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Reduction of Surface Roughness in Cold Forging Dies with Abrasive Flow Machining Method

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Abstract*— This study explores the enhancement of surface roughness in various types of dies—stepped, flat, and chamfered—used in fastener production through Abrasive Fluid Machining (AFM) technology. Unlike traditional hand polishing methods, AFM provides a faster and less skill-dependent alternative. Surface roughness values (Ra and Rz) for each die type were measured before and after the AFM process, and the impact of AFM on surface quality was assessed. The results demonstrated a significant reduction in surface roughness across all three die types. Notably, the stepped die exhibited reductions of up to 85.82% in Ra and 80.13% in Rz. The flat die showed a decrease in Ra and Rz values by 84.43% and 79.65%, respectively. Similarly, the chamfered die experienced reductions of 74.46% in Ra and 77.58% in Rz following the AFM process. These findings indicate that AFM is a highly effective method for improving the surface quality of fastener dies, thereby potentially extending their operational lifespan.

***Index Terms*— Cold Forging, Surface Roughness, Die, AFM.**

I. INTRODUCTION

Surface quality plays a vital role in industrial production, especially in the production of parts with precise and complex geometries [1]. This also applies to the fastener sector as well. During the process,these dies are continuously subjected to load and simultaneously experience abrasion damage. Figure 1 shows a visualization of a cold forging machine used for fastener production

Fig. 1. Cold Forging Machine [2]

Cold forging machines consist of multiple stations. The production stages vary according to the head, body shape, metric diameter and shaft length of the product produced The production stages vary depending on the product's head, body shape, metric diameter, and shaft length. The dies used in production must be sufficiently smooth in order to ensure the continuous passage of wires through them[2], [3]. A die with a high surface roughness can cause burrs, dimensional errors, and surface defects in the produced parts. Besides, rough surfaces can shorten die life by accelerating die wear rate[4].Therefore, minimizing die surface roughness during production is crucial, as it not only improves production efficiency but also enhances the quality of the final product.Surface quality is an important factor that directly affects the performance, durability, and aesthetics of the product. Surfaces subjected to contact experience continuous wear and deformation, leading to a progressive increase in surface roughness over time. A profilometer is employed to quantify surface roughness Among the evaluated surface parameters, Ra and Rz values are commonly utilized. Ra represents the average surface roughness, reflecting the variations in height across the surface. Rz denotes the maximum height of the profile [5][1].Abrasive Fluid Machining (AFM) is an advanced surface polishing technology that enhances surface quality and is capable of accessing complex geometries that are otherwiseunreachable by conventional methods[6]. The apparatus used for AFM is illustrated in Figure 2.

AFM holds great importance in the die-making industry due to its ability to extend the lifespan of dies, improve product quality, and reduce production costs. AFM involves the passage of a semi-solid mixture composed of a viscoelastic polymer and abrasive particles (abrasive fluid) under pressure across or through the surface of the part being machined. This process effectively removes accumulated debris and reduces surface roughness. AFM is particularly favored in the die-making industry because it offers several advantages, including access to complex internal surfaces, deburring, and polishing, allowing for multiple surface treatments in a single operation. One of the most notable advantages of AFM is its capability to reach intricate internal surfaces, corners, and transitions that are challenging or impossible to polish using conventional methods. Consequently, AFM significantly enhances the surface quality of dies used in the production of parts with complex geometries, such as fasteners[7].

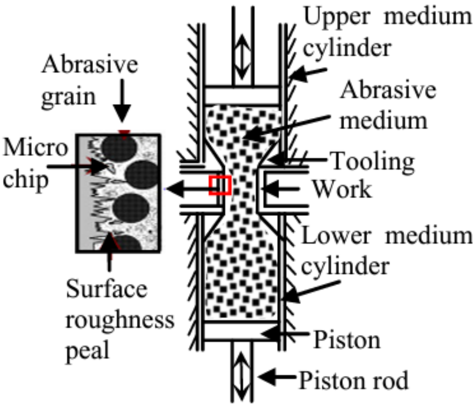


Fig. 2 Two-way AFM Machine [6]

II. MATERIALS AND METHODS

A. Die Preparation

Cold forging dies used in the fastener production are produced by machining methods. Typically, either a manual lathe or a CNC lathe is used for die fabrication, with materials such as steel or tungsten-carbide being preferred for applications requiring high strength and wear resistance. During the manufacturing process, these dies are subjected to high pressure and repeated impact loads. Die production generally involves a shell structure, consisting of an outer layer of 1.2344 steel and an inner core made of G55 tungsten carbide, which is produced by powder metallurgy. To join these two components, the steel barrel is first expanded through controlled heat treatment, allowing the G55 tungsten Cold forging dies used in the fastener production are produced by machining methods. Typically, either a manual lathe or a CNC lathe is used for die fabrication, with materials such as steel or tungsten-carbide being preferred for applications requiring high strength and wear resistance. During the manufacturing process, these dies are subjected to high pressure and repeated impact loads. Die production generally involves a shell structure, consisting of an outer layer of 1.2344 steel and an inner core made of G55 tungsten carbide, which is produced by powder metallurgy. To join these two components, the steel barrel is first expanded through controlled heat treatment, allowing the G55 tungsten carbide core to be inserted with a tight fit. This is followed by an oil cooling process to enhance the structural integrity and durability of the joint. Heat treatment procedures are crucial for extending the lifespan and optimizing the performance of dies. In this study, three different die patterns were used. The images of the dies—stepped die, flat die, and chamfer die—are shown in Figure 3, Figure 4, and Figure 5, respectively.

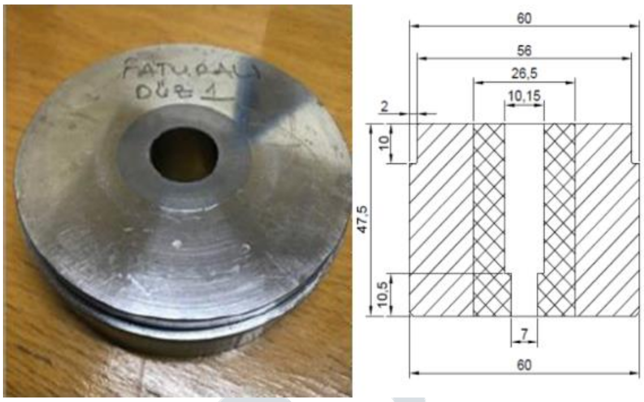


Fig. 3. Stepped Die

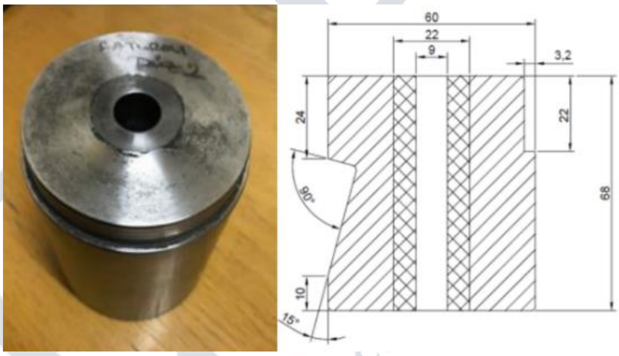


Fig. 4. Flat Die

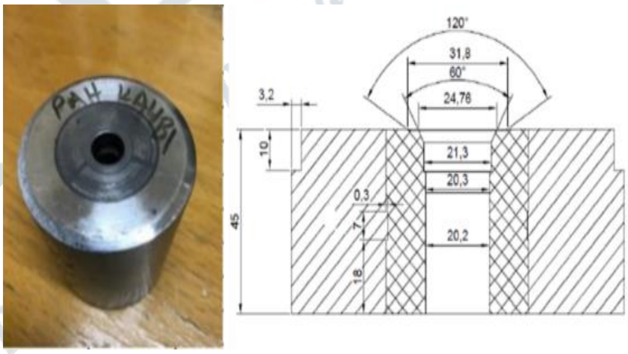


Fig. 5. Chamfer Die

B. AFM Machine

The AFM process is conducted using a specially designed machine capable of operating either unidirectionally or bidirectionally. In unidirectional machines, the abrasive fluid moves in a single direction, whereas in bidirectional machines, the fluid moves back and forth to polish the component surface more effectively.

In this study, a bidirectional AFM machine was utilized. These machines feature two hydraulic cylinders, between which the abrasive fluid is moved back and forth, applying pressure to the workpiece surface [11]. Before being attached to the machine, the dies are placed in a specially designed handle that not only secures the die but also aids in the homogeneous distribution of the abrasive fluid across the die surface [7]. The specifications of the AFM machine used in this study are presented in Table 1..

Table 1. AFM Machine Specifications

Specifications	Unit
Hydraulic Pressure	10-400 bar
Piston Capacity	6 Liter
Piston Operatin Length	400 mm
Piston Diameter	140 mm

Before initiating the experimental studies, Ra and Rz values of the dies intended for polishing were measured and recorded using a profilometer. The same surface roughness measurements were repeated after 20, 40 and 60 cycles of the AFM process and the effect of the AFM process on the surface quality was evaluated. The detailed experimental data are presented in the 'Experimental Results' section.

III. EXPERIMENTAL RESULTS

Separate graphs were produced for each die as a result of the experiments. Figure 6 and 7 illustrate the results obtained for the chamfer die.

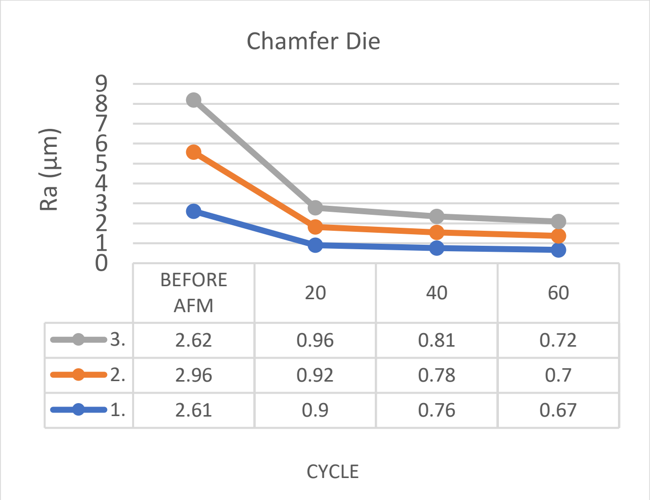


Fig. 6. Ra values of chamfer die before and after AFM

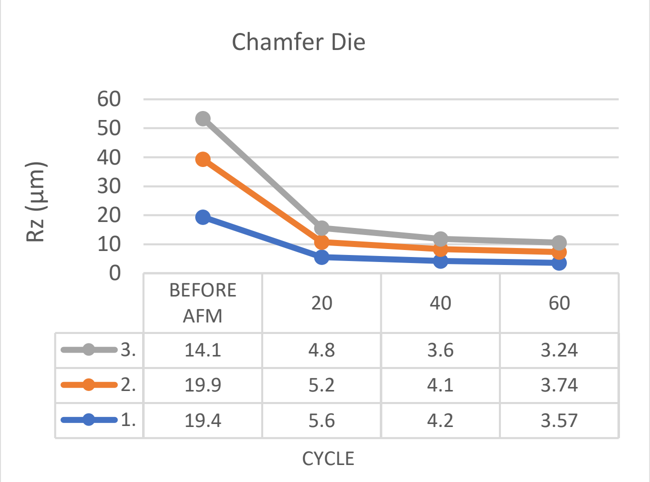


Fig. 7. Ra values of chamfer die before and after AFM

The experiments revealed that the AFM process significantly improved surface roughness. Notably, after 20 cycles, a substantial reduction in Ra and Rz values was observed compared to the pre-AFM measurements, indicating that AFM can markedly enhance surface quality even with short-term applications.

The precise entry zone at the end of the chamfer dies is critical for forming the chamfer portion of the fastener. Preserving the surface integrity of this region is essential for the quality of the manufactured part. In this study, a specialized holder was designed to regulate the abrasive fluid velocity in the precision entry zone of the chamfer dies. By reducing the entry speed of the abrasive paste, this holder mitigates potential deformation or damage to the chamfer structure caused by high flow rates, thereby maintaining surface quality during the AFM process. After 20 AFM cycles, the average roughness (Ra) value decreased by 66.03% and the maximum roughness depth (Rz) decreased by 70.27%. Continued improvements in surface roughness were observed with an increasing number of AFM cycles.

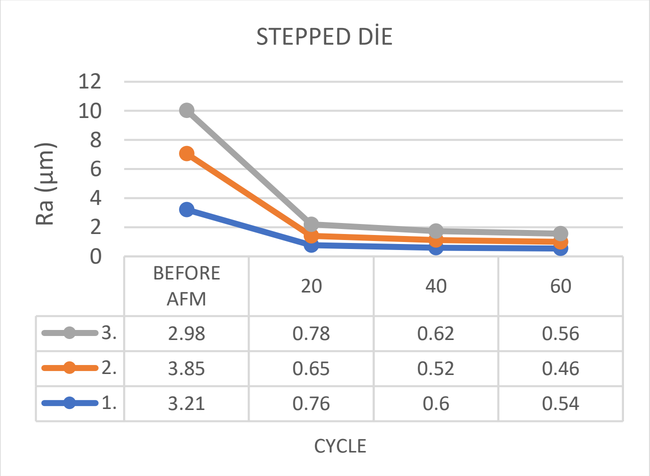


Fig. 8. Ra values of stepped die before and after AFM

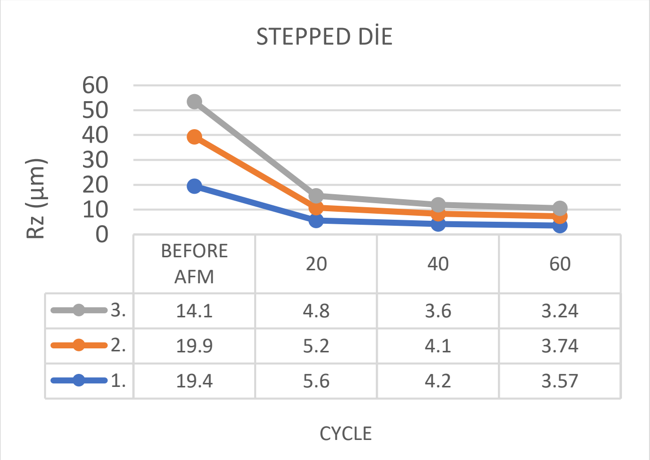
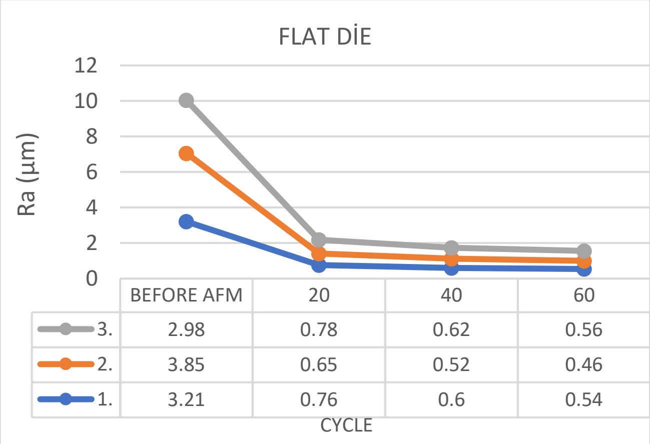


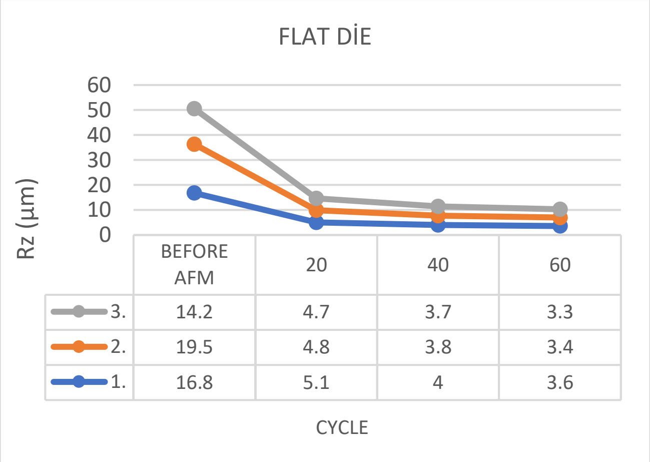
Fig. 9. Rz values of stepped die before and after AFM

When comparing the surface roughness values before and after AFM for the step die, it was noted that the reduction rates were higher compared to the chamfer die. This is attributed to the greater proportion of flat surfaces in the step die structure relative to the chamfer die, as the AFM process is more effective in reducing roughness on flat surfaces. Additionally, increasing the abrasive paste speed for the step die further enhanced the reduction in Ra and Rz values, with a 78.11% decrease in Ra and a 70.79% decrease in Rz after 20 AFM cycles. Figures 8 and 9 demonstrate that the increased flow rate led to more effective material removal due to improved abrasive particle contact with the surface.



	BEFORE AFM	20	40	60
3.	2.98	0.78	0.62	0.56
2.	3.85	0.65	0.52	0.46
1.	3.21	0.76	0.6	0.54

Fig. 10. Ra values of flat die before and after AFM



	BEFORE AFM	20	40	60
3.	14.2	4.7	3.7	3.3
2.	19.5	4.8	3.8	3.4
1.	16.8	5.1	4	3.6

Fig. 11. Rz values of flat die before and after AFM

The flat die structure, lacking any chamfer or radius, facilitated the most efficient passage of the abrasive paste. This configuration enhanced the effectiveness of the AFM process, leading to a significant improvement in surface quality. The high roughness reduction rates observed for the flat die compared to the other die types indicate that AFM is particularly effective on homogeneous and unobstructed surfaces. Figures 10 and 11 show that after 20 AFM cycles, the Ra value decreased by 78.13%, after 40 cycles by 82.65%, and after 60 cycles by 84.43%. In terms of Rz, reductions of 71.08% after 20 cycles, 77.25% after 40 cycles, and 79.65% after 60 cycles were observed.

IV. CONCLUSION

This study investigated the improvement of surface roughness for three different die types (step die, flat die, and chamfer die) used in fastener production through Abrasive Fluid Machining (AFM). The experimental results demonstrated that the AFM process significantly reduced surface roughness values (Ra and Rz) for all die types. Particularly after the initial 20 AFM cycles, all die types exhibited substantial improvements in surface roughness. Specifically, the Ra and Rz values decreased by 78.11% and 70.79%, respectively, for the step die; 78.13% and 71.08%, respectively, for the flat die; and 66.03% and 70.27%, respectively, for the chamfer die.

Although reductions in surface roughness continued as the number of cycles increased from 20 to 40 to 60, the rate of these reductions was less pronounced after the initial 20 cycles. This observation suggests that the early stages of the AFM process are characterized by rapid removal of large-scale surface roughness, while subsequent stages involve finer, more gradual polishing.

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