches formed on the surface of Ti-6Al-4V

5.2.4 White Layer

Figure 5.36 and Figure 5.37 show the sample surface which has not applied AFM process and the sample surface which has applied AFM process. The white part seen in the images shows the inefficient white layer. This makes the white layer more understandable. The images were taken from the Inconel 718 and Ti-6Al-4V surfaces. The obtained images were taken in the 5 cycles, the number of workpieces treated with abrasive media prepared using 180 abrasive mesh size and 60% abrasive concentration.

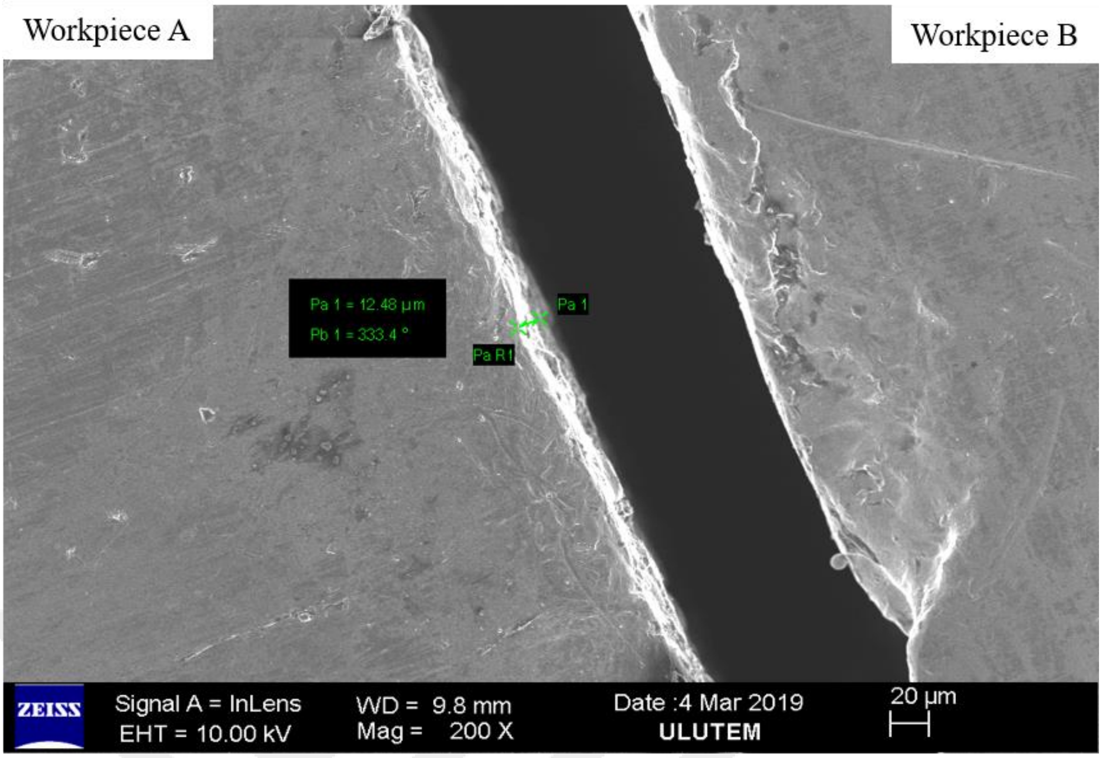


Figure 5.36 White layer appearance on Inconel surface

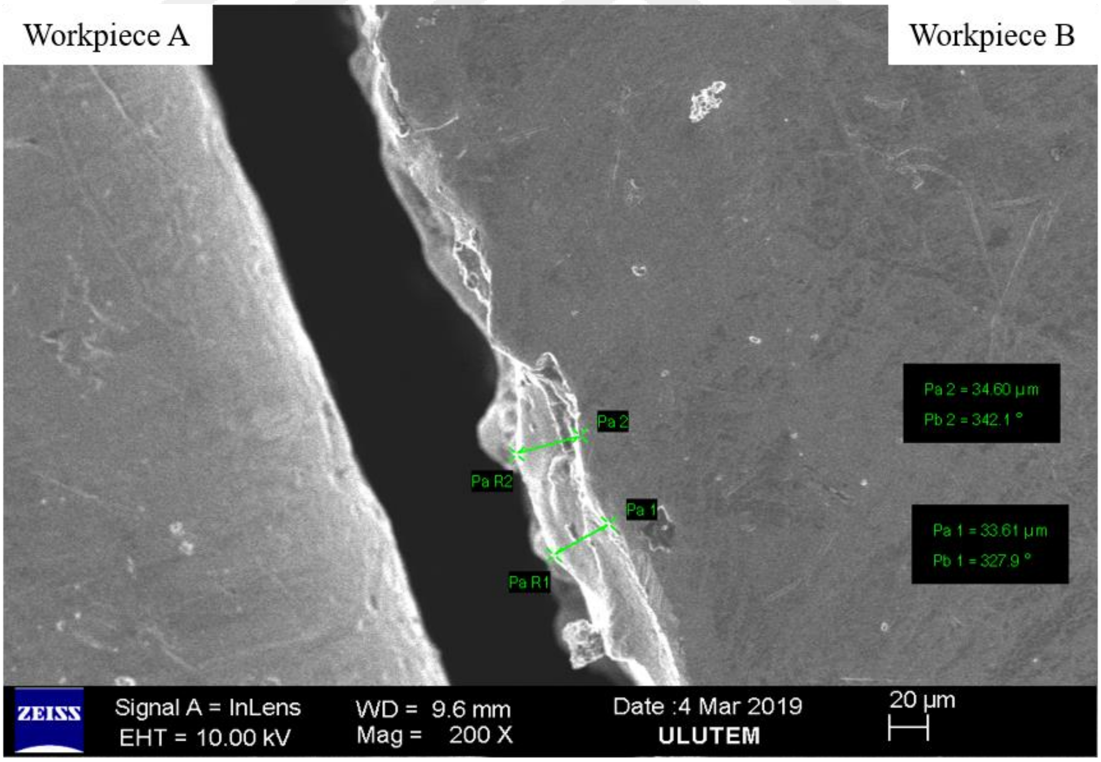


Figure 5.37 White layer appearance on Ti-6Al-4V surface

CHAPTER 6

CONCLUSIONS AND FUTURE WORKS

6.1 Conclusions

In this thesis, the AFM method was applied to Ti-6Al-4V and Inconel 718 WEDM surfaces which are frequently used in aviation materials. The number of cycles, abrasive mesh size, and abrasive concentration were determined as input parameters in the experiments. Surface roughness and material removal rate were measured as output values and SEM images of workpieces were taken. The followings have been concluded from the experimental results;

- The desired good surface quality is obtained after the AFM process.
- As the number of cycle increases, the surface roughness value declines. This decline is in a nonlinear form. This is due to the peaks in the EDM surface structure. These peaks begin to be removed in the first cycles.
- Increased abrasive concentration increases the material removal rate. The surface roughness values measured from the workpieces are reduced. However, the processing time must be well adjusted because it removes more material. Since, when working with a high abrasive ratio in high cycle numbers, abrasive scars were seen on the surface.
- The decline in abrasive mesh size increases the material removal rate. Therefore, the surface roughness value is reduced faster in the lower abrasive mesh size, i.e. in the larger grit size. Therefore, the process time should be determined by considering the abrasive mesh size.
- During the WEDM process, a white layer is formed on the material surface. This layer does not carry the basic mechanical properties of the material. For this reason, this layer is not desired on the surface. This white layer was removed as a result of the studies by applying the AFM operation.
- Compared to the Ti-6Al-4V and Inconel 718 surfaces used in the experiments, the surface roughness value in the Inconel 718 is less. At the

same time, the material removal rate from Inconel 718 is higher than Ti-6Al-4V.

6.2 Future Works

The following may be recommended for the future researches:

- The combinations of the AFM parameters appropriate to the materials commonly used in the aviation industry, such as Inconel 718 and Ti-6Al-4V, should be further investigated.
- The life and economic effects of the abrasive media used can be evaluated.
- The effects of application to complex components can be examined.
- Simulations of the AFM process can be developed. Thus, the deficiencies in the application can be understood more easily.

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