A NOVEL APPROACH FOR FINISHING INTERNAL COMPLEX FEATURES USING DEVELOPED ABRASIVE FLOW FINISHING MACHINE

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ABSTRACT

Manufacturing processes converts the raw materials into functionally usable goods. This conversion process adds value to them. Over the last few years, surface machining has assumed a greater importance in manufacturing. In recent years, surfaces are being engineered to make surface texture more suitable to the required specified functions. Finish machining of the external surfaces and easily accessible internal surfaces to specification can be accomplished by traditional processes. However, with the exception of lapping, most of these processes are nonflexible in nature and cannot access internal surfaces of intricate shapes. For this type of problems extrusion honing can be a viable solution. Extrusion honing is a process to deburr, polish and radius difficult-to-reach surfaces. The process can be applied to an impressive range of finishing operations that provide uniform, repeatable, predictable results. In this process, the small quantities of work material are removed by flowing semi solid, abrasive dispersed putty, under pressure through or across workpiece material. Abrasive flow machining was developed in 1960s as a method to deburr, polish, and radius difficult to reach surfaces with required surface finish. So in this paper an attempt has been made to develop a prototype model of a Abrasive Flow Machine (AFM) with various sensors to monitor process parameters. Experimentation was carried out on various engineering materials and studied the quality characteristics-surface finish achieved on various kinds of workpieces. It was shown that a very high surface finish is achieved as the experiments were carried out for more number of passes and even small intricate cavities available on internal surface of the workpiece was machined to high quality surface finish. Also the obtained results show that this process completely removes all traces of thermal recast layers remaining after spark erosion processes.

KEYWORDS

Abrasive Flow Machine, Carrier Medium, Viscoelastic Polymer,Surface Roughness and Characterization

1. INTRODUCTION

Abrasive finishing processes use a large number of multi point or random cutting edges for effective removal of material at smaller chip sizes than in the finishing methods that use defined cutting edges. Machining at small chip sizes allows improved surface finish, closer tolerances, more localised control, generation of more intricate surface features. For producing small chip sizes, abrasive processes are more suitable than processes with defined cutting edges. By mixing abrasive grains with some bond material or matrix material small cutting edges can be delivered directly to the machining area. The ability of the abrasive processes to produce closer tolerances has enhanced product performance; greater consistency of the processes has made it more amenable to control and thereby less rejection and faster production rates. Grinding, honing, superfinishing, lapping, polishing and buffing etc. can be grouped under this category.

Abrasive finishing processes involves the interaction of abrasive grits with the workpiece at shallow/superficial penetration depth. Development of artificial abrasives and a better understanding of the abrasive processes have resulted in placing these processes among the most important of all basic machining processes. Abrasive machining processes have two distinctive characteristics. First, each cutting edge is very small, and many of these cutting edges can cut simultaneously. With suitable machines very fine surfaces can be produced to closer tolerances. Second, since very hard abrasives can be produced, hard work materials can readily be machined. Hence these processes are not only important as manufacturing processes, but also certainly indispensable. Products like modern machine tools, automobiles, space vehicles, and so on, cannot be manufactured without these processes. Grinding can be a semi finishing process / occasionally even roughing process.

Honing, super-finishing and lapping process use abrasive in different form. The material removal in this process is by shearing action of the abrasive. The honing process is generally applied to internal cylinder surfaces, but sometime on few external surfaces also as a finishing operation. Bonded abrasive sticks /stones known as honing tool are fitted on the honing shoe of a mandrel called honing head. The honing tool is subjected to simultaneous action of rotation, reciprocation and expansion in radial direction resulting in grooves with crosshatch lay surface texture. The ratio of reciprocation speed to rotational speed decides the crosshatch lay pattern which is referred as honing angle. Honing angle of about 300° to 600° is reported to have better fluid retention properties. It provides a fine roughness of the order of 0.5 μm Ra. Typical component finished by honing are cylinder liners, engine blocks, hydraulic cylinder bores, compressor cylinder bores, connecting rods, fuel injector, bearings, hydraulic brake drums.

A study on conventional honing process reveals a number of practical difficulties in machining an inclined and complicated feature. The search for a better option reached in which a abrasive mixed polymer media for removing the material in the form of small debris to obtain a smooth finish. Extrusion honing process was born as aerospace application about 30 years back. It was developed by extrude hone corporation of USA for finishing aerospace components such as critical aircraft hydraulic and fuel system components. Since then, it has been a field of intense research by many people. The abrasive action of medium was reported [1]. When the abrasive media is forced into a restrictive passage, the polymeric carrier viscosity temporarily increases which momentarily holds the abrasive grains rigidly in place. They abrade the passages only when the matrix is in this thicker viscous state. The influencing factors of the process as extrusion pressure, volume of media flow, grit composition and type, work material are studied and presented in the obtained results [2]. This process polishes internal passages of cast automotive heads and manifolds that provide uniform, streamlined flow paths within the head and manifold [3]. Streamlining and directional surface finish lay produced by the process enhances the passage flow efficiency and fuel efficiency in turn economy of engine application [4]. Also the process is extended to study the usefulness of the process in finishing the components produced by stereolithography [5]. Abrasive flow machining was identified in 1960s as a method to deburr, polish, and radius difficult to reach surfaces and edges by flowing an abrasive laden viscoplastic polymer medium over them. The medium should have bonding strength, compatibility, higher abrasive exposure, stabilization of formulation, thickening efficiency and ease of processing. The viscosity of polymeric medium plays an important role in finishing operation [6].

Hence the proposed paper is planned with an objective of characterizing the AFM surfaces and evaluation of process parameters. In this paper an attempt has been made to develop a prototype model of AFM with various sensors to monitor process parameters and experimentation was carried out on various engineering materials machined previously with conventional machine tools like CNC machining centers and studied the quality characteristics-surface finish achieved on various workpieces. The present paper contains the results obtained during the machining of one of the precision aerospace component nitralloy collar sleeve.

2. EXPERIMENTAL SETUP

Figure 1 shows the schematic diagram of the developed experimental setup of abrasive flow machine basically consists of two abrasive slurry cylinders and two hydraulic cylinders. The two abrasive cylinders are connected with flexible steel hose pipe to feed the abrasive slurry exiting from the bottom cylinders to top cylinder to ensure the continuous machining at the cylinders. It will reduce the time for feeding the cylinders and hence it will increase the productivity of the system. The hydraulic cylinders are drive through the power pack to give the linear movement to push the abrasive slurry present in the slurry cylinders through the workpieces to be machined. To monitor the hydraulic cylinder positions at extreme ends, limit switches are mounted on hydraulic cylinders: LS1 to LS2 on hydraulic cylinder 1 and LS3 and LS4 on hydraulic cylinder 2. These limit switches are very much essential for cylinder synchronization-extension and retraction of hydraulic cylinders in turn controls the abrasive cylinders 1 and 2. Abrasive impregnated polymeric medium with different volume fraction and abrasive mesh size is employed in the current study. The workpieces are rigidly held between the designed work fixtures at the exit of abrasive cylinders.

A 4/3 solenoid operated closed centre direction control valves are used to control the direction of fluid flow into the hydraulic cylinders 1 and 2, so as to reverse the forward and return strokes which in turn control the direction of the abrasive slurry cylinders 1 and 2. Pressure gauges are mounted on the hydraulic cylinders to monitor the pressure variations during the machining operation. The measuring scale is also mounted on the hydraulic cylinders to monitor the stroke length of the hydraulic cylinder. The speeds of the hydraulic cylinders are controlled through a flow control valve.

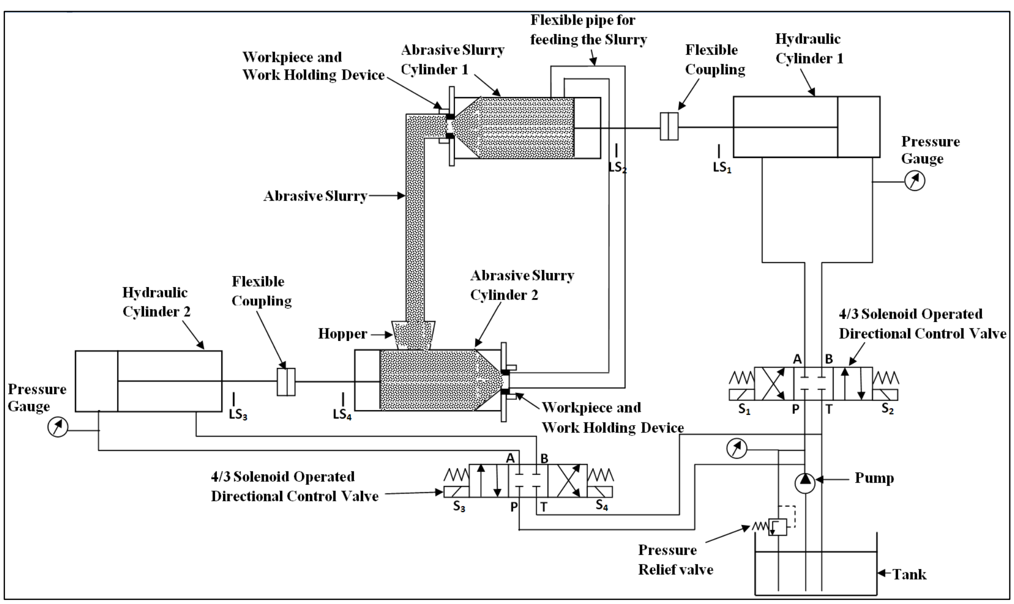


Figure 1. Schematic diagram of developed abrasive flow machine

At most care is taken to connect two hydraulic cylinders to operate in a sequential manner. That is when the hydraulic cylinder 1 extends (it moves from LS1 to LS2) and pushes the abrasive media present in the abrasive cylinder 1 and it will comes out in the all the direction along the cavities/holes present on the workpiece mounted at the exit of abrasive slurry cylinder 1. The pushed abrasive media along with debris machined will fall in the bottom slurry cylinders through gravity. After hydraulic cylinder 1 reaches the limit switch position LS2 and immediately it will retract back to position LS1. Now the hydraulic cylinder 2 extends (it moves from LS3 to LS4) and pushes the abrasive media present in the abrasive cylinder 2 and it will comes out in all the direction along the cavities/holes present on the workpiece mounted at the exit of abrasive slurry cylinder 2 and abrasive slurry will pass through the flexible pipe to the inlet of abrasive slurry cylinders 1. As hydraulic cylinder 2 reaches the limit switch position LS4, hydraulic cylinder 1 is in action and cycle repeats.

Figure 2 shows the photographic view of the developed experimental setup of abrasive flow machine and the enlarged view showing the flow of abrasive media through the workpieces having various intricate cavities and holes during the machining process.

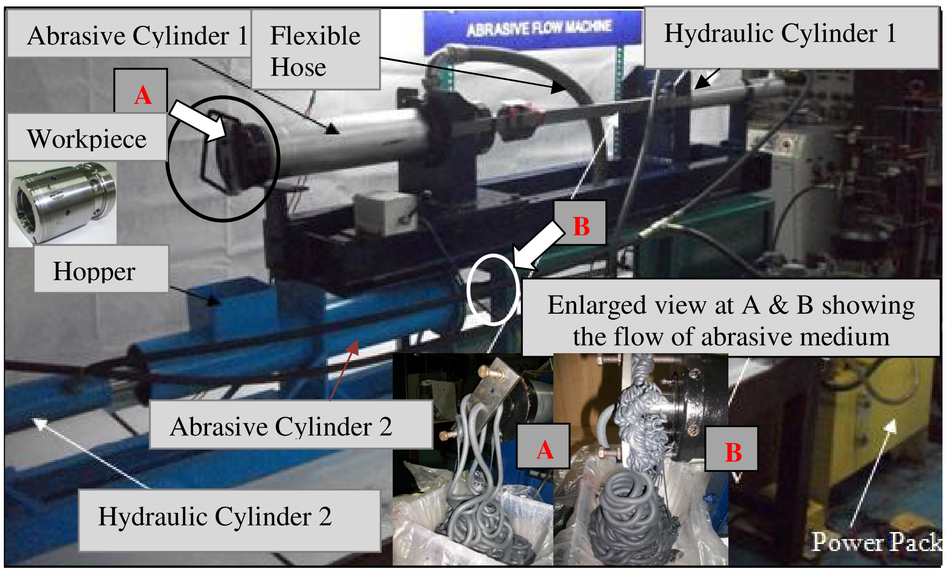


Figure 2. Experimental setup of developed abrasive flow machine

3. RESULTS AND DISCUSSIONS

Preliminary experiments are carried out to study the individual stage of abrasive flow machining operations and to arrive at the selection of process parameters. Parameters that are used to characterize measurements of surface topography are defined almost entirely in terms of the profile signal generated by stylus type measuring instruments. Methods that characterise surface roughness ideally need to embody an assessment of the height (amplitude) and the spatial (wave length) characteristics of the topography of a specimen [7]. In the present study the parameters of interest on the quality of surface finish produced on the workpiece are Ra, Rmax, and Rz values.
In the present paper the results concerning to the machining operation carried out on one of the aerospace component nitralloy collar sleeve made with AISI 1117 material having HRC 24-30 (shown in Figure 2). Initially the component was machined with 5-axis CNC machine and measured the surface characteristics- Ra, Rmax and Rz values. Later the component is machined with the developed AFM with number of passes. The machining operations are carried out with a

pressure of 22 kg/cm^2, abrasive concentration 40% in the medium and velocity of the slurry comes out of the component at 0.93 m/min. The time required to complete one pass was found to be 20 minutes. After machining the components with required number of passes, they are cleaned with cleaning agent acetone and then measured the roughness values using perthometer. Traversing length 5 mm is used to evaluate the surface roughness. The care should be taken to measure the surface characteristics for every 3rd and 6th passes. Figure 3 shows the variation in surface characteristic- surface roughness Ra with number of passes at different locations on the machined piece. As the number of passes increases there is a drastic reduction in Ra value is seen from the Figure 3. Figure 4 and Figure 5 shows the Rmax and Rz values measured at different locations.

Table 1 shows the complete list of parameters measured on the sleeve component for different passes. From the obtained results it is seen that there is a progressive reduction in Ra, Rz and Rmax values as the number of passes increases. It is also seen that only marginal improvement in the surface texture beyond 6th passes.

An attempt has been made to show this process is very much efficient to remove the recast layer formed during electro discharge machining process. Figure 6 shows the effect of abrasive flow machining to remove the recast layer as formed during the electro discharge machining process. As the number of passes increases the recast layer will completely removes from the work surface.

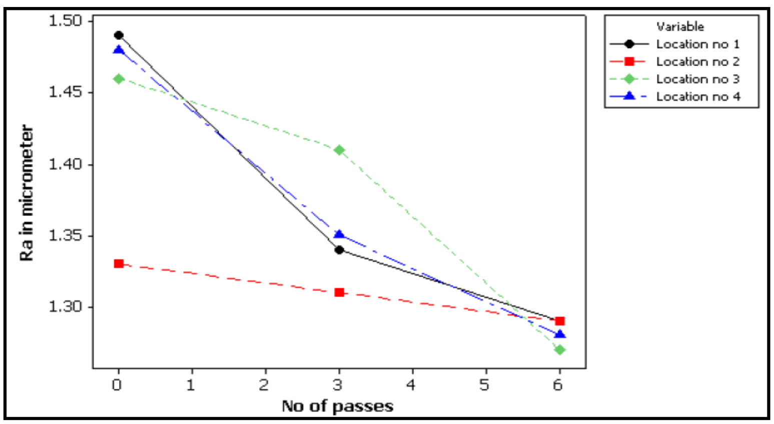


Figure 3. Number of passes vs. surface roughness characteristic -R_a value

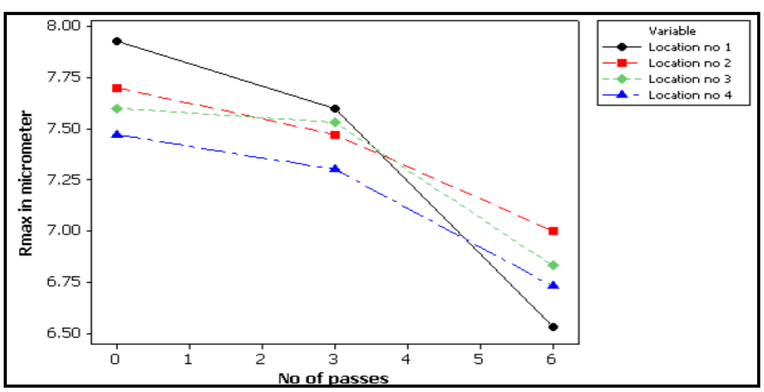


Figure 4. Number of passes vs. surface roughness characteristic -R_{max} value

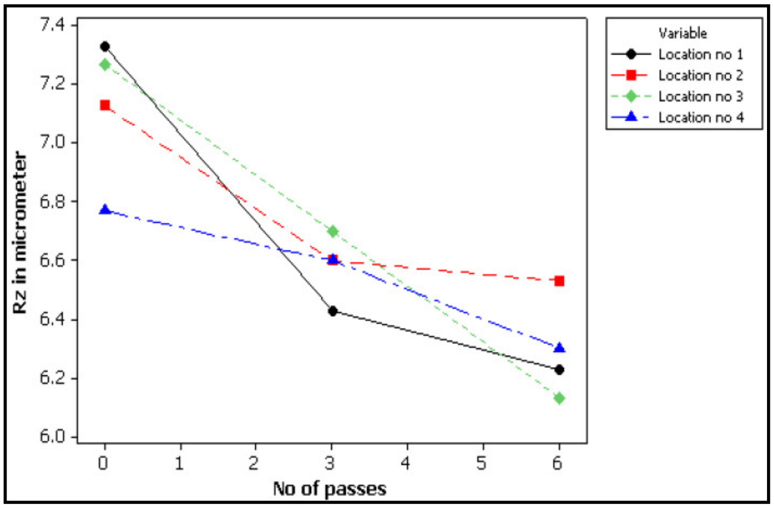
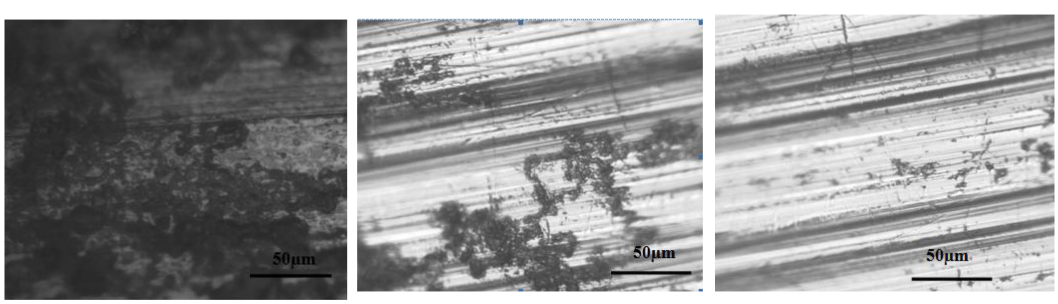


Figure 5. Number of passes vs. surface roughness characteristic -R_z value

Table 1. Surface roughness values at different stages of AFM with Nitroalloy Collar

Surface Roughness values after machining from Abrasive Flow Machine																		
Material : Nitralloy collar				Machining Time : 20min/pass				Application: Automobile Engine component						Abrasive concentration 40%				
Location Number	Ra in µm						Rmax in µm						Rz in µm					
	After 5 axis CNC		After 3rd pass		After 6th pass		After 5 axis CNC		After 3rd pass		After 6th pass		After 5 axis CNC		After 3rd pass		After 6th pass	
1	1.61	1.49	1.38	1.34	1.28	1.29	8.20	7.93	8.90	7.60	7.00	6.53	7.10	7.33	6.80	6.43	6.90	6.23
	1.55		1.32		1.33		7.90		7.10		6.30		7.80		6.40		5.80	
	1.32		1.31		1.26		7.70		6.80		6.30		7.10		6.10		6.00	
2	1.36	1.33	1.29	1.31	1.26	1.29	7.70	7.70	7.40	7.47	7.30	7.00	7.30	7.13	6.90	6.60	6.70	6.53
	1.24		1.27		1.33		7.50		7.00		6.60		7.10		6.60		6.10	
	1.40		1.36		1.27		7.90		8.00		7.10		7.00		6.30		6.80	
3	1.37	1.46	1.40	1.41	1.25	1.27	7.20	7.60	7.10	7.53	6.20	6.83	6.70	7.27	6.60	6.70	5.90	6.13
	1.55		1.43		1.27		7.60		7.70		7.10		8.00		6.40		6.30	
	1.45		1.39		1.30		8.00		7.80		7.20		7.10		7.10		6.20	
4	1.33	1.48	1.30	1.35	1.30	1.28	7.00	7.47	8.10	7.30	7.00	6.73	6.40	6.77	6.90	6.60	6.30	6.30
	1.67		1.31		1.26		8.20		7.10		6.20		7.00		6.70		6.10	
	1.45		1.43		1.28		7.20		6.70		7.00		6.90		6.20		6.50	
Traversing Length :5mm			Pressure: 22 Kg/cm²			abrassive mesh size 120			Velocity 930mm/min						Identfication No : F-100			



(a) Before AFM (b) After 6 passes (c) After 12 passes

Figure 6. Lay pattern of recast layer after 6^{th} and 12^{th} passes in abrasive flow machining

4. CONCLUSIONS

Abrasive flow machining is relatively a new non-traditional machining process which is being used to deburr, polish, radius, remove recast layers, or to produce compressive residual stresses in a wide range of applications.

So for finishing of inaccessible surfaces, most suitable and viable method known as abrasive flow machining used to produce a super finish on various components made with newer engineering materials used in industry, aerospace and defence applications.

The following are the major contributions and conclusions drawn from the study:

- An attempt has been made to develop an experimental setup of abrasive flow machine used to machine various components having intricate profiles and inaccessible areas efficiently and effectively
- The machining operation was carried out with one of the aerospace precision component nitralloy collar sleeve and the obtained results show the progressive reduction in Ra value with number of passes and also there is a visible/drastic reduction in Ra, Rz and Rmax values as the number of passes increases. It is also seen that only marginal improvement in the surface texture beyond 6^{th} passes.
- Also an attempt has been made to show this process is very much efficient to remove the recast layer formed during electro discharge machining process

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