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**DEVELOPMENT AND EVALUATION OF
ADVANCED ABRASIVE FLOW MACHINING
TECHNIQUE**

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Development and Evaluation of Advanced Abrasive Flow Machining Technique

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Abstract – Advancement in material sciences has led to the development of smart engineering materials viz. composites, ceramics, polymers and super-alloys. These materials find exhaustive use in modern manufacturing industries, especially, in aircraft, automobiles, cutting tools, die and mold making industries. Higher costs associated with the machining of these materials besides stringent design requirements, which include precision machining of complex and complicated shapes and/or sizes, machining of inaccessible areas at micro or nano levels with tight tolerances are the major limitations which have led to the development of newer advanced non-traditional machining processes. Abrasive flow machining (AFM) is a novel technique having potential to provide high precision and economical means of finishing inaccessible areas and complex internal passages on otherwise difficult to machine material and components. AFM has been likened to a semi-solid flowing file wherein the media acts as a flexible cutting tool whenever it is subjected to any restriction; and perhaps its greatest advantage lies in its ability to finish, deburr, polish, radius and removing the recasted layers from complex internal passages or areas that are inaccessible to more traditional methods such as mechanical honing.

The vast potential applications and capabilities of the AFM process attract the attention of machinists and make it imperative upon researchers to overcome the major limitations of the process. The present research initiative identifies the limitations and gaps through exhaustive review of published literature on AFM technique with the intent to explore the possibilities for improving the efficiency and capabilities of the process/technique. It has been recognized that very few research studies have been conducted on the optimization of the process parameters for enhanced quality characteristics. Therefore, it is required to study the AFMed surfaces to get more insight into the real interaction between flowing abrasive particles

INTRODUCTION

Manufacturing machine components having complex geometric shapes and profiles made up of smart materials requiring nanometer range surface finish and dimensional accuracy has led to the development of newer finish-machining techniques. It has been reported that final finishing operations constitute the most essential, sensitive, labour intensive and time consuming operations which consume almost 10-15 percent of the total manufacturing costs. Abrasive flow machining (AFM) is a novel non-traditional machining process developed as a method to debur, polish, and radius surfaces and edges by flowing an abrasive laden media over otherwise difficult to machine areas and surfaces. In AFM, a semi-solid medium consisting of a polymer-based carrier and abrasives in typical proportions is extruded through or past the surface to be machined. The visco-elastic medium acts as a deformable grinding tool whenever and wherever it is subjected to restriction. The medium is flexible enough to mould itself to virtually any complex shape or contour, and it has the ability to abrade hard and tough materials. A high degree of surface finish and close tolerances can be achieved on a wide range of components by AFM.

Potential applications of the process are the finishing of critical aircraft hydraulic and fuel system components and accessory parts, such as fuel spray nozzles, fuel control bodies and bearing components which are otherwise tedious to machine. The process has potential ability of achieving high production rates in the processing of fuel injection systems, hydraulic transmissions, steering and braking systems, splines and gears, pumps, valves and fittings, textile machinery, hardware industry, etc.

The vast potential applications and capabilities of the AFM process attracts the attention of machinists and makes it imperative upon researchers to overcome the major limitation of low volumetric material removal rate of this process – a limitation shared by almost all NTM processes. Although AFM is primarily a surface finishing technique yet material removal plays a major role in providing the final surface finish to the component finish-machined by AFM. The study of AFM process mechanism indicates that with increase in material removal the finished surface texture improves and this rapid surface finishing is accomplished as a result of material removal from the high peaks present on the work-piece surface. Therefore, improvement in surface roughness and

material removal are generally considered as output responses indicating performance/quality characteristics.

The present research initiative identifies the limitations and gaps through exhaustive review of published literature on AFM technique with the intent to explore the possibilities for improving the efficiency and capabilities of the process/technique.

The following observations have been made:

1. Conflicting opinion of researchers regarding the effect of certain process parameters on quality characteristics.
2. Consistent and sufficient theory about the process mechanism remains yet to be established.
3. Little information reported in the direction of optimization of process parameters based on diverse performance characteristics.
4. Little effort directed towards improving the overall efficiency and capability of the process with emphasis on quality characteristics.
5. There is no information on efforts directed towards integration of this charismatic technique with present day small scale industries making it relevant, feasible, economic and viable for widespread applications.

Although certain good research initiatives have been reported in the direction of controlling the process parameters and analytical modeling for suggesting the process mechanisms but several key issues remain unexplored and the process can still be considered to be in its nascent stage.

The present research initiative identifies the major concern areas for improving the efficiency and capability of the process and enhancing the output performance characteristics in finish-machining of multiple holes in pin cylinder lock bodies by AFM. Live industrial components widely used in the hardware industry have been used as work-pieces with the perspective of studying the feasibility of integration of this charismatic technique with small scale industries thereby making it relevant, economic and viable for wide spread applications. The major emphasis of the current research initiative is on optimization of process parameters for enhanced/improved quality characteristics. The importance of visco-elastic medium which acts as a deformable grinding tool and its composition is also highlighted.

Parametric optimization is crucial to obtain the optimal setting of AFM process parameters which would yield better performance of the process by enhancement of quality characteristics. Extensive experimental work is

therefore needed to study the effect of various operating parameters, having stochastic nature, and to obtain optimal settings of process parameters which yield better quality characteristics in AFM.

LITERATURE REVIEW

Abrasive flow machining (AFM), also known as extrude honing, is a method of smoothing and polishing internal surfaces and producing controlled radii. A one-way or two-way flow of an abrasive media is extruded through a work piece, smoothing and finishing rough surfaces. One-way systems flow the media through the work piece, then it exits from the part. In two-way flow, two vertically opposed cylinders flow the abrasive media back and forth. The process was first patented by the Extrude Hone Corporation in 1970.

The most time consuming and labour intensive segment of the manufacturing process in today's industry is the final finishing of complex and precision components. This consumes as much as 5 – 15% expenditure of the overall manufacturing process. The manufacture of precision parts emphasizes final finish machining operations, which may account for as much as 15% of the total manufacturing costs. Abrasive flow machining (AFM) has the potential to provide high precision and economical means of finishing parts. Inaccessible areas and complex internal passages can be finished economically and productively. To finish an external surface, additional tooling is generally required to ensure that the flow gap between the external surface and the tooling is sufficiently tight for adequate abrasive action. AFM has been likened to a semi-solid flowing file; and perhaps its greatest advantage lies in its ability to finish (deburr, polish and radius) complex internal passages or areas that are inaccessible to more traditional methods such as mechanical honing.

Today, AFM enjoys the status of one of the best processes for finish machining of inaccessible contours on difficult to machine components of a wide range of metallic materials. AFM can produce surface finishes of the order of $0.05 \mu\text{m}$. Holes as small as 0.2 mm and edge radius from 0.025 mm to 1.50 mm can be successfully finish machined with this process.

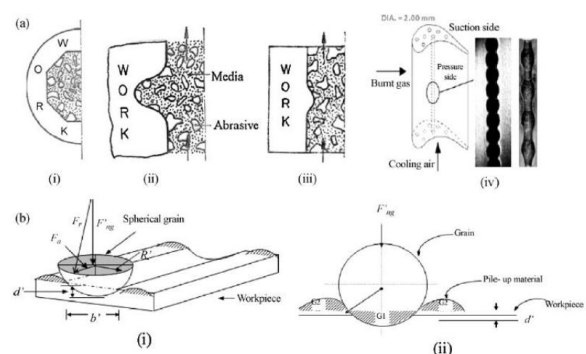


Fig.2.1 (a) Abrasive Flow Finishing medium adapts the shape of the work-piece (i) Octogonal,

**(ii) Concave, (iii) Convex, (iv) Turbulated hole, and
 2.1 (b) Schematic diagram of material removal by
 ploughing**

Ravi Sankar *et al* suggested that the chip size in AFM is far smaller (μ -chips) than the ones obtained during machining with tools having well-defined cutting edges.

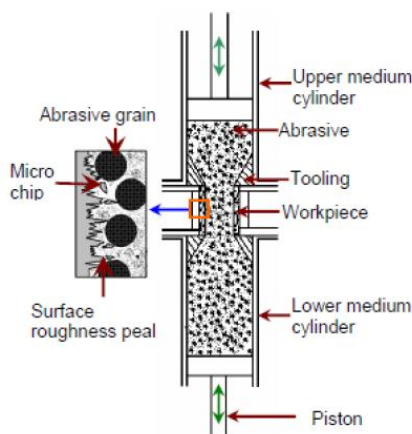
Micro to Nano level removal of material in AFM process allows production of better surface finish, closer tolerances, and more intricate surface features.

Three modes of metal deformation so far have been identified in any abrasive machining processes which are as follows:

1. Elastic deformation associated with rubbing;
2. Plastic deformation or ploughing where majority of the material is displaced without being removed, as shown in Figure 2.1(b);
3. Micro-cutting where removal of material takes in the form of miniature chips.

**PRINCIPLE OF MATERIAL REMOVAL
 MECHANISM IN AFM PROCESS**

Abrasive flow machining is complex because of the little-understood behavior of the non-Newtonian medium and the complicated and random nature of the mechanical action of material removal.



**Fig.2.2 Principle of material removal mechanism in
 two way AFM process**

Commonly used AFM is Two-way AFM in which two vertically opposed cylinders extrude medium back and forth through passages formed by the work piece and tooling as shown in Fig.2.2. AFM is used to deburr, radius and polish difficult to reach surfaces by extruding an abrasive laden polymer medium with very special rheological properties. It is widely used

finishing process to finish complicated shapes and profiles. The polymer abrasive medium which is used in this process, possesses easy flow ability, better self-deformability and fine abrading capability. Layer thickness of the material removed is of the order of about 1 to 10 μm . Best surface finish that has been achieved is 50 nm and tolerances are $\pm 0.5 \mu\text{m}$. In this process tooling plays very important role in finishing of material, however hardly any literature is available on this aspect of the process. In AFM, deburring, radiusing and polishing are performed simultaneously in a single operation in various areas including normally inaccessible areas. It can produce true round radii even on complex edges. AFM reduces surface roughness by 75 to 90 percent on cast and machined surfaces. It can process dozens of holes or multiple passage parts simultaneously with uniform results. Also air cooling holes on a turbine disk and hundreds of holes in a combustion liner can be deburred and radiused in a single operation. AFM maintains flexibility and jobs which require hours of highly skilled hand polishing can be processed in a few minutes; AFM produces uniform, repeatable and predictable results on an impressive range of finishing operations.

DEVELOPMENTS IN PROCESSES OF AFM

The basic principle behind AFM process is to use a large number of random cutting edges with indefinite orientation and geometry for effective removal of material with chip sizes far smaller than those obtained during machining with tools having defined edges. Because of extremely thin chips produced in abrasive machining, it allows better surface finish, close tolerances, and generation of more intricate surface features. One of the limitations of AFM process is the low productivity. The time to achieve the required surface finish is longer in AFM process as compared to other finishing processes. Researchers have tried to overcome this difficulty by using hybrid approach and have reported improvement in process efficiency of

AFM when centrifugal force was applied on the abrasive media while it abrades the Work piece.

Walia *et al*. Recently explored centrifugal force assisted abrasive flow machining (CFAAFM) process as a hybrid machining process with the aim towards the performance improvement of AFM process by applying centrifugal force on the abrasive laden media with a rotating centrifugal force generating (CFG) rod introduced in the work piece passage. For optimization of process parameters, an approach based on a Utility theory and Taguchi quality loss function (TQLF) has been applied to CFAAFM for simultaneous optimization of more than one response characteristics. Three potential response parameters i.e., material removal, % improvement of surface

finish and scatter of surface roughness over the fine finished surface of a sleeve type work piece of brass are examined. Utility values based upon these response parameters have been analyzed for optimization by using Taguchi approach.

The enhancement of the process efficiency of different non-traditional machining processes has been explored by researchers. In the case of AFM, Singh *et.al.* have shown the improvement in the process efficiency when the magnetic field was applied to the work piece.

Many researchers have been working to overcome the limitations, such as low finishing rate, and incapability to correct the form geometry, and at the same time to improve the finishing rate, surface integrity and compressive residual stresses produced on the workpiece surface. Singh and Shan applied magnetic field around the workpiece in AFM and developed a set-up for a composite process termed magneto abrasive flow machining (MAFM), and the effect of key parameters on the performance of the process has been studied. It was 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. Experimental results indicate significantly improved performance of MAFM over AFM.

CONCLUSION

The following conclusions have been drawn from the present study based on the statistical analysis of our research design by modern statistical techniques for data analysis and validation of the obtained results.

A simple yet versatile abrasive flow machining setup has successfully been developed with inbuilt provision for variation in process parameters to facilitate the parametric study for evaluation of the process.

Silicon based polymer mixed with AP3 Grease and Base Oil has been developed and its composition identified as SMART visco-elastic medium which acts as a deformable grinding tool for obtaining enhanced quality characteristics and improved efficiency and process capabilities from amongst various media alternatives used by application of TOPSIS with AHP. The effect of Extrusion Pressure, A; Abrasive Concentration, B; Number of Cycles, D; and Oil Concentration, E; on the material removal are found to be significant. It is further established that Extrusion Pressure, A; and Number of Cycles, D; are the most significant factors influencing the **material removal, MR** values. While Abrasive Concentration, B; and Oil Concentration, E; in the medium also have some contribution in influencing the material removal values.

SUGGESTIONS FOR FUTURE WORK

Efforts should be made to investigate the effects of AFM process parameters on performance measures in a cryogenic environment.

The weightages to be assigned to various characteristics in multi response optimization models should be based upon requirements of industries.

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