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Finishing of Multiple Components and Surface Characterization

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Abstract

Finishing of machined components before putting into actual work is very much essential to ensure their performance in the assembly as a whole, so the working of these components greatly depends on its surface qualities. Finishing operation represents a critical and expensive process in the overall manufacturing process. It consumes 15% of the overall manufacturing cost. One of the major drawbacks with the available finishing processes is restrictions to access the complex internal and external geometries. In the present investigation, an effort has been made to develop an experimental setup of abrasive flow finishing process to study the machinability of four different workpiece materials prepared using milling process. Aluminum, Brass, Copper and Mild Steel workpiece materials are selected in the present investigation and surface roughness is measured before finishing and after every three passes of the finishing process. Improvement in surface finish is observed as the number of passes of abrasive media increases. The overall effects of finishing process on different materials are discussed in the paper.

Keywords

Hydraulic Cylinder, Abrasive Cylinder, Finishing, Abrasive Media, Surface Profile, Surface Roughness

1. Introduction

Finishing is the final process in the manufacturing of any components, which gives the final shape to the components. A fine-finished component has better aesthetics, life and performance due to its minimum surface irregularities, close dimensional controls and strength endurance. Grinding, lapping and honing are the well-established finishing processes using from many years for finishing of the components but these processes are time-consuming, labor dependent and restricted to finish only accessible geometries. To overcome these problems in 1960 Extrude Hone Corporation developed Abrasive Flow Machining (AFM) process for finishing of aerospace components.

Abrasive flow finishing process is an advanced finishing process used to finish the internal and external surfaces to nano-level in engineering materials like non-ferrous alloys, super alloys, ceramics, refractory materials, carbides, semiconductors, quartz, composites etc. that cannot be machined by the conventional machining processes efficiently and economically [1]. In this process flexible abrasive media - viscoelastic polymer mixed with abrasive particles is extruded through the internal cavities to remove the burrs and machined marks present on the surfaces and to give a mirror like finish to the surface. Rhoades and Clouser [2] have reported the principle of abrasive action of the medium while machining the internal cavities. Williams and Rajurkar [3] developed the modelling of the surface generated by abrasive flow finishing process and online monitoring system to monitor the AFM process while machining. Figure 1 shows the mechanism of material removal by AFM process and the forces acting on the work surfaces while finishing the components. The mechanism of material removal is almost similar to that of the grinding process but in this process, a flexible abrasive medium is used to finish the surfaces. Many researchers are constantly trying to improve the performance of AFM process and some literature findings are explained below:

Loveless et al. [4] studied the effectiveness of abrasive flow machining process in the finishing of various work materials pre machined by grinding, turning, wire electrical-discharge machining and milling. On observing the roughness pattern by scanning electron microscope images it was found that the surface machined by wire electrical-discharge machine is improved greatly after finishing with AFM process compared to other processes. Jain and Adsul [5] examined the dominant process parameters that affect the material removal rate and surface finish. The experiment was conducted on brass and aluminum workpiece and the surface texture was examined using scanning electron microscope. The abrasive mesh size, concentration of abrasive, working cycles and abrasive media flow rate are the dominant process parameters, which affects the material removal rate and surface topography reported in the paper. To enhance the Material Removal Rate (MRR) and surface finish many researchers are developed hybrid AFM process in which AFM process is combined with other non-traditional machining processes.

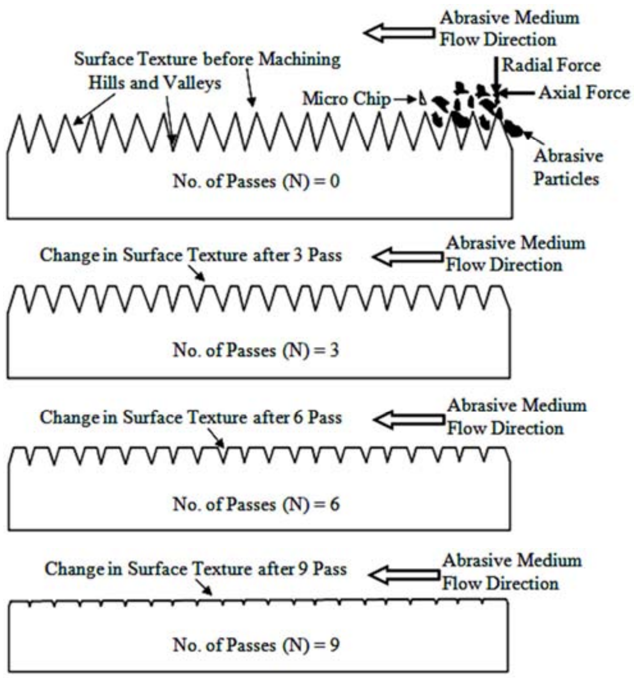

Figure 1. *Material removal mechanism.*

Some of the recent developments in hybrid processes are: Magneto Abrasive Flow Machining (MAFM) [6], Magnetorheological Abrasive Flow Finishing (MRAFF) [7], Centrifugal Force Assisted Abrasive Flow Machining (CFAAFM) [8], Electro-Chemical aided Abrasive Flow Machining (ECAFM) [9], Drill Bit Guided-Abrasive Flow Finishing (DBG-AFF) [10], Rotational-Abrasive Flow Finishing (R-AFF) [11], Ultrasonic Assisted Abrasive Flow Machining (UAAFM) [12] and Rotational Magneto Rheological Abrasive Flow Finishing (R-MRAFF) [13]. Hiremath et al. [14] developed one-way abrasive flow machining process for finishing EDM machined surfaces. They have concluded, AFM process is best suitable for finishing recast layer present on EDM machined surfaces.

Abrasive media is the main constituent of the AFM process; it consists of viscoelastic polymer reinforced with the abrasive particles. In this viscoelastic polymer acts as a carrier medium and abrasive particles act as a cutting tool which removes the material from the workpiece. The commonly used polymer media are polyborosiloxane and silicone rubber and commonly used abrasives are silicon carbide, aluminum oxide, boron carbide and polycrystalline diamond. Many researchers have tried to develop alternative natural rubber and synthetic rubber based flexible abrasive media mixed with Silicon Carbide (SiC), Alumina Oxide (Al_2O_3) and Boron Carbide (B_4C) apart from commercially available media from Extrude Hone Corporation and Kennametal to meet their requirement and to study the media characteristics in finishing of different materials.

To understand the complexity of the process it is necessary to construct a model either mathematical or simulation to study the effect of various process parameters on the output responses – surface finish and material Removal Rate (MRR). The model in general provides the information, which gives an insight into the nature of the phenomenon occurring in the real life situation. Petri et al. [15] developed the predictive process modeling to determine the set of process parameters effects on surface finish. It consists of a set of neural networks models that predict the process behavior. Jain et al. [16] developed a Finite Element Model (FEM) to evaluate the stresses and forces developed during the machining process. A theoretical approach is also proposed in the paper to estimate the MRR and surface finish during the machining process. The theoretical results are compared with the available literature on experimentation and they are found to agree well with the published literature. Jain et al. [17] evolved a versatile simulation model to predict surface roughness and MRR with reference to the abrasive size and concentration. Jain et al. [18] proposed a model to determine the specific energy and tangential forces acting on AFM process based on five main parameters- grain size, applied pressure, hardness of workpiece, number of active grains and number of cycles. In our previous work [19, 20] we developed prototype abrasive model for finishing of hydraulic components such as nitroalloy collar and convergent divergent nozzles. Some of the advantages of abrasive flow finishing process are - less residual stresses, does not effect on the microstructure of materials and very less temperature interaction which may effect on strength of the materials.

In this paper, an effort has been made to develop the experimental setup of abrasive flow finishing process to finish different workpiece and to understand the effect of developed finishing process on finishing of soft and hard engineering materials like aluminum, brass, copper and mild steel. In-house developed visco-elastic polymer based flexible abrasive media has been used to finish these materials and roughness is measured using perthometer M2 with a sampling length of 5.6 mm. The roughness profiles and effect of finishing process on different surface roughness parameters are discussed detail in this paper.

2. Materials and Methods

2.1. Materials and Media

A material selection to be considered for experimentation depends on its practical applications, properties and availability of materials. In the present study, for machinability study aluminum, brass, copper and mild steel workpieces are selected to study the effect of the finishing process. These materials are commonly used in almost all industrial applications like automotive, aerospace, bio-medical and naval industries. The geometry of the workpiece is shown in Figure 2. Abrasive media used in finishing process is a mixture of viscoelastic polymer, abrasive particles-SiC and plasticizer. The individual materials are selected in definite proportion and mixed using two-roll mill machine for homogeneous mixing.

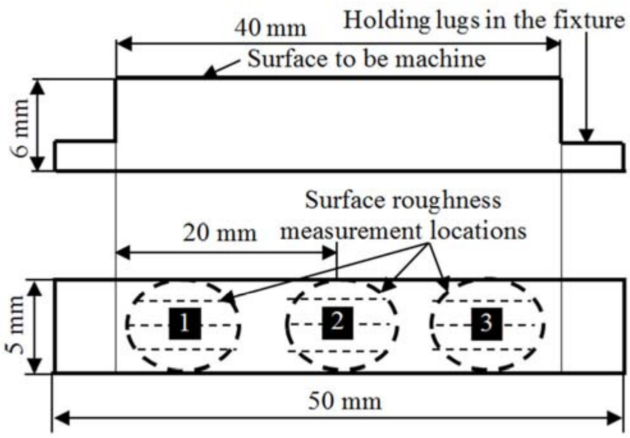

Figure 2. *Geometry of the workpiece.*

2.2. Finishing Process

Figure 3 shows the schematic diagram of the developed experimental setup of abrasive flow finishing process. It consists of abrasive media cylinder, hydraulic cylinder, 4/3 solenoid operated direction control valve, flow control valve, pressure relief valve, hydraulic power pack and flexible hoses.

Hydraulic cylinder piston is coupled to the abrasive cylinder piston. The hydraulic cylinder is driven by the supply from a power pack to give the linear movement to push the abrasive media present in the abrasive media cylinder through the workpiece to be machined. Pressure gauges are fixed at hydraulic cylinder end to note down the pressure at which the media is pushed through the workpiece. After finishing one complete stroke the abrasive media coming out of workpiece is collected and re-filled to the cylinder for next stroke. The surface roughness is measured using perthometer before and after finishing. Initially, the workpiece are machined using a milling machine and later finished with the developed process. Roughness is measured at 3 locations to check the uniform texture present on the workpiece.

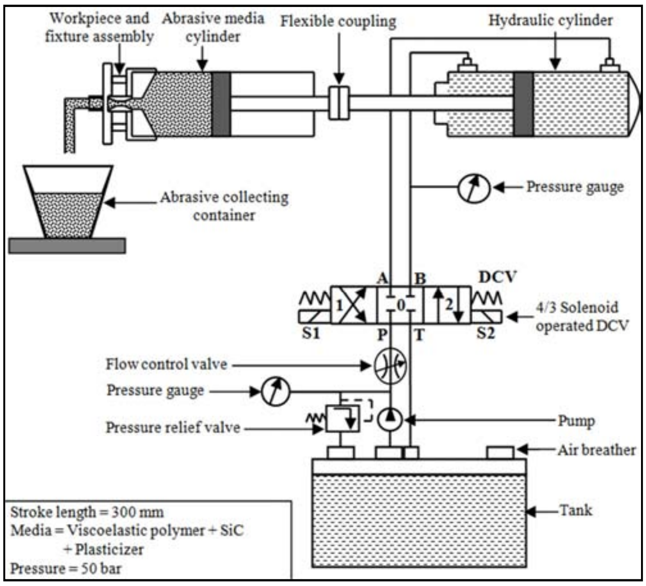

Figure 3. *Schematic diagram of the developed experimental setup*

3. Results and Discussions

Experiments were conducted to remove the irregularities present on aluminum, brass, copper and mild steel milled surfaces and to study the effect of a number of passes on different roughness parameters. Some of the process parameters maintained while finishing are: abrasive concentration of 50%, the operational pressure at the cylinder was 50 bar, the average velocity of the media coming out of the component is around 0.34 m/min, the time required to complete one pass was found to be 80 s, and number of passes are varied from 0 to 12 for all the materials.

Figure 4 shows the effect of number of passes on the average surface roughness (R_a) of different workpiece materials. It is observed that as the number of passes increases the average surface roughness value is reduces.

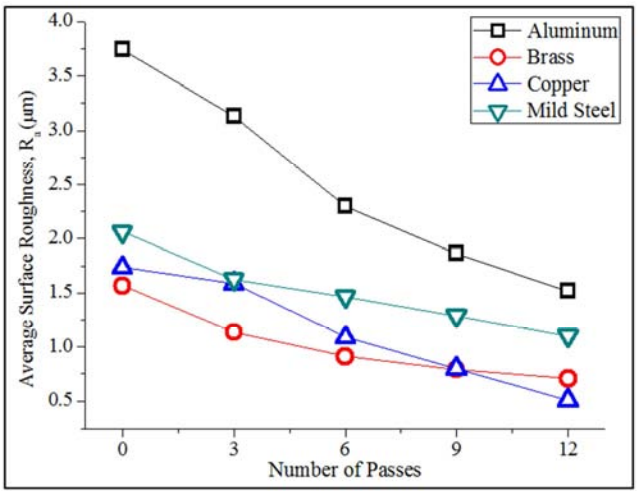

Figure 4. *Effect of number of passes on the average surface roughness (R_a) of different workpiece materials.*

Surface roughness varies nonlinearly with an increase in a number of passes irrespective of material. Initially, for the first few number of passes, the drastic changes in roughness value is an observed but later progressive reduction in roughness values are observed with increasing number of passes. Because, initially machined surfaces will be having more sharp edges, when the abrasive media is exposed to these peaks, the peaks get machined due to abrasion after first few passes the density of sharp peaks reduces and surface attains a critical surface roughness value.

The R_a values for aluminum reduced from 3.74 µm to 1.51 µm, in case of brass 1.568 µm to 0.86 µm, in case of copper 1.735 µm to 0.508 µm and in case of mild steel 2.063 to 1.101 µm reduced respectively. Figure 5 shows the effect of number of passes on the change in average surface roughness of different workpiece materials. Comparing change in average surface roughness (ΔR_a) of four materials, maximum ΔR_a 2.23 µm is observed in aluminum and minimum ΔR_a is observed in mild steel and brass. The ΔR_a of the brass is minimum as compared to mild steel as because the surface has reached the maximum finish level and some machining marks were still present which are not able to remove with finishing process. From the experiments, it can be concluded abrasive flow finishing process is very effective for finishing smooth materials and required finish can be achieved in less number of passes as compared to hard materials.

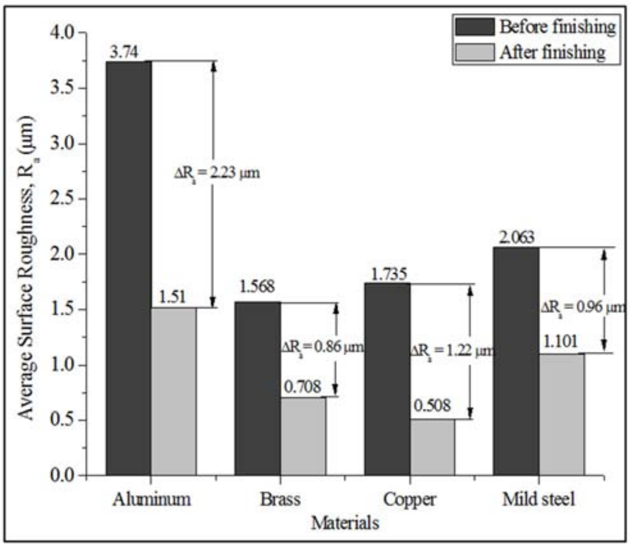

Figure 5. *Change in average surface roughness (R_a) of different workpiece materials.*

Figure 6 shows the effect of number of passes on the maximum roughness depth (R_{max}) of different workpiece materials. The R_{max} is reduced drastically irrespective materials after finishing with the developed setup. The maximum surface depth is reduced from 31.98 µm to 14.9 µm in case of aluminum, 17.38 µm to 4.47 µm in case of brass, 10.73 µm to 2.93 µm in case of copper and 12.96 µm to 10.63 µm in case of mild steel as the number of passes of abrasive media increased from 0 to 12.

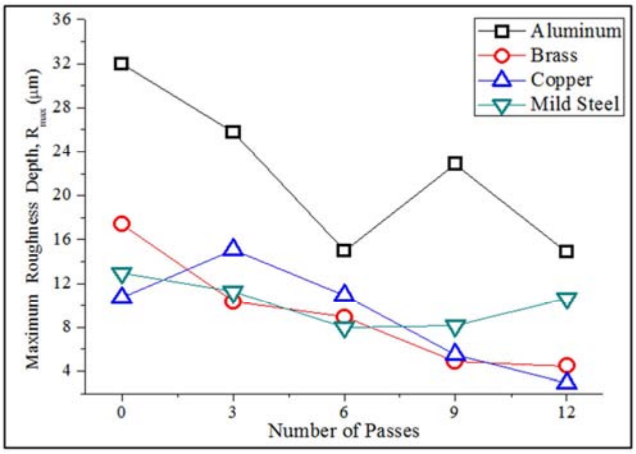

Figure 6. *Effect of number of passes on the maximum roughness depth (R_{max}) of different workpiece materials.*

Similarly, as the number of passes changes, a decrease in average maximum height of roughness profiles was observed on different surfaces. Figure 7 shows the effect of number of passes on the average maximum height (R_z) of different workpiece materials. The average maximum surface height (R_z) is reduced from 18.49 µm to 7.28 µm in case of aluminum, 8.45 µm to 2.93 µm in case of brass, 7.901 µm to 2.33 µm in case of copper and 9.22 µm to 4.91 µm in case of mild steel as the number of passes of abrasive media increased from 0 to 12.

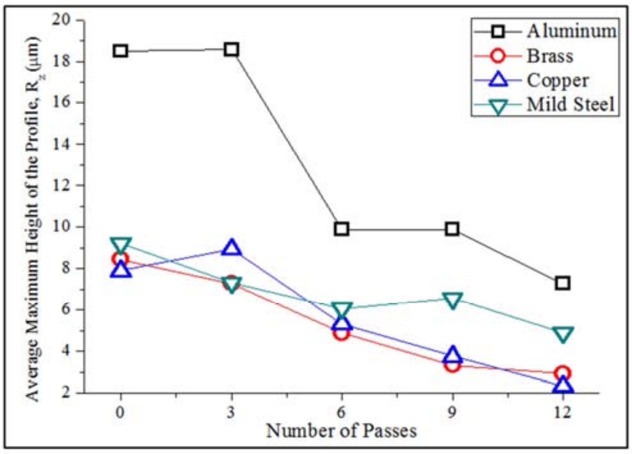

Figure 7. *Effect of number of passes on the average maximum height (R_z) of different workpiece materials.*

Figure 8 shows the surface roughness profile of the aluminum workpiece. Initially, the height of peaks and depth of valleys on milled aluminum workpiece surfaces were more. It was in the range of 8-10 µm after finishing the height of peaks and depth of valleys reduced to the 3-4 µm. A drastic change in roughness profile is observed in aluminum workpieces because of its soft nature, which is easy to finish. Similarly, in case of brass the height of peaks and depth of valleys reduced from the range of 4 µm to 1 µm. Figure 9 shows the surface roughness profile of the brass workpiece. The roughness profiles images clearly show the changes in irregularities before finishing and after finishing.

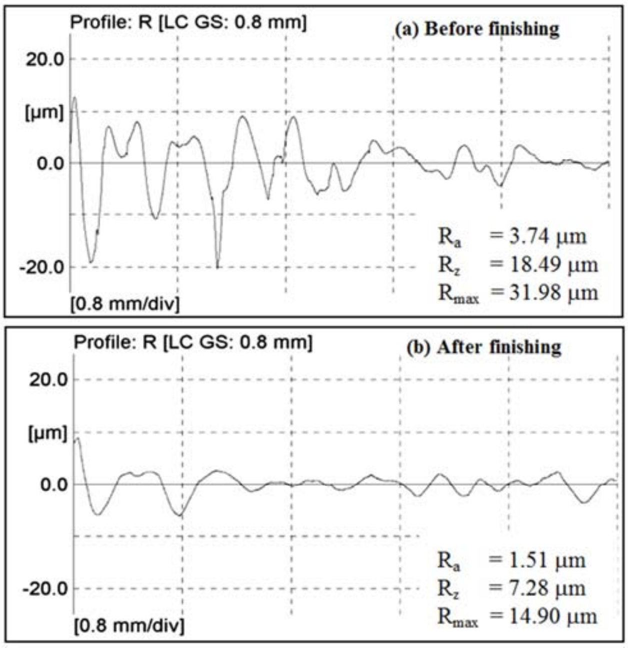

Figure 8. *Surface roughness profile of the aluminum workpiece.*

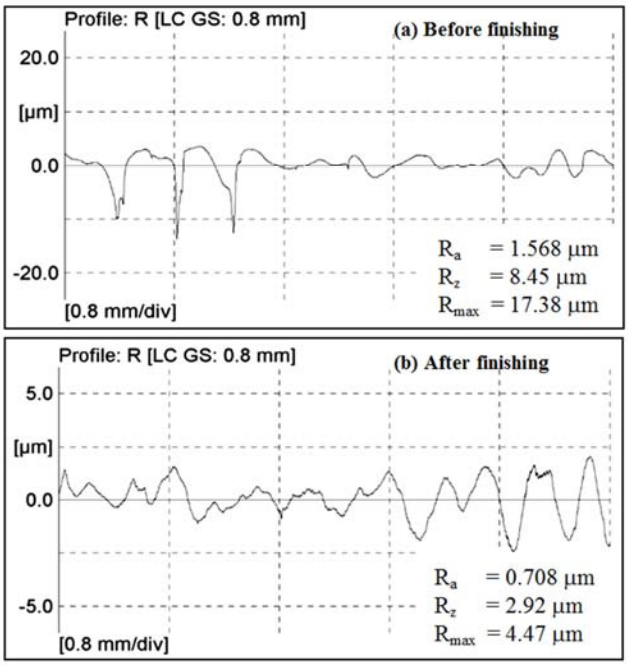

Figure 9. *Surface roughness profile of the brass workpiece.*

Figure 10 shows the surface roughness profile of the copper workpiece. Initially, the height of peaks and depth of valleys on milled copper workpiece surfaces were more. It was in the range of 4 µm after finishing the height of peaks and depth of valleys reduced to the 1 µm.

Similarly, in case of mild steel the height of peaks and depth of valleys reduced from the range of 5 µm to 2 µm. Figure 11 shows the surface roughness profile of mild steel workpiece. The roughness profiles images clearly show the changes in irregularities before finishing and after finishing.

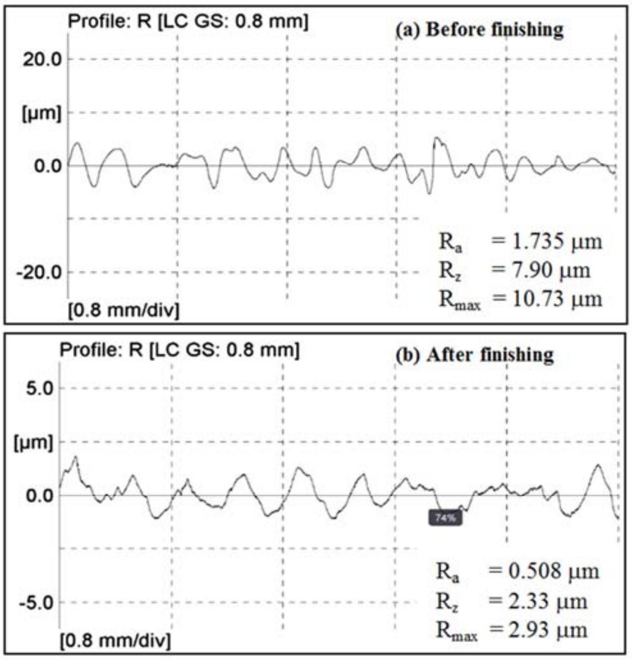

Figure 10. *Surface roughness profile of the copper workpiece.*

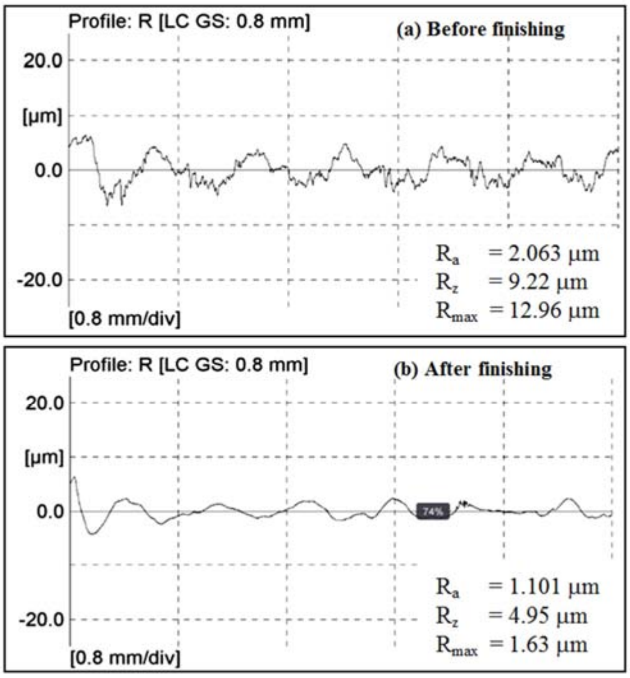

Figure 11. *Surface roughness profile of the mild steel workpiece.*

The surface textures of workpieces are examined using Scanning Electron Microscopy (SEM) before and after finishing to investigate the effect of finishing process on the surface texture. Figure 12 shows the SEM images of the aluminum workpiece before and after finishing. It is clear from the SEM images before machining, rough surface and deep machining feed marks present on the workpiece. After 12 passes of the finishing process, there is a significant reduction of these feed marks on the finished surfaces shown in Figure 10 (b). Figure 13 shows the SEM images of the brass workpiece before and after finishing. Initially, the density of the pits and feed marks are more. After 12 passes of finishing the pits are reduced and uniform unidirectional lay patterns are seen on the machined surfaces from the SEM images. Figure 14 shows the SEM images of the copper workpiece before and after finishing. Initially, more surface irregularities are observed on copper work surfaces. After 12 passes of finishing the work, the surface is clear from irregularities and drastic change in the roughness is observed.

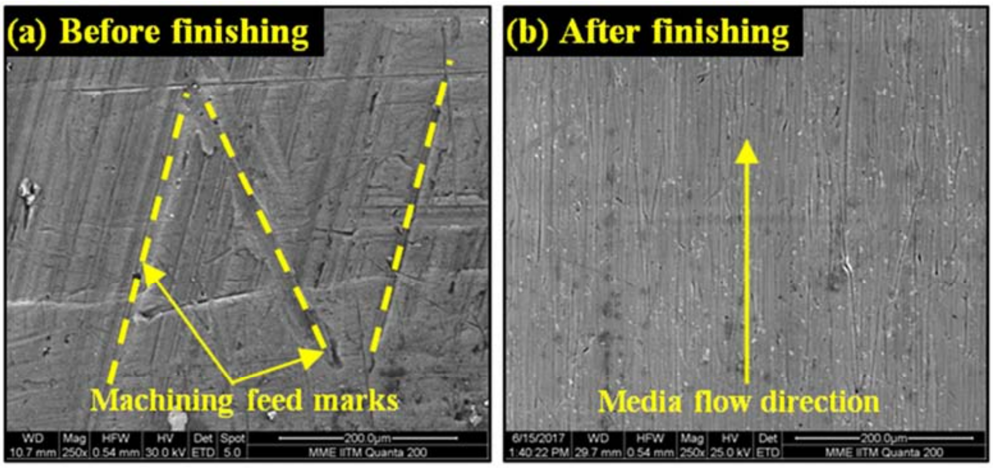

Figure 12. *SEM images of the aluminum workpiece.*

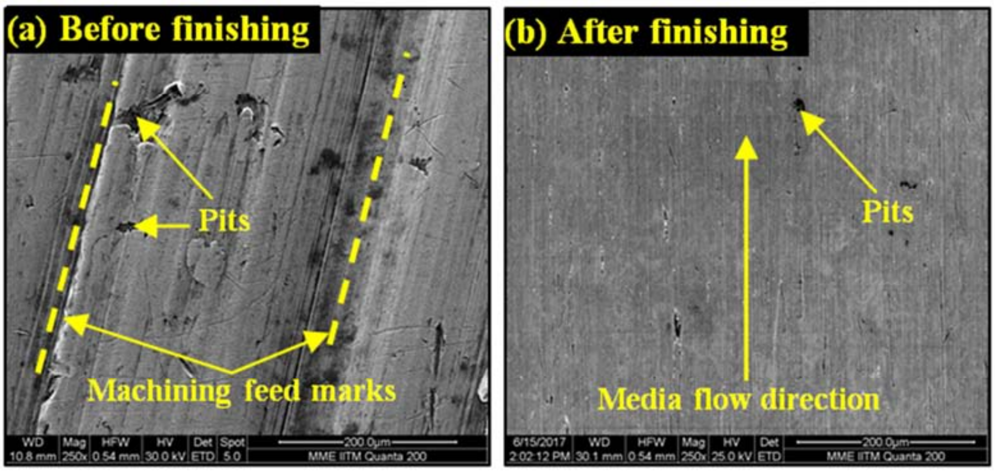

Figure 13. *SEM images of the brass workpiece.*

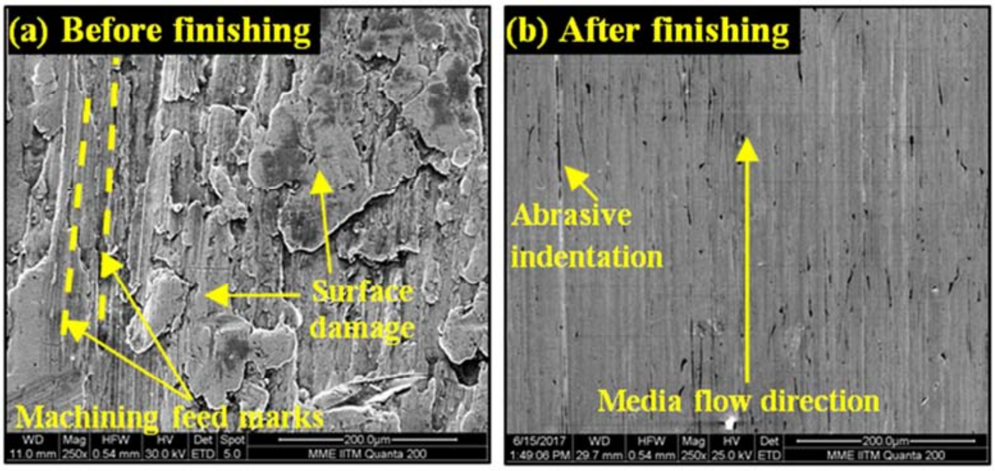

Figure 14. *SEM images of the copper workpiece.*

Figure 15 shows the SEM images of mild steel workpiece before and after finishing. The feed marks are reduced after 12 passes of finishing process and it is clear from the SEM images.

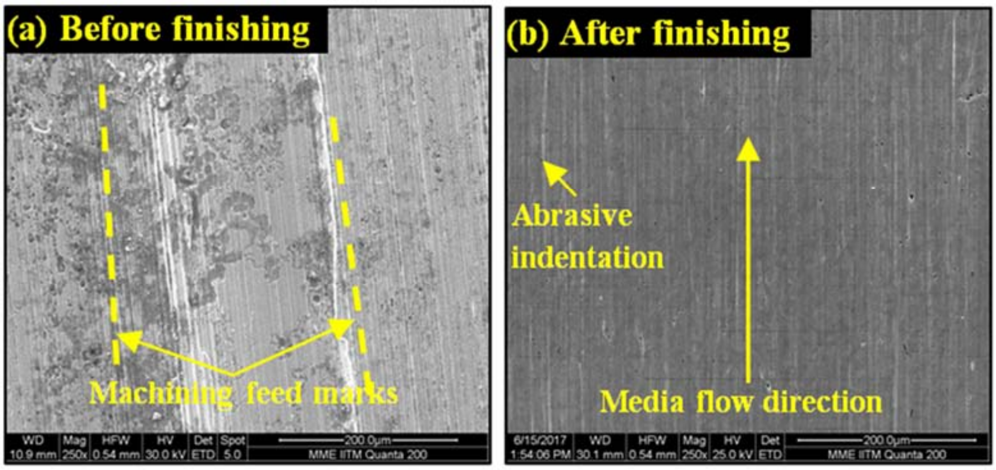

Figure 15. *SEM images of the mild steel workpiece.*

4. Conclusions

Abrasive flow machining is an advanced finishing process in which viscoelastic polymer based abrasive media is used to finish the complex internal intricate geometries. In the present study finishing experiments are carried out on aluminum, brass, copper and mild steel workpieces to show the effectiveness of the developed process in the finishing of soft and hard materials and to study the finishing effect on surface texture. Following are the conclusion drawn from the present study:

a. An attempt has been made to develop an experimental setup of abrasive flow finishing process to finish various components having intricate profiles and inaccessible areas efficiently and effectively.
b. Irrespective of materials, the drastic reduction in roughness values are observed during the early phase of machining up to 9 passes. Only marginal improvement in surface finish can be seen beyond 9 passes.
c. The average surface roughness (R_a) value for aluminum reduced from 3.74 µm to 1.51 µm, in case of brass 1.568 µm to 0.86 µm, in case of copper 1.735 µm to 0.508 µm and in case of mild steel 2.063 to 1.101 µm reduced respectively after finishing.
d. From comparison in terms of reduced average surface roughness (R_a) of different materials, it has been proved that AFM process is a more efficient process for finishing soft materials as well as hard materials.
e. The densities of sharp peaks present on the machined surfaces are reduced after finishing with abrasive media.
f. The finishing experiments demonstrated that the developed process could alter the surface irregularities by reducing the roughness peaks.

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