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Recent Progress in Extrusion Honing Process: An Overview

Jayasimha SLN[1]
Research Scholar, Department of Mechanical Engineering, P.E.S. College of Engineering, Mandya-571401, India

H.P. Raju[2]
Professor, Department of Mechanical Engineering, P.E.S. College of Engineering, Mandya-571401, India

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Abstract-The ultimate operation accomplished in any of the production process is finishing. As the prerequisite for surface integrity enhances, the price of the commodity escalates exponentially. The need for surface finish of one-micron improvement on component surface increments the cost greatly. Surface texture plays a vibrant role on significant tribological properties such as wear resistance and power loss due to friction in most of the assembly elements. Manufacturing of machine elements for precision, accuracy and tolerances within the limits is a complicated, unavoidable and laborious in nature. The remedy for such a barrier is extrusion honing (EH). This is an unconventional finishing process where in many shearing edges at irregular positions achieve material removal in the form of minute chips compared to traditional methods. This process has a diverse use in variety of industries such as automotive, aerospace, defence, medical, tool and die making. Some of the examples include nozzles, impellers, precision dies, micro holes etc. The current article makes an attempt in identifying the diversified opportunities available in EH process and efforts of the research scholars to evaluate the surface characteristics and material removal under different input conditions, optimization of process parameters, real time monitoring, simulation, modelling, developments and applications of EH process.

Keywords: Extrusion Honing (EH), Surface Finish, Material Removal (MR)

1. INTRODUCTION

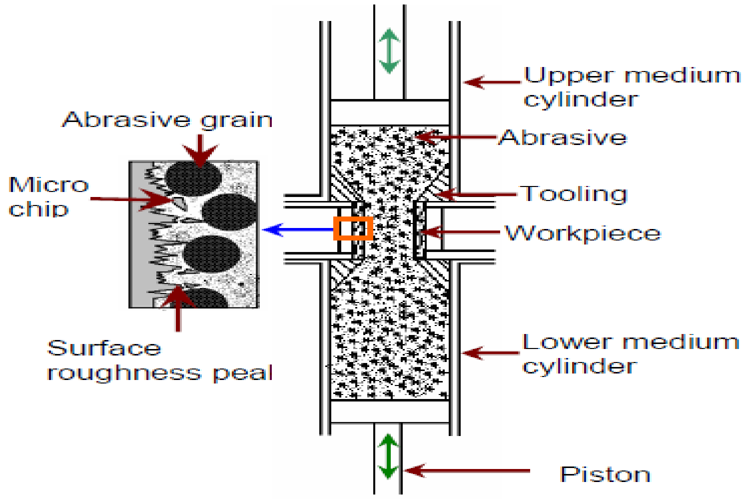
The quality of surface and dimensional accuracy is taken by precision finishing operations such as deburring, honing, lapping and grinding. To meet the requirement of a finishing technique which has extensive purposes, better conformity of performance, higher efficiency and automatic operation, extrusion honing (EH) process has been developed and is also called as abrasive flow machining (AFM)/abrasive flow finishing (AFF). This finishing technology has been developed by Extrude Hone Corporation, USA in 1960 to finish aerospace components to the required accuracy and the machines are commercially available as Extrude Hone Machines. Finishing process usually account for 15 % of entire finishing cost in a production cycle [1].

Extrusion Honing (EH) is a fine finishing process focusing towards limitations in tooling, precise finishing of complicated shapes and interior cavities in components. The process involves pressurized flow of semi viscous polymer mixed with abrasives particles of known mesh size and concentration is extruded over the surface to be finished. In EH deburring, radiusing and polishing are performed simultaneously in a single action including unreachable zones by a carrier medium having distinct visco elastic properties [6].

In EH media is the key component that regulates the finishing action and a visco-elastic medium which is a polymer generally polyborosiloxane or silicone [7] with a unique property of viscosity associated with elasticity (elasticity, compression, resistance, increased relaxation time) and an abrasive (SiC) blended with a known volume of medium in pressurized condition is allowed to flow over the region to be polished. The specimen is held across the opposed medium chamber with suitable fixtures and the abrasive media is encased inside the cylinders. The advantage of EH is accomplished by reaching remote areas, complicated shapes with an enhanced surface texture, reduced reworking and rejection.

Variable factors include extruding pressure, number of strokes, mesh size and type, volume fraction have the effect on EH output reactions i.e surface integrity and stock removal. The predominant input parameters discovered are concentration of abrasive succeeded by mesh size, number of strokes and medium flow speed [5]. The polymeric rough medium utilized in this procedure have flowability, better self-deformability and good abrading capability.

Figure 1: Process of Extrusion Honing



2. EXTRUSION HONING PROCESS

The EH machine consists of structural frame, medium cylinder, hydraulic arrangement and control system. The tooling is designed in a manner to accommodate the specimen in location and direct the flow for polymeric medium.

The major component of extrusion honing machine includes EH machine, tooling and media.

EH Machine: It consists of cylinders containing polymeric medium with abrasives. The hydraulic setup is responsible for extruding the media inside the cylinder and squeezing the medium with the pressure from 0.7 to 22 MPa.
Tooling: It is employed to restrict and direct the flow of media into the exact areas. The basic principle is to permit the flow of media in to the work piece cavities where finishing is required and to grip the element in required orientation.
Media: The characteristic feature of media determines the aggressive action of abrasive during EH process. The base material is a semi viscous polymer and the medium interacts with the specimen texture to be finished. The abrasives are held rigidly in position and the medium acts as a deformable grinding stone. The commonly used abrasives are Al_2O_3, SiC, CBN and Diamond.

Table1.Extrusion Honing Process Parameters

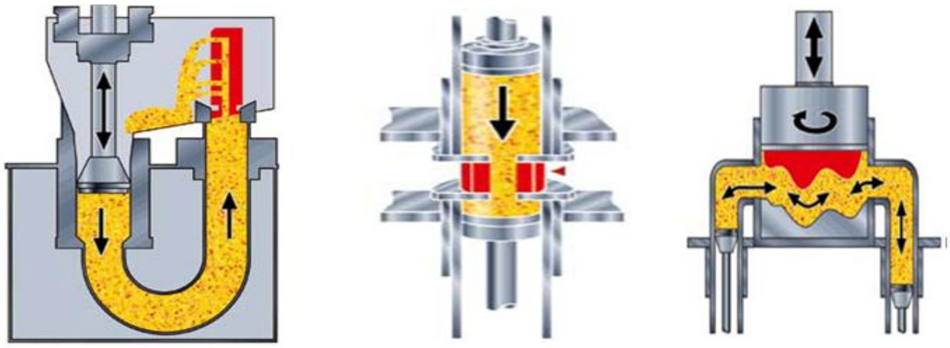
MACHINE	MEDIA	WORK PIECE
Extrusion Pressure	Abrasive Concentration	Composition
Number of Cycles	Abrasive Mesh Size	Hardness
Position of Machine	Type of Abrasive/Volume	Geometry
Stroke Length	Polymer Type	Initial Surface Finish
Velocity of Media	Viscosity	
	Additives	

Based on the relative motion between polymeric medium and specimen, AFM machines are categorized into following types:

One-way EH process is furnished with a hydraulically triggered reciprocating piston and a cylinder to get the medium and then force the medium in unidirectional track over the interior passage of a work piece having core sections [2]. Fixture guides the stream of silly-putty from cylinder to the interior cavities of the work piece.
Two-way EH consists of two hydraulic reciprocating piston in association with dual medium cylinders. The medium is extruded from supply cylinder via interior cavities of workpiece and then collected in the receiving chamber [3]. In this type medium is reciprocated in between the cylinders for known number of cycles.
Orbital EH the specimen is subjected to vibrations in more than two directions within a slow flowing abrasive medium. Appreciable finishing is obtained by rapid low-amplitude oscillations of the specimen relative to a self-forming elastic plastic abrasive polishing tool [4]. The medium is similar in nature as used in previous two methods of AFF, but higher in

viscosity and more elastic. The concept of this method is to provide translatory motion to the specimen. Blow moulds of pet bottles are processed by this finishing technique [8].

Fig 2: Types of Extrusion Honing (Courtesy: Extrude Hone Corporation)



a. One Way Flow EH b. Two Way Flow EH c. Orbital EH

3. EH INPUT PARAMETERS OPTIMIZATION AND THEIR EFFECT ON SURFACE FINISH

Rhoades [1] explored the essential law of AFF technique and determined its control factors. The author concludes that when the media is quickly constrained across unaffordable cross section the viscosity of the media rises momentarily. Appreciable amount of material is evacuated and is a result of abrasion which relies on viscosity, flow rate and pressure. Each of these parameters finally alter the intensity of abrasive grains collaborating with the work piece and the force developed on an abrasive particle. High volume of medium enhances the abrasive grains interacting with the work piece thus more MR is resulted.

Jain and Adsul [5] detailed existing waviness and resistance of the work piece impacts material expulsion in AFF process. Material expulsion and decrease in waviness is accounted greater if there is an easy work piece material. Enriched material evacuation and decrease in surface roughness increments when the percentage of abrasive grains in the medium increments. For all the factors considered, the most influencing one is the concentration of abrasives chased by grit size and strokes.

Rahul O Vaishya et.al [6] efforted in finishing gun metal for reducing the roughness texture by AFF process by considering the number of cycles, grit size and pressure with steady rotational speed on material evacuation. To visualize the impact of different parameters Taguchi method L9 orthogonal array has been applied. There has been a significant achievement of influence of pressure as the number of cycles increases from 3 to 7 R_a enhances further.

Sachin Singh [7] attempted to compute the axial and radial force generated in AFF process by finding the visco elastic properties of the medium. Theoretical development of ΔR_a w.r.t variation in expulsion pressure, AFF cycles and weight % of plasticizer has been assessed. As the AFF strokes extends, ΔR_a increments with the expansion in pressure, F_R and F_A acting in the medium increments, hence ΔR_a increments. ΔR_a diminishes as the weight percentage of plasticizer increments in the AFF medium. The authors also designed and structured the AFF setup for miniaturized abrading of interior passages of Cr coated alloy pipes and validate the consistency by FEA simulation [19].

Raju H P [8] clarified that silicone can be utilized to finish SG Cast Iron at lower pressure range (10 bar) yields anticipated outcomes instead of using polyborosiloxane. A dynamic advance in surface finish is realized upto seventh pass after which the texture initiates to decline. Enhancement in bearing region is significantly credited by the investigator.

Jain V.K. et al. [9] reported the impacts of grit size, concentration of abrasives and temperature on viscosity of the medium. Study has been executed for grit sizes and medium temperatures. Viscosity of the medium expands with increment in abrasive concentration and diminishes with decline in grit size and medium temperature. It has been found that as viscosity of the medium increase material removal increases and surface finish decreases.

Jain V.K. et al. [9] explained about the abrasive activity of the medium. When the medium is constrained into an unaffordable region the viscosity of the polymer rises temporally which holds the abrasive particles firmly and scratch the channel when the matrix is in the dense viscous phase.

Williams and Rajurkar [11] proposed that affecting variables of this finishing method are expulsion pressure, volume of medium flow, grit structure and specimen. This procedure shines interior sections of engine heads and exhaust system that gives uniform streamlined flow ways. Polishing delivered by this procedure upgrades the fuel effectiveness thus cost reduction in IC engine.

Williams and Melton [12] portrayed the significance of this process by finishing the segments delivered by Stereolithography (SL). It is a layer manufacturing technique that delivers a tangible model from computer graphical data. In this process material is added layer by layer to develop a model having stair-case/vertical or slanted surfaces demanding post-curing to accomplish enhanced surfaces of the model. Customary techniques like sandblasting and tumbling have been utilized as finishing procedures on stereolithography models delivering conflicting outcomes. Surface investigation utilizing AFM resulted a good surface finish.

Davies and Fletcher [13] considered the rheological qualities of the medium utilized in AFM process. Functioning of polyborosiloxane and abrasive blend used have been examined. Examinations were led by utilizing low, moderate and high viscosity medium mixed with SiC particles of various grit size. Moderate viscosity produces decrease in temperature rise, increment in pressure across the die and low handling time is accomplished. An expansion in mesh size has insignificant impact on rheological parameters and gradual utilization of the medium enhances its thickness.

Raju H.P et al. [14] investigated EH on Inconel 600 utilizing silicone polymer. The response factors for Inconel 600 sample were estimated at two areas, one on arrival side and other on the depart side of the sample. The surface characteristics exhibit a dynamic improvement upto thirteenth trial at both arrival side and depart side of the passage after which surface begins to fade. Surface at the depart edge is superior to arrival edge because of well interaction with abrasive medium.

Murali Krishna N.L et al. [15] depicted the texture qualities of Ni alloy 625 pre machined by EDM for square shape. The finishing process with 60 bar, mesh 36 and 15 passes exhibit vast outcomes in finishing. The sheared surfaces have been examined under surface roughness analyzer and SEM. Excellent decrease in surface roughness parameters happens at third pass and constant improvement in surface finish up to eleventh trial after which surface begins to decay. Refined surface disclosed minute cracks and recast layer has been eliminated.

Wang A.C. and Weng S.H. [16] informed that AFM produces incredible polishing impact in intricate cavities cut by wire electrical electric discharge machining (WEDM). The recast layers resulted by WEDM can be eliminated. Media is the key component answering for shining effect in AFM. The silicone polymer won't adhere on to the work piece surface after machining.

Ravi Shankar M et al. [17] expressed that the AFF of intricated shape parts requires superior finishing to create nano level surface finish. This method utilizes abrasives blended with SB polymer to polish intricate profiles, it must have three fundamental properties i.e., better flowability, self-deformability and abrading capacity to refine the offered texture to nano scale. Different flow and deformable properties of the medium can be examined by polymer rheology.

Gourhari Ghosh et al. [18] explored WC-Co coating deposited on low carbon steel test specimen using high velocity oxy-fuel spraying technique. The roughness of the as-sprayed surface is around 4.882 µm. A multipurpose honing process is included to enhance the texture of the test sample. In the first step, surface grinding using diamond grit wheel is performed then shape adaptive grinding (SAG) is achieved using a Zr-Al polishing pad mounted on an elastic base. The purpose of SAG is to shrink the surface finish close to sub-micron level. Finally, chemical assisted SAG is executed using Murakami's reagent and surface roughness of the component reduced to 0.18 µm.

Kenda et al. [20-21] analyzed in finishing hardened tool steel samples which were pre-drilled by EDM method. They outlined the impact of the AFM process constraints on characteristics of the surface texture and the initiation of residual stresses. The investigator extended the utilization of AFM process for plastic gears and recognized the improved surface from R_a = 0.68 to 0.08 mm in 120 secs.

Przyklenk [22] efforted the effects of work piece geometry, surface roughness and change in microstructure adjacent to the machined surface with different media. It has been concluded that with minor hole dia more abrasive grains interacts with the wall and MR increments. With the increment in number of cycles there is an enhancement in MR due to high primary unevenness of the specimen surface, it gradually reduces per cycle. It has been suggested that the medium should not be permitted to attain a temperature greater than 1000ºC and maintain the viscosity of the media within the limits.

Studly [23] summarized some of the aerospace applications of AFM process for finishing hundreds of holes in a disk in one operation, uniform and controlled stock removal of cast blades with minimum dimensional change, resizing of cooling holes in aircraft engine, combustion liners and finishing of turbine components.

Bahre.D et al. [24] featured that the two most critical process parameters affecting the integrity of surface and the MR are number of strokes and intensity of pressure. The scope of number of cycles applied in present trials are extensive in nature. Many investigators have performed the trials with 15 cycles [8], while others have performed the trials by taking 100 as the number of cycles [29]. From the literary works it is clear that the majority of the examinations have been performed by applying the cylinder pressures in the span of 5 to 80 bar.

Martin Swat et al. [25] described the use of automotive steel AISI 4140 as a material interest for the investigation of AFM by relating various levels of piston pressure. Further, a force model which is dependent on in-process estimation of axial forces has also been established. The force model concentrated on the cylinder pressure and friction in the AFM medium.

Ghadikolaei and Vahdati [26] obtained higher surface integrity in copper when compared to aluminium. They determined the occurrence of greater magnetic field strength in copper samples reveal superior surface condition in MRAFF.

Perry [27] established an improvised tooling method in AFM, that allows minute passages, multiple cavities that can be processed after boring process.

Rhoades [28] automated the AFM by providing a new controlled and automatic process for finishing the work piece surface. The author introduced transposition compartment connecting the work to be abraded and silly putty. The superior surface finish has been attained because of centrifugal force developed by the bar on the abrasives because of rotating the bar. It has been noticed that the chance of medium getting rotated at the abrasive-work piece interface is small and recognized it as CFAAFM [63]. Further improvement of the process also includes introducing a drill bit in the direction of medium flow [65] and identified as DBG-AFF. The investigations are also progressed by improving the surface texture on Al MMCs with SiC reinforcement by imparting rotary motion [66] to the work piece and identified it has rotational abrasive flow finishing (R-AFF).

Rajeshwar et al. [30] advised a numerical simulation model to adopt the attributes of the medium flow during polishing and its experimental investigation has been performed. This model is constructed utilizing constitutive conditions of Maxwell model considering the medium obeys non-newtonian flow. Researchers revealed that a linear relationship exists between shear stress developed on the surface and thick film of stock removed. Attempts are also made in analyzing the heat flow to know the difference in work piece temperature [31].

Jain et al. [32] explored the flow of visco elastic polymer and the outcomes ensued have been utilized to govern the material removal and surface characteristics. Hypothetical outcomes are contrasted with test results. The central composite rotatable design is utilized to structure the experiments and to condense the number of trials.

Walch et al. [33] structured and constructed AFF machine for finishing the cavities of specimen utilizing abrasive medium possessing dissimilar viscosities by adjusting the dimensions of pistons and cylinders in positive displacement pumps.

Gorana et al. [34] advised a hypothetical model of forces acting up on a solitary abrasive to understand the honing procedure of AFM process. Examination of hypothetical model outcomes with that of exploratory information of force and dynamic grains density process have been performed. The intensity of forces and density of abrasive grains obtained as a result of comparison between theoretical model and experimental results have been studied.

Jain et al. [36] applied back propagation neural network with augmented Lagrange multiplier [35], artificial neural network (ANN), multivariable regression analysis (MVRA) and nonlinear MVRA [39] methods in AFF. From trial results it was found that proportion change in assessing of untrained data got varied significantly in all the approaches. Al/SiC MMCs as a material interest also been focused by this manner [37]. Investigators also demonstrated Heuristic search algorithm with ANN [39].

Williams R E [40] reported the application of acoustic emission (AE) technique for observing the abrasive flow machining process. It has been observed that the acoustic emission sign mainly depends on primary surface characteristics (R_a) associated with attributes of work material. The initial AE signal had a frequency of 160kHz because of work piece composition and flow lines. With the increment in number of strokes the amplitude of this frequency also improved. The smaller diameter passage processed with AFM, using AE monitoring system resulted good correlations between voltage, emitting signal, orifice dimensions and volume of flow. Data Dependent Systems (DDS) frequency decomposition of the AE signals obtained during this process yielded unique occurrence of bands. The same method has been employed for Ni based alloys utilizing one-way extrusion honing [41]. Some of the authors also emphasized acoustic emission sign as key factors in artificial neural network to forecast nanoscale objected polishing [42] and in magnetic abrasive finishing [43].

4. SIMULATION AND MODELLING OF EH PROCESS

Jain V.K.et al. [44] explained AFM process by utilizing FEM technique by studying the forces exhibited on a solitary grain has been examined to know the material evacuation on brass. Response surface methodology is used as a research interest to examine the impact of pressure and number of strokes on surface integrity. Material expulsion halts to increment after 20 cycles. There has been an assumption that all the grains are spherical possessing solitary shearing edge with identical size and load bearing on individual abrasive particle is constant with identical indentation depth depending on applied load. The abrasive action in AFF is a sequence of micro ploughing followed by micro cutting [29].

Rupalika Dash et al. [45] performed simulation of AFM on copper specimen with SiC as abrasives by considering laminar mixture model. The CFD analysis is executed for constant volume fraction and mesh size of abrasives. The flow analysis of the polymeric medium across the intricated passage have been studied. The MR is computed by considering the displacement of the upper piston only. The material evacuation can be escalated by incrementing the number of strokes, extruding pressure, grit size and active abrasive particles in the medium. The finishing technique studied by Ansys fluent approach is significant, since testing method is laborious and time consuming.

Sachin Singh et.al. [46] analyzed investigations on nano finishing of surgical stainless steel 316L tubes using AFF. Indigenous polymeric medium blended with abrasives has been utilized to avail nano finishing. To realize the AFF in detail, finite element approach has been applied to govern the finishing forces produced. Surface integrity in the interior passage reduces in the span of 0.67-0.50 µm. The fine texture of 48 nm with enrichment of % R_a 92.20 % is attained. Virtual data have been corelated with test data and the variations are in the tolerable range.

Liang Fang et.al. [47] applied the computational method to AFM method, viscosity of the medium leads the flow velocity when cylinder pressure has been kept constant. High viscosity in the media flats the gradient flow velocity that decrements the rolling tendency of abrasive particles ensuing in escalation of the stock removal efficacy. The difference in cylinder pressure has an advantage in the AFM process also supplement the material removal efficiency and AFF method has been demonstrated by COMSOL segment of MAT LAB [48].

Li et al. [49] structured AFM arrangement to achieve precise machining of components. The investigators simulated the AFM by attempting speed and pressure distribution by exercising flow analysis software (Ansys Fluent).

Uhlmann et al. [50] established a model utilizing advanced simulation methods on AFM for ceramic materials and emphasized the connection among flow parameters, surface characteristics and edge rounding.

Jain et al. [51] expressed the MR mechanism in AFM by developing FE model of forces and random probability distribution [52] exhibiting on an individual grain. The researchers also linked the results acquired from FEA for material removal.

Wan.S et al. [53] reported his descriptive analysis on two-way abrasive flow machining process by considering in-elastic non-newtonian model to understand the flow nature of the abrasive medium with a wall slip model. To evaluate the relative motion between the medium and the confining wall, wall shear rate has been considered describing the surface integrity and stock removal. Projected results were in good agreement with test trials got from the simulation on straight tubes with elliptical profiles.

Pawan Pal and K K Jain [54] assumed the polymeric medium as Newtonian and flow to be laminar in nature with no wall slip. The multiphase mixture model has been considered with two phases for the flow analysis. A 2D model has been framed and compared with the test results. In the flow analysis, estimation of force has been done and analyzed for different volume fractions. The flow simulation has been accomplished using Ansys fluent.

5. DEVELOPMENTS IN EH PROCESS

To improve the capability of EH process numerous investigators have put forwarded their ideas by combining conventional EH with other machining process such as ECM, USM, CHM etc. to ensure optimum surface integrity.

Singh and Shan [55] improved the capacity of AFM process by introducing magnetic field (MAFM) around the specimen and noticed the effect of magnetic field on MR and honing characteristics. When the work piece has been exposed to magnetic flow lines resulted high material evacuation and severe change in surface finish on brass with least number of strokes and reduced medium flow.

Shinmura et al. [56-60] executed sequence of practical and empirical study on MAFM utilizing magnetic abrasives by inducing honing pressure exerted by a magnetic field. Also, it has been noticed that characteristics of surface at micron levels [60] is achieved and by extending this technology for refining surfaces on SS41 steels [59]. An FEM model has also been put forwarded for this process for knowing the surface texture [61]. The MAFF is also studied by using magneto rheological fluid i.e carbonyl iron powder and SiC blended with visco elastic polymer consisting of lubricating oil has been employed to finish steel alloy samples and called it as MRAFF [62].The studies are further enhanced by incorporating rotary motion to the as discussed technique [71]. Authors also emphasized electrolytes mixed with polymers for levelling the waviness in the surfaces and named it has electro-chemical aided abrasive flow machining [64].

Sharma et al. [67] explored ultrasonic assisted abrasive flow machining (UAAFM) process in which work piece has been exposed to ultrasonic vibration normal to the medium stream path. In addition, they analyzed the mechanism of ultrasonic vibrations involved in surface finishing [68-70].

6. APPLICATIONS OF EH PROCESS

Kavithaa Thirumalai Subramanian [72] emphasized by finishing hip joint made of Co-Cr alloy. For nano level finishing the R_a trials utilizing surface roughness tester are noted and the surface texture of hip joints has been analyzed using SEM and for residual stress utilizing XRD. The medical application has made AFM a flexible process emphasizing it as worth, efficient and multipurpose process in finishing of bio-medical implants and also semiconductors in electronic industry.
It is capable of producing surface texture R_a with accuracy 0.05 µm, burrs in the cavities removed is as tiny as 0.2 mm and hones edges from 0.025 mm to 1.5 mm. Largest diameter processed by this method is around 1000 mm. Depth of stock removed is about 1 to 10 µm. Fine surface texture attained is 100-50 nm and tolerances are ± 5 µm. Diffusers, impellers, nozzles, orifices, manifolds, pistons, gears, couplings, tubes and pipes, spring collets, cylinders and engine heads are some of the elements finished by AFM. Elimination of thermal recast layers left by EDM, LBM, IBM and PAM. Biomedical applications include hip joints and orthopaedic implant by utilizing magneto rheological fluid type honing tool and heart valves by basic EH process.

7. CONCLUSIONS

EH is a significant unconventional and multipurpose finishing process for finishing complicated profiles. The idea of extruding polymeric media by suspending abrasive particles and forced to flow across the sections of interior and exterior surfaces is discussed. This technique is fulfilling the assurance by honing intricated geometries made from materials which are challenging in nature.

Outcomes of AFF process i.e surface finish is a function of factors such as number of cycles, extruding pressure, velocity of flow, mesh size and concentration of abrasives. Due to mechanical impact of abrasive particles on the work-pieces surface the material is abraded from the surface. From the literatures it has been evident that there is a peculiar behaviour of visco elastic nature of the polymer.

Hybrid EH processes such as R-AFF, MRAFF, CFAAFM, and DBG-AFF have been admired for simultaneously deburring and polishing to finish hard materials like Ni, Ti alloys and MMCs. The main drawback of this method is reduced MR. Efforts are being made to rise the finishing rate. Finishing of additive manufactured and powder metallurgy components will be the upcoming area in finishing [12 and 73].

The optimization techniques employed is found to be ANOVA, Taguchi, Central composite rotatable design, RSM, and MVRA. The EH process has also been studied by modelling the process using ANN, Stochastic, CFD, Mathematical, FEM, MATLAB programming and COMSOL Multiphysics environment techniques.

This technique is active in radiusing, finishing, deburring and polishing the inaccessible areas simultaneously. The current review paper explores a research avenue for enhanced work in the area of extrusion honing process with new innovations.

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