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Research Paper / Makale

Surface Finishing of Aerospace Materials

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Abstract: Abrasive flow machining is a non-traditional production method applied to complex surfaces. It is a very useful method to achieve good surface quality which is very important nowadays. Especially, it is desired that the surface quality of materials with high corrosion and high heat resistance used in aviation and automotive industry is good. In this paper, the effects of abrasive flow machining (AFM) technique on the surface quality of material such as Ti-6Al-4V, especially used in the aerospace industry, have been observed. Taguchi method was used to see appropriate parameters and noise factors. The surface roughness values (R_a), material removal rate (MRR) were measured and the white layer formed by high heat during cutting was removed in the high cycle numbers. Wire electrical discharge machining (Wire EDM) process the white layer formed during cutting and corrected by the AFM technique is an undesirable layer on the material surface. Experiments were carried out by changing the abrasive concentration and abrasive mesh size in this abrasive media. The number of cycles was increased, and experiments were continued with up to 50 cycles. The best surface quality values were achieved in experiments using 180 abrasive grain size and 60% abrasive concentration. The surface roughness (R_a) values, material removal rate (MRR) were measured and the white layer formed by high heat during cutting was removed in the high process cycles.

Keywords: Abrasive flow machining, aerospace materials, surface roughness, material removal

Havacılık Malzemelerinin Yüzey İşlemesi

Özet: Aşındırıcı akış işleme, karmaşık yüzeylere uygulanan geleneksel olmayan bir üretim yöntemidir. Günümüzde çok önemli olan iyi yüzey kalitesi elde etmek için çok yararlı bir yöntemdir. Özellikle Havacılık ve otomotiv endüstrisinde kullanılan yüksek korozyon ve yüksek ısı direncine sahip malzemelerin yüzey kalitesinin iyi olması arzu edilmektedir. Bu yazıda, aşındırıcı akış işleme (AMİ) tekniğinin, özellikle havacılık endüstrisinde kullanılan Ti-6Al-4V gibi malzemelerin yüzey kalitesi üzerindeki etkileri gözlenmiştir. Uygun parametreleri ve gürültü faktörlerini görmek için Taguchi yöntemi kullanıldı. Yüzey pürüzlülüğü değerleri (R_a), malzeme kaldırma oranı (MKO) ölçüldü ve kesme sırasında yüksek ısıdan oluşan beyaz tabaka yüksek devir sayılarında çıkarıldı. Elektriksel tel erozyon ile kesme (Tel EDM) işlemi sırasında oluşan ve AFM tekniği ile düzeltilen beyaz tabaka, malzeme yüzeyinde istenmeyen bir tabakadır. Deneyler, bu aşındırıcı macundaki, aşındırıcı konsantrasyon ve aşındırıcı ağ boyutunu değiştirerek gerçekleştirildi. Döngü sayısı arttırıldı ve deneyler 50 döngüye kadar devam etti. En iyi yüzey kalitesi değerleri, 180 aşındırıcı tane boyutu ve %60 aşındırıcı konsantrasyon kullanılarak yapılan deneylerde elde edilmiştir. Yüzey pürüzlülüğü (R_a) değerleri, malzeme kaldırma oranı (MKO) ölçüldü ve kesme sırasında yüksek ısıdan oluşan beyaz tabaka yüksek döngü sayılarında çıkarıldı.

Anahtar Kelimeler: Aşındırıcı macunla işleme, havacılık malzemeleri, yüzey pürüzlülüğü, malzeme kaldırma

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1. Introduction

Surface finishing operations are the most costly operations in the manufacturing sector. Besides being costly, it is also a long time-consuming process. In addition, the parts used in industry have taken an increasingly complex shape, and traditional methods of processing the surfaces of these parts are insufficient. New methods are being developed to save time and reduce costs. Abrasive Flow Machining (AFM) is one of these newly developed methods.

Abrasive Flow Machining was developed by Extrude Hone Corporation in the 1960s [1]. Nowadays, needs have changed with the developing technology. Especially in the medical, automotive, and aerospace industries, the surface quality of the increasingly complex parts is desired to be excellent. The AFM method is a suitable method for improving the surface quality of complicated shaped workpieces [2]. It is a very convenient method to use to improve the quality of hard-to-reach surfaces [3]. Surface quality of aerospace components is important for fuel savings [4].

Kumar and Hiremath [5] applied the AFM method to complex shaped components with different abrasive types. The parameters used in the AFM method and the surface of the part used affect the decrease in surface roughness values (R_a) [6]. Rhoades [7] also stated that the previous surface quality of the workpiece was important while achieving the desired surface quality.

Abrasive media is the most important parameter in the AFM process [8]. it is stated that it is difficult to determine parameters such as the type and amount of abrasives to be used in the media prior to application in the AFM process [9]. AFM processing has been applied to parts used especially in automotive and aviation, with different abrasive ratios and mesh sizes and variable cycle numbers [10]. When the AFM parameters were examined, the improvement in surface roughness values decreased as the abrasive concentration decreased [11].

During the Electrical Discharge Machining (EDM) process, a very hard layer forms on the surface of the part being studied [12]. This unproductive layer is called the white layer [13]. The amount of material reattached to the material surface during the EDM process affects the R_a values [14]. The type of cooling water used in the EDM process also affects the R_a value and it is stated that de-ionized water gives the best results [15].

The AFM method has been proposed to improve the surface quality of workpieces prepared with Wire EDM [16]. Göv and Eyercioğlu [17] applied the AFM method to the Ti-6Al-4V workpiece produced by the EDM method with abrasive media prepared using SiC and stated that the inefficient layer had been removed. Göv and Eyercioğlu [18] also applied different types of abrasives to the surfaces of samples prepared with the Wire EDM method and stated that the undesirable layer was removed more quickly using SiC and B_4C (Boron carbide).

The AFM method uses various methods to determine the parameters, and the Taguchi method is one of these methods [19]. Ibrahim [20] used the Minitab program to estimate the amount of material removal.

The analysis programs, which have become widespread with the developing technology, are also used for the AFM method. Seifu et al. used ANSYS FLUENT to work on the amount of material removal in the AFM method [21].

In this study, improvement of surface quality by applying the AFM method to Ti-6Al-4V workpiece commonly used in aviation sector was studied experimentally. However, the process parameters; abrasive mesh size, abrasive concentration, number of cycles and changing the type of abrasive, output parameters; material removal rate, surface roughness value and SEM images, were studied experimentally and the results of the effects outlined.

2. Material and Methods

2.1. Abrasive Flow Machine

In this study, two-way AFM machine was used. The machine has three units; the hydraulic system, the workpiece holder, and the electronic controller. The hydraulic unit provides sufficient pressure. The number of cycles is determined by the control screen. In the two-way AFM machine, a cycle starts with the upward movement of the lower and upper pistons at the lowest level, and one cycle is obtained by returning to their former position. Depending on the speed of the pistons, the time is measured as two minutes for one cycle in this experiment. There is also a holder for placing work pieces to be used in experiments. With this holder, the desired surface of the workpiece can be processed. Figure 1 shows the Two-way AFM machine used in the studies and located within the University of Gaziantep.

Figure 1. Two-way abrasive flow machine

2.2. Workpiece Material

Ti-6Al-4V sample to be used in the experiment were cut by using Wire EDM of 5x10x20 dimensions. The R_a values of each samples to be used were measured and all of weights were recorded. So, the MRR was calculated. Figure 2 shows a picture of the workpieces used in the studies.

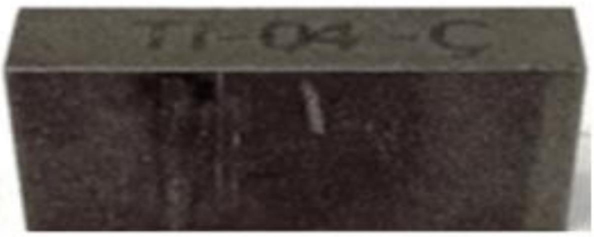

Figure 2. Workpiece Ti-6Al-4V

2.3. Abrasive Media

400, 240, and 180 mesh sizes of SiC and 20%, 40%, and 60% polymer based abrasive media is prepared for use and 1,3,5,10,20, and 50 cycle numbers have been studied in this study. One of the prepared abrasive medias is shown in Figure 3.

Figure 3. Polymer-based abrasive media

2.4. Design of Experiment

With using DOE method, the quantity of test to be done in normal condition was reduced considerably, thus diminished the workload, which can obtain more test results in a short time with less experiment. In this case, it was decided to use Taguchi method as experimental design (Table 1).

Table 1. Determination of parameters by Taguchi method

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

Taguchi method focus on the design to the development of superior performance, designs to deliver quality in comparison with statistical process control, which tries to control the factors that unfavourably affect the quality of product. 4 factors and 3 level were defined for process parameters of A, B, C, D and level 1, 2, 3 respectively as shown in (Table 1).

2.5. Experimental Procedure

The experiments were performed on surface of Ti-6Al-4V. The workpieces were placed in a suitable size holder. One side of the holder has an openness to influence the workpiece surface of the abrasive media. Hence, we can observe the effect of the abrasive media flowing from the surface of the workpieces and the previous version of the workpieces. Each sample was operated with the calculated concentration and mesh size of abrasive. Pre-weighed samples are weighed once more after the process by running Shimadzu Aux220 balance belonging to the University of Gaziantep. The surface roughness value was measured by using Mitutoyo SJ 401 machine belonging to the University of Gaziantep. The SEM images of the surfaces were taken by using Zeiss Gemini SEM 300.

3. Results and Discussion

3.1. Material Removal Rate

Each workpiece whose weights were previously measured with precision scales was also measured after AFM. In experiments where a cycle number lasted two minutes, post-processing numbers and weights of the samples executed in the desired cycles were recorded. So, we had all the values needed to determine the amount of material removed in the unit time shown in Equation 1 and were able to calculate the MRR. In Figure 4, graphs of experiments with media prepared in the size of 400 abrasive grains are given. 20%, 40%, 60% abrasive concentrations of three different media prepared by the results of the experiments were shown.

$$\mathrm{MRR} = \frac{\text{initial weight} - \text{final weight}}{\text{process time}} \left(\frac{\mathrm{mg}}{\mathrm{min}}\right) \qquad (1)$$

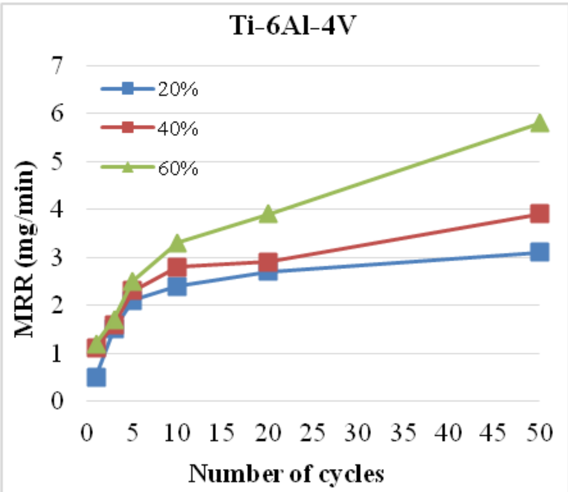

Figure 4. MRR of Ti-6Al-4V in 400 abrasive mesh size

The maximum material removal rate in the experiments using the Ti-6Al-4V sample was after the experiment using media with an abrasive concentration of 60%. A fast MRR has been observed from the twentieth to the fiftieth cycle.

Figure 5 shows the work done with the media prepared in 240 abrasive grain sizes. A graph of the values obtained from three different concentrations of abrasives is shown.

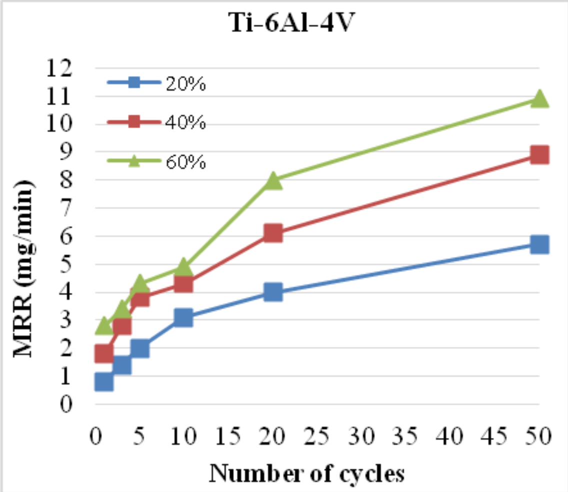

Figure 5. MRR of Ti-6Al-4V in 240 abrasive mesh size

MRR increased in studies with 240 abrasive grain sizes. For Ti-6Al-4V, up to 50 cycles of MRR at 60% abrasive concentration were observed to follow rapidly increasing course.
Figure 6 shows a graph of values taken in 180 abrasive grain sizes and three different abrasive concentrations.

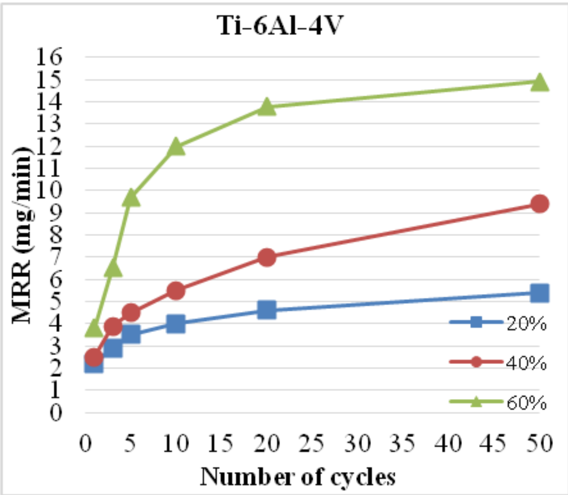

Figure 6. MRR of Ti-6Al-4V in 180 abrasive mesh size

After experiments with 180 abrasive mesh size, the maximum MRR was observed in this abrasive mesh size.

Experiments with media containing 60% abrasive for Ti-6Al-4V samples showed a fast MRR compared to other abrasive concentrations.

3.2. Surface Observations

Three R_a values were taken from the surface of Ti-6Al-4V samples. Three of these values were measured in the direction perpendicular to the flow and their averages were taken. Surface roughness graphics are formed with these obtained values.

As a result of the studies, the best surface quality of different media types was obtained with the media prepared with 180 abrasive mesh size and 60% abrasive concentration. Surface quality improves as values get closer to zero.
SEM images of samples used in the studies were taken. In the images taken, an inefficient layer called the white layer was observed after the EDM process. In experiments with different abrasive mesh sizes and abrasive concentrations, it was observed whether the white layer was removed.

3.2.1. Processed Surfaces With 400 Abrasive Mesh Size

Surface roughness values obtained after experiments with media prepared with three different abrasive concentrations and 400 abrasive mesh size are shown in Figure 7. The samples were run in cycle numbers 1, 3, 5, 10, 20, 50.

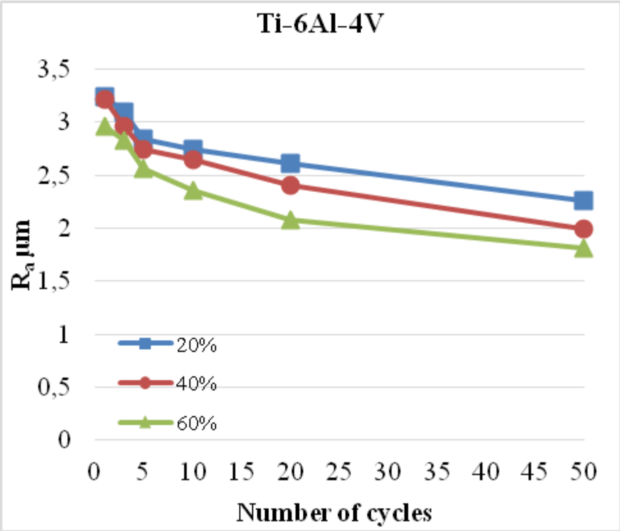

Figure 7. R_a perpendicular to flow of surfaces of Ti-6Al-4V

Surface roughness values decreased as a result of the values taken. Furthermore, the decrease in values relative to the different abrasive concentration followed a different course.

3.2.2. Processed Surfaces With 240 Abrasive Mesh Size

The graphic obtained from experiments with media prepared with 240 mesh size is shown in Figure 8.

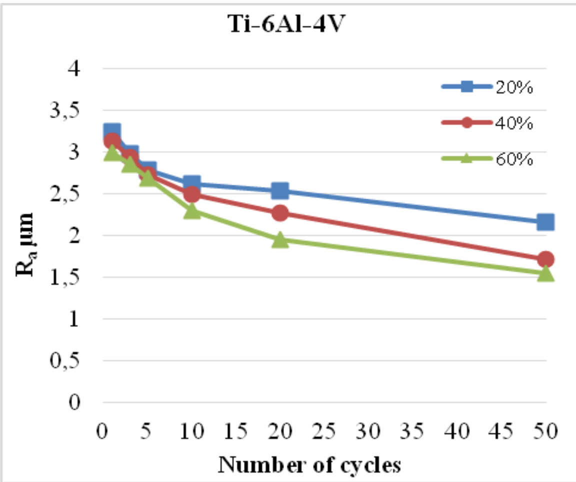

Figure 8. R_a perpendicular to flow of surfaces of Ti-6Al-4V

Better surface roughness values were obtained compared to experiments with 240 abrasive mesh size and 400 abrasive mesh size. Decreased R_a values were observed.

3.2.3. Processed Surfaces With 180 Abrasive Mesh Size

Figure 9 shows a graphic of R_a values taken from Ti-6Al-4V surfaces, where experiments were carried out with 180 abrasive mesh size.

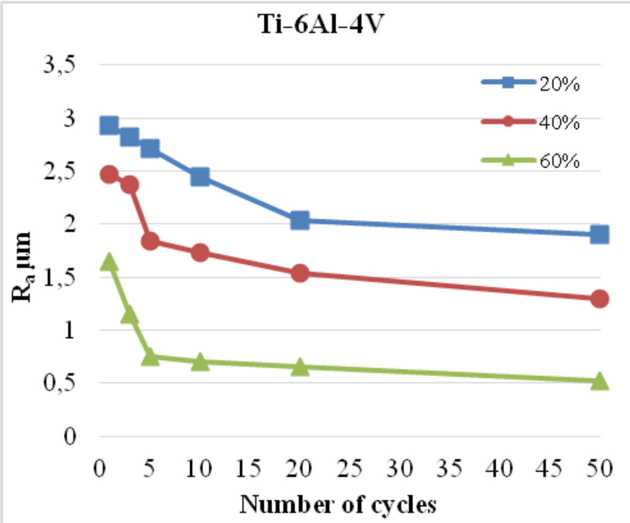

Figure 9. R_a perpendicular to flow of surfaces of Ti-6Al-4V

A rapid reduction in surface roughness values were observed as a result of the measurements. The best results were achieved in this abrasive mesh size compared to other abrasive mesh sizes. A rapid decrease in R_a values was observed in the first cycles at a rate of 60% abrasive. The lowest R_a values were measured. As with other abrasive mesh sizes, R_a values decreased with the increase in abrasive concentration and number of cycles.

In Figure 10, SEM images taken from sample surfaces after experiments with media prepared with 180 abrasive mesh size are given.

After experiments with the media prepared in 180 abrasive mesh size, the white layer on the surface of Ti-6Al-4V was considerably reduced. The unproductive layer was removed from the first cycle by increasing the abrasive concentration.20% abrasive concentration is insufficient for Ti-6Al-4V in this abrasive mesh size. However, at 40% and 60% abrasive concentrations, the white layer has been completely removed. In fact, traces of abrasives have been observed on the surface along with the increasing number of cycles.

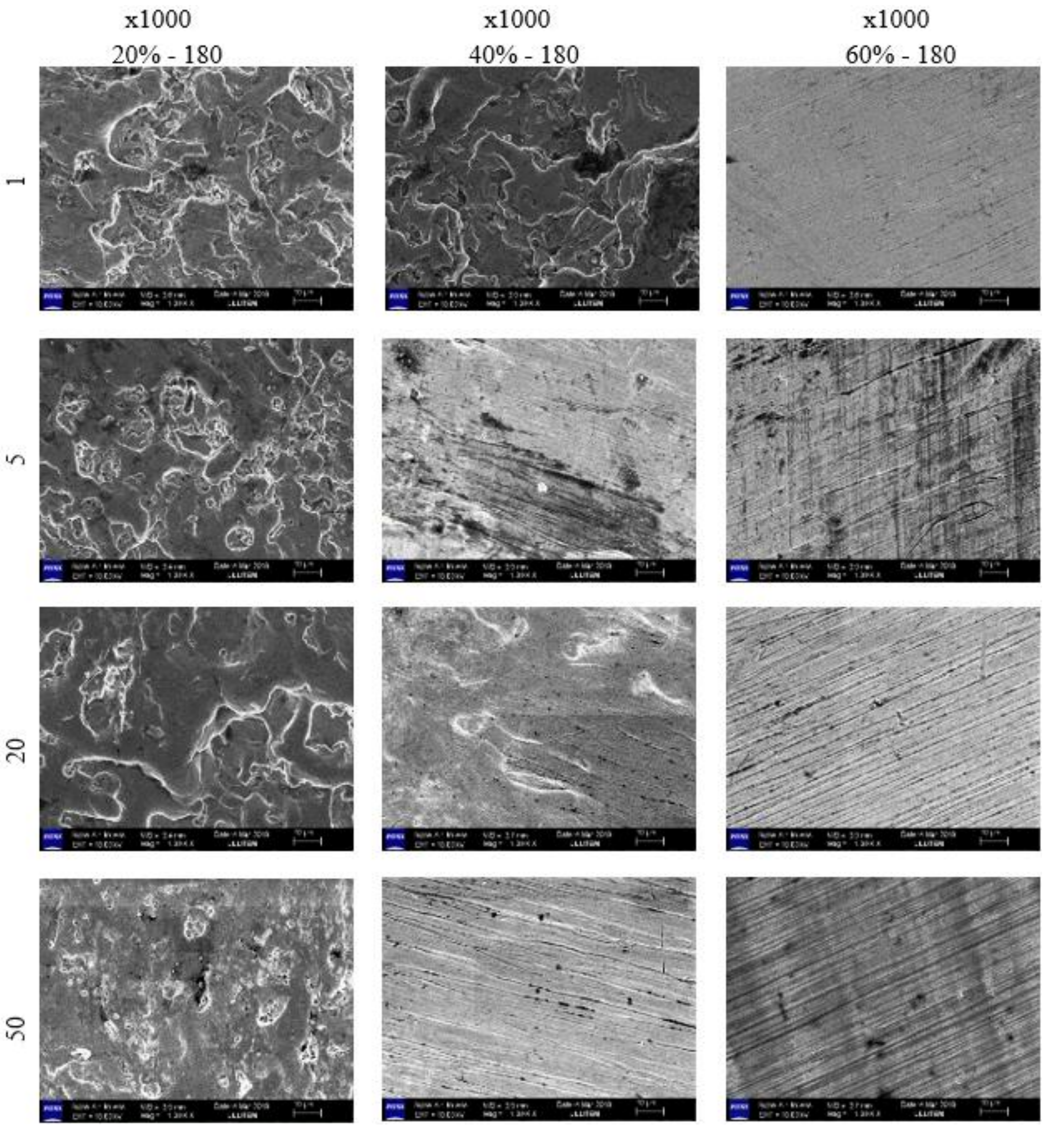

Figure 10. 180 mesh size; 20%, 40%, 60% concentration SEM images of Ti-6Al-4V after AFM

4. Conclusions

Ti-6Al-4V, type of material frequently used in the aerospace industry, was produced by wire EDM method while the inefficient layer formed on the surface was removed by applying the AFM method. In short, if we explain the matter:

1. As the number of cycles increases in the AFM process, the MRR increases, thus the inefficient layer is removed, the R_a value decreases, and consequently the surface quality increases.
2. As the abrasive concentration of the media used in the studies increased, the white layer was removed more quickly from workpiece surfaces.
3. With the reduction in abrasive mesh size, the MRR increased. The inefficient layer is removed in fewer cycle numbers.
4. The white layer was removed in the first cycles, both by increasing the abrasive concentration and by decreasing the abrasive mesh size.

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