Effect of Unconventional Machining on Surface Roughness of Metal: Aluminum and Brass- A Case Study of Abrasive Flow

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ABSTRACT

Abrasive finishing techniques are developed to overcome the problems such as high direct labor cost and to produce finished precision parts with specific features for finishing inaccessible areas. Abrasive finishing is carried out with a large number of cutting edges, which have indefinite orientation and geometry. Abrasive fine finishing processes are commonly employed because of their inherent capabilities of finishing various geometries of form, (i.e., flat surface, round surface, etc), and various geometries of surface relation (i.e. parallelism, squareness, straightness, angularity, etc.), with the desired dimensional accuracy and surface finish. In AFM, the medium gently and uniformly scrape the surfaces and/or edges, whereas it is not so in the case of grinding. In grinding, abrasives are held rigidly by hard (solid) bond material, whereas in AFM abrasives are held by semisolid bond (or medium). In all these abrasive finishing processes, the grain-workpiece interaction involves one or more of the basic modes of material deformation, i.e., cutting, ploughing and rubbing. Basically cutting is a material removal process, ploughing is a material displacement process and rubbing / sliding is a surface modification process. The key components of AFM process are the machine, tooling and abrasive medium. Process input parameters such as extrusion pressure, number of cycles, grit composition and type, tooling and fixture designs have impact on AFM output responses (such as surface finish and material removal). AFM is capable to produce surface finish (Ra) as good as 0.05 ?m, deburr holes as small as 0.2 mm and radius edges from 0.025 mm to 1.5mm. AFM has wide range of applications in industries such as aerospace, medical, electronics, automotive, precision dies and moulds as a part of their manufacturing activities.

Keywords: *AFM, BBG, AFF, dies and moulds.*

1. INTRODUCTION

ABRASIVE flow machining was developed by the Extrude Hone Corporation, USA in 1960s. Abrasive flow machining can be thought of as a process generating a self-forming tool that precisely removes workpiece material and finishes the surface at those areas restricting to the medium flow. AFM method is used for precision deburring, edge contouring, and surface finishing. It produces uniform, repeatable and predictable results on an impressive range of finishing operations. It can produce true round radii even on complex edges. It can processes dozens of holes or multiple passages parts simultaneously with uniform results. Also, air cooling holes on turbine discs and hundreds of holes in a combustion liner can be de-burred and radiused in a single operation.

The properties of carrier in AFM are important. They should be visco-elastic and nonsticky in nature. The polymer abrasive medium which is used in this process possesses easy flowability, better self deformability and fine abrading capability. Generally used carrier belongs to the category of silicon rubber, i.e. polyborosiloxane / polydimethylsiloxane / silly putty. This carrier is a very viscous fluid and highly compressible and can flow in any blind recess. The commonly used abrasive grains in this process are aluminum oxide, silicon carbide, boron carbide and diamond.

Important feature which differentiates AFM from other finishing processes is that it is possible to control and select the intensity and location of abrasion through fixture design, medium selection and process parameters. In general abrasive medium, the type of fixture and the type of machine determine the type of abrasion, place where to abrade and how much to abrade. In abrasive flow machining, the finishing action on the workpiece surface takes place by forcing a self-deformable medium which is a mixture of

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viscoelastic putty and abrasive particle across the workpiece surface. [1]

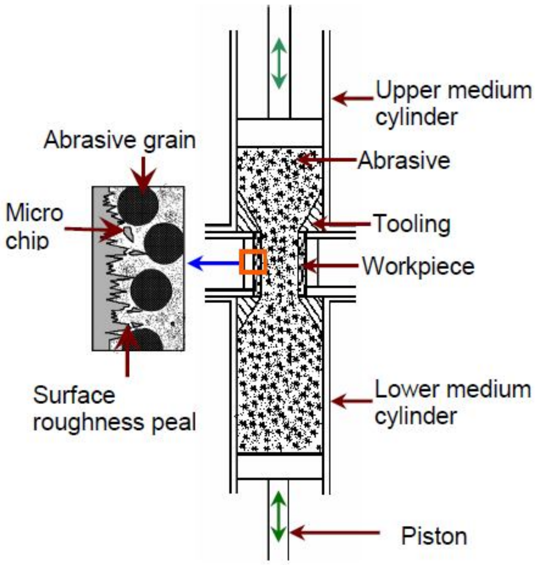


Fig. 1 : Abrasive Flow Machining

2. Process parameters and their influence on Material removal and Surface Roughness (Mr and Ra): Aluminum and Brass

Experimental investigations have been carried out by various researchers to investigate the effects of process parameters like extrusion pressure, number of cycles, viscosity, abrasive concentration and grain size on the output responses namely, surface finish and material removal during AFM. The controllable input parameters are shown in Fig.2.

Table 1: Experimental Parameters

Input Variables	Constant parameters
No. of cycles, *N* (00, 20, 40, 60, 80, 100)	Conc=80%; *U*=515 mm/min; Ab. mesh size=100
Concentration (50, 60, 70, 80); *N* (00, 20, 40, 60, 80, 100)	*U*=515 mm/min; Ab. mesh size=100
Ab. mesh size (100, 150, 180, 240)	Conc=80%; *U*=515 mm/min; *N*=50
Media flow speed (mm/min) (406, 515, 652, 812)	Conc=80%; Ab. mesh; size=100; *N*=50

- All experiments were conducted on both aluminum and brass workpieces.
- Material removal and surface roughness values were responses in each case.
- Ab. mesh size Abrasive mesh size; Conc Concentration of abrasive in the media by weight; MR material removal (g); Ra surface roughness value (m); U media flow speed (mm/min); N no. of cycles.

2.1 Material removal (Mr)

2.1.1. Number of cycles

Material removal increases nonlinearly with the increase in number of cycles (Fig. 3). The rate of

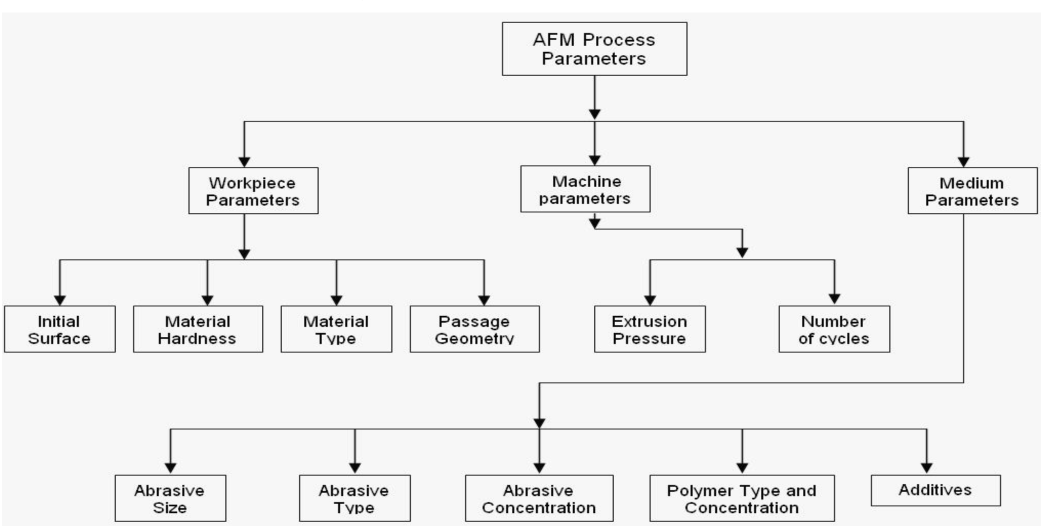


Fig.2 : Input parameters of AFM

material removal, however, decreases with the increase in the number of cycles. This can be explained as follows. The initial surface (before AFM) has sharp peaks. When abrasive particles move against these peaks, the peaks get machined and become somewhat flatter than before [1-3] . In the following cycles, this will result in lower material removal rate. Fig. 3, also shows that the trend of material removal for brass and aluminum is similar, except that the total material removal is higher in the case of aluminum because it offers less resistance to abrasion compared to brass.

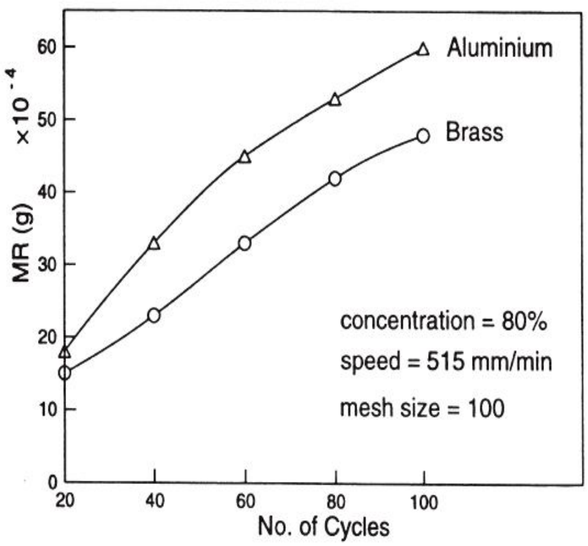
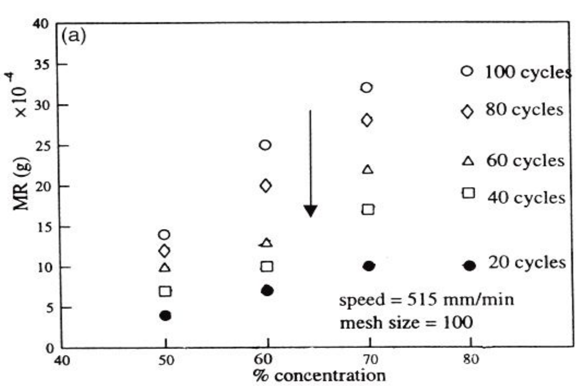


Fig. 3 : Effect of number of cycles on material removal.

2.1.2. Abrasive concentration

As the concentration of abrasive in the media increases, material removal increases (Fig. 4) because more abrasive grains come into contact with the surface to be finished.[4-6] Further, a higher concentration of abrasive grains permits the media to sustain a larger cutting force. Fig. 4 a & b, also show that there is a comparatively small difference in material removal between 70% and 80% abrasive concentration.



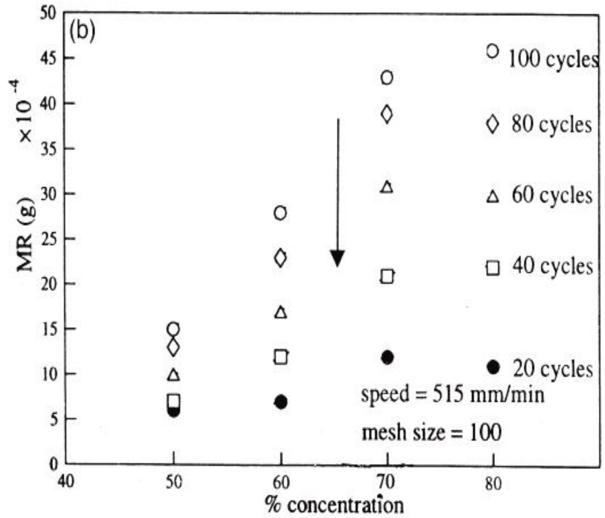


Fig. 4 : Effect of percentage abrasive concentration on material removal at different number of cycles for (a) brass and (b) aluminum as workpiece material.

2.1.3. Abrasive mesh size

Fig. 5 shows the effect of mesh size on material removal. As mesh size increases, material removal decreases in both types of workpieces. The reason for a decrease in material removal is that with an increase in mesh size (or decrease in grain size in mm) the depth of penetration, as well as width of penetration, decreases (see photographs in Fig. 5). Aluminum, being a softer material, yields higher material removal than brass.

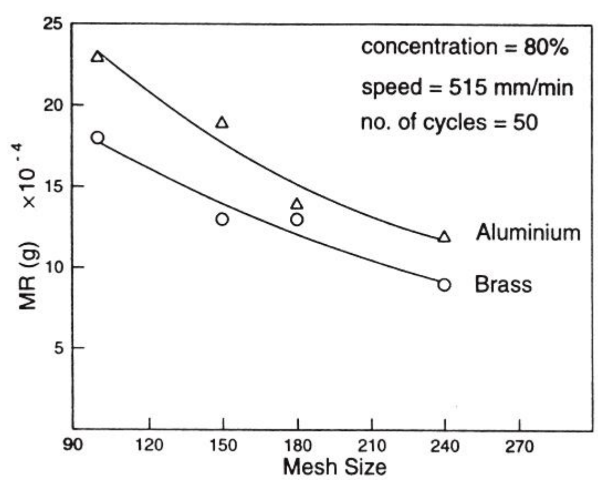


Fig. 5: Effect of abrasive mesh size on material removal.

2.2. Surface roughness (Ra)

2.2.1. Number of cycles

Fig. 6a, shows the effect of number of cycles on surface roughness value (Ra) of the workpieces. As the number of cycles increases the Ra value decreases. Initially the percentage improvement in Ra value is high because of availability of peaks in early stages of machining, but as these peaks get machined the percentage improvement in Ra values slowly decreases (Fig. 6b).

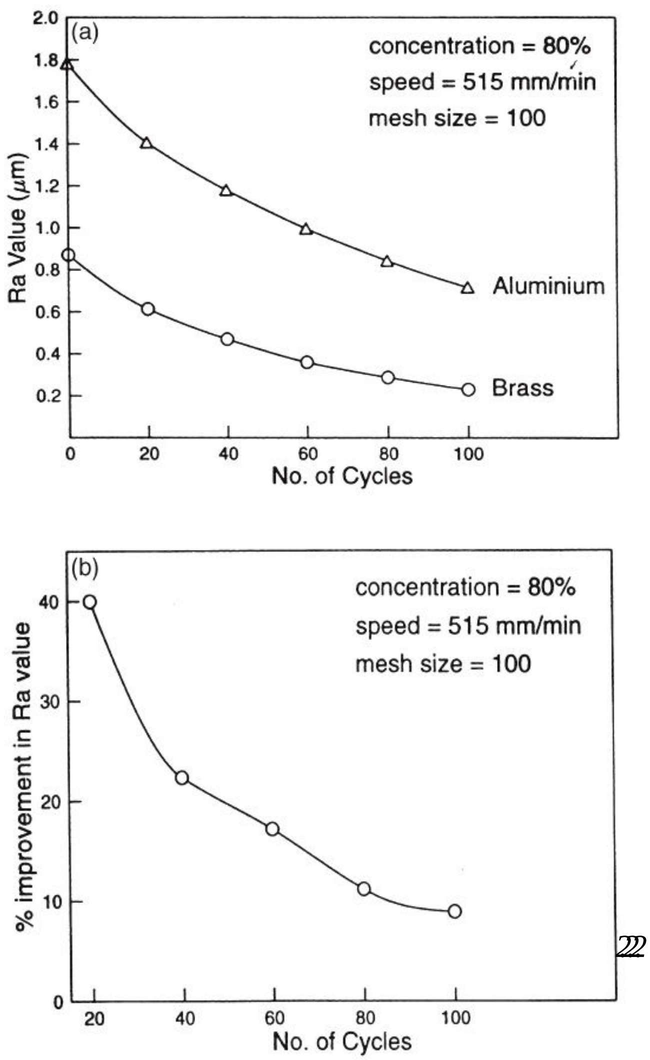


Fig. 6 : (a) Effect of number of cycles on surface ughness value, Ra.
(b) Percentage improvement in Ra value with change in number of cycles.

2.2.2. Abrasive concentration

With the increase in concentration of abrasive for different numbers of cycles, the Ra value decreases as shown in Fig. 7(a&b). Different experiments were conducted at specified abrasive concentrations by varying the number of cycles (Table 1). Hence, the

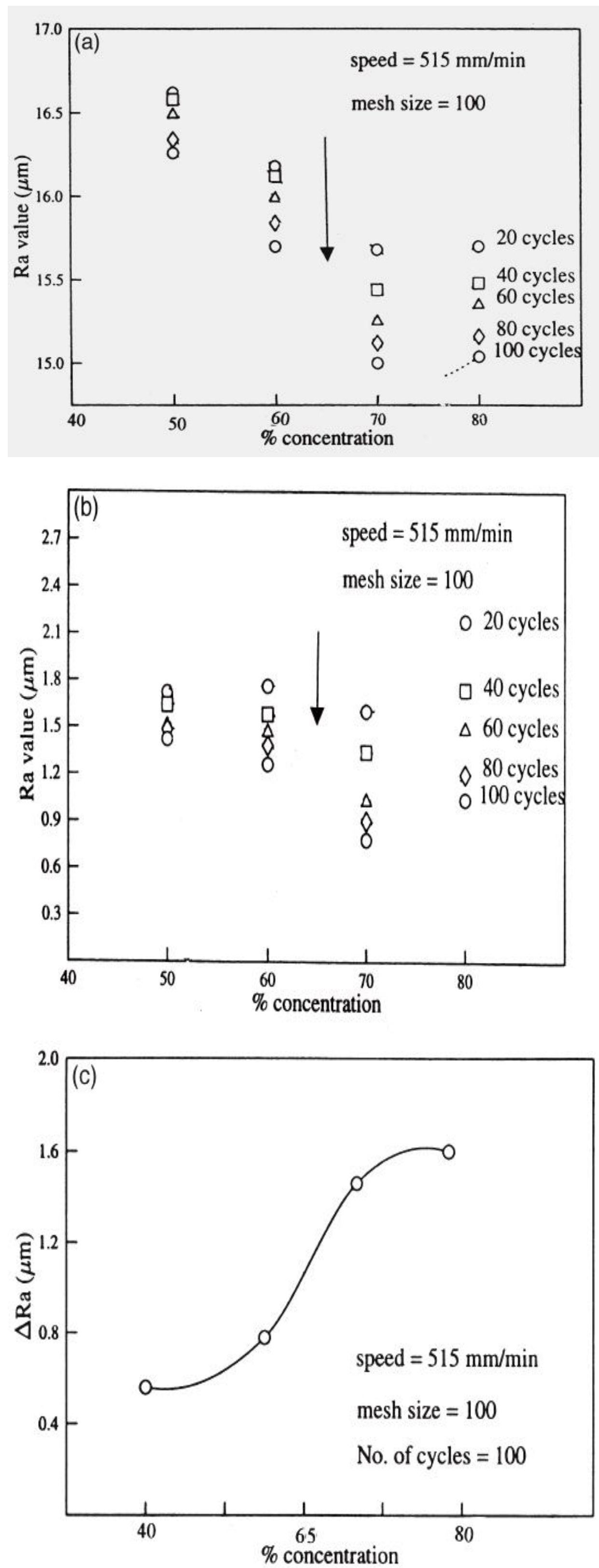


Fig. 7 : Effect of percentage abrasive concentration on: (a) Ra value at different number of cycles for brass as work material; (b) Ra value at different number of cycles for aluminum as work material; (c) change in surface

measurements were taken at different number of cycles for material removal as well as surface roughness in the direction of the arrow, i.e. vertically downward or at constant abrasive concentrations. This is true for each percentage concentration of abrasive and for both type of workpieces. From Fig. 9a and 9b, it can be inferred that with an increase in percentage concentration of abrasive, the improvement in Ra is rapid (Fig. 7c). With higher concentration, more abrasive grains come into contact with the workpiece resulting in more abrasion, hence higher Ra.

2.2.3. Abrasive mesh size

Fig. 8, shows that as the abrasive mesh size increases, the Ra value decreases. Further, the effect of mesh size on change in Ra is very low in the case of brass compared to aluminum.

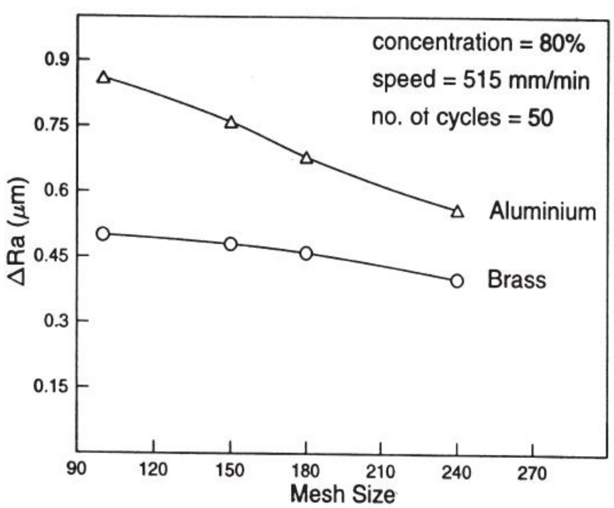


Fig. 8 : Effect of abrasive mesh size on Ra value.

3. RECENT DEVELOPMENTS IN AFM PROCESSES

Though there are many advantages of AFM process, it has a few disadvantages also, such as low finishing rate, and incapability to correct the form geometry. Many researchers have been working to improve the finishing rate, surface integrity and compressive residual stresses produced on the workpiece surface.

Singh and Shan [7] applied magnetic field around the workpiece in AFM and observed that magnetic field significantly affect the material removal and change in surface roughness. With the application of magnetic field, less number of cycles are required for the higher material removal. Higher material removal and higher change in surface roughness are observed (in case of brass as workpiece material) with the low flow rates of medium and high magnetic flux density.

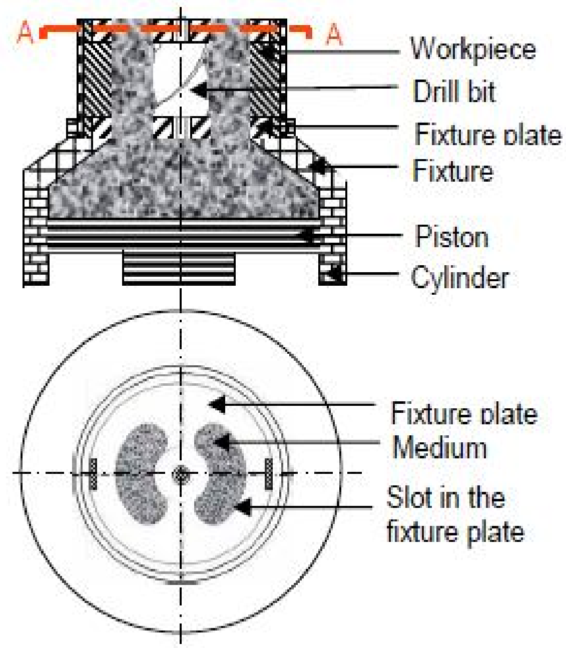


Fig. 9 : Sectional front view of tooling in the finishing region in DBG-AFF process and top view of medium splitting through twin slotted fixture plate

Ravi Sankar et.al., [8] tried to improve finishing rate, material removal and surface texture by placing drill bit in the medium flow path called Drill Bit Guided Abrasive Flow Finishing (DBG-AFF) (Fig. 9). The inner part of medium slug flows along the helical flute which creates random motion among the abrasives in inner region of the medium. This causes reshuffling of abrasive particles at outer region. Hence, comparatively more number of new and fresh abrasive grains interacts with the workpiece surface. From the experimental results, it is concluded that the abrasive traverse path is longer than the AFM abrasive traverse path in each cycle. It results in higher finishing rate in DBG-AFF as compared to AFM. Material removal is found to decrease with decrease in drill bit diameter.

Biing-Hwa Yan et. al., [9] placed spiral fluted screw in the medium flowing path to improve surface quality. Walia et. al., [10] rotated different shaped tiny rods at the centre of the medium flow path and used a low viscosity medium to finish. He concluded that the better surface finish is achieved due to centrifugal action caused by the rod on the abrasives and this process is called centrifugal force assisted abrasive flow machining (CFAAFM). But all these three rotating medium methods may rotate the medium at and near the axis of the medium but the probability of rotating the medium at the abrasive-workpiece interaction region is very low.

Ravi Sankar et. al [11] developed a new set-up to rotate the workpiece so that the probability of active abrasive particle rotation in the workpiece finishing region is high which improves both surface finishing rate and material removal rate.

4. APPLICATIONS OF AFM

AFM is being used for finishing of various components in a wide range of industries. The AFM process was originally identified for de-burring and finishing critical hydraulic and fuel system components of aircraft, automobiles, dies and moulds etc.

4.1 Aircrafts

It is frequently used in aircraft industries for adjusting airflow resistance of blades, vanes, combustion liners, nozzles and diffusers. AFM process is capable for improving airfoil surface conditions on compressors and turbine section components, and finishing accessory parts such as fuel spray nozzles, fuel control bodies and bearing components. It is more required for edge finishing of holes and attachments to improve the mechanical fatigue strength of blades, disks, hubs, and shafts with controlled polished, true radius edges.

The surface finish on the cast blades is improved from original 1.75 μm to 0.4 μm Ra (Fig.10.a). Cooling air holes are deburred and radiused in one operation on turbine disks as large as 760 mm in diameter (Fig.10.b). It is also used to remove milling marks and improve finish on complex airfoil profiles of impellers and blades (Fig.10.c).

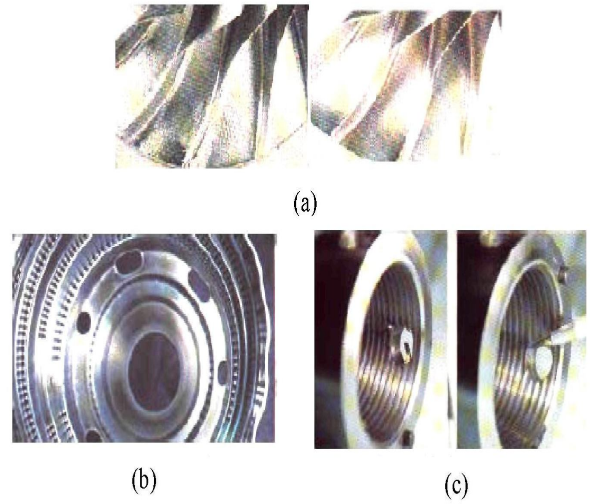


Fig. 10: (a) Surface finish improvement on cast blades, (b) Deburring of cooling holes in turbine blade, and (c) Finishing of intersections

4.2 Automobiles

The demand for this process is increasing among car and two wheeler manufacturers as it is capable to make the surface smoother for improved air flow and better performance. AFM process is used to enhance the performance of high speed automobiles engines. AFM process is capable to finish the complex parts of automobiles engines. AFM abrades, smoothes and polishes the surfaces of 2- stroke cylinders and 4 stroke engine heads for improved airflow and better performance.

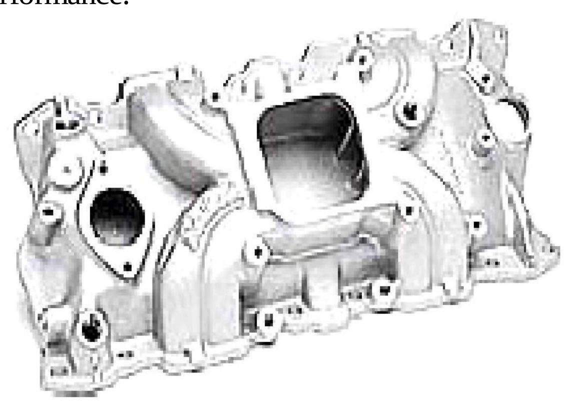


Fig. 11 : Intake port of engine (Automobile)

It is a well-known fact in automobile engineering that smoother and larger intake ports produce more horsepower with better fuel efficiency. But it is very difficult to obtain good surface finish on the internal

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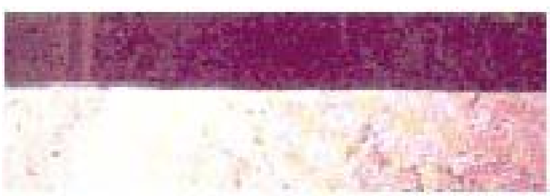
passageway of intake ports because of its complex shape (Fig.11). By applying the AFM process to intake and exhaust manifolds, the internal passages are enlarged and the surface contours improved.

Finishing of fuel spray orifices of fuel injector nozzles, smoothing and removing the surface stress risers, cracks, as well as uniform radiusing of sharp edges of diesel engine component by AFM can significantly enhance component life and can reduce particulate emission with improved fuel efficiency of diesel-powered engines.

4.3 Dies and Moulds

AFM process has capability of finishing the precision dies by polishing the die surfaces in the direction of material flow, and by producing a better quality and longer lasting dies with a uniform surface and gently radiused edges. Since in the AFM process, abrading medium can flow in any blind passage geometry, complex shapes can be processed as easily as simple ones. EDM recast layer can be completely removed as shown in photomicrograph in Fig.12. AFM can process multiple die passages simultaneously, reducing labor cost and production time significantly.

Before AFM



After AFM

Fig. 12 : 500X photomicrograph showing complete removal of EDM recast layer

5. CONCLUSIONS

- AFM is a well established advanced finishing process capable of meeting the advance finishing requirements in various sectors of applications like aerospace, medical and automobile. It is commonly applied to finish complex shapes for better surface roughness values and tight tolerances.
- Though there are many advantages of AFM process, but it has a few disadvantages also, such as low material removal and surface finishing rate, and incapability to correct the form geometry.
- The better performance is achieved if the process is monitored online. So, acoustic emission technique is used to monitor the surface finish and material removal but ended with only marginal improvement.
- To achieve an accurate and efficient finishing operation without compromising the finishing performance, input parameters and output responses, many modified processes such as Magnetic Abrasive Flow Machining (MAFM), Drill Bit Guided Abrasive Flow Finishing (DBGAFF), Centrifugal Force Assisted Abrasive Flow Machining (CFAAFM), R-AFF , Spiral Polishing Method etc are used.
- In spiral polishing, CFAAFM and DBGAFF processes, the probability of role of additional tooling which is at the middle of the slug has less influence on the finishing direction of active abrasive grain. But later this problem is solved by rotating the workpiece itself. It makes the active abrasive grains to follow helical path, which improves the contact length of the active abrasive grain with workpiece.
- In R-AFF process, better improvement in surface roughness is achieved compared to AFM and takes lesser time to achieve same surface finish that can be achieved through AFM process.
- Now, a lot of improvements have been carried out in AFM process, but researchers feel that there is still room for lot of improvements in the present AFM status.

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