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Research Paper

Surface finish characteristics of distinct materials using extrusion honing process

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Abstract

Traditional methods of finishing like grinding, lapping, and honing are limited to finishing of vital shapes such as flat and circular. These conventional methods are lagging for processing components that are fabricated by hard materials, involving complicated profiles in particular. Hence, it is essential to explore a finishing process, which addresses wide applications, better accuracy, higher efficiency, consistent quality and economy in finishing complex shaped parts. So, a new precision finishing process like extrusion honing has been implemented for polishing from several microns to the nano level. This work aims to assess the influence of a number of abrasive media passes on the surface integrity of aluminum, copper, and titanium grade-2 materials. The study has been performed by adopting an abrasive 36 mesh size with a concentration of 40% followed by 10 abrasive media passes. The influence of these process parameters has been studied in analyzing the roughness characteristics R_a, R_{max}, R_z, and R_{max}/R_a and the nature of surface induced by SEM characterization for the metals of consideration using the extrusion honing process.

1. Introduction

The challenges in material processing have initiated new difficulties in manufacturing machine components having complex geometric profiles possessing high hardness, difficult-to-machine, accurate dimensions, and surface finish at nano range. This has led to a new avenue for the development of advanced finish-machining techniques. The finishing of precision parts accounts for 15% of total manufacturing costs [1]. Aerospace and automotive components, having intricate profiles, demand high precision and finishing challenges. Typical applications of the interior honing process include gun barrels, bearings, manifolds, impellers, nozzles, valves, fuel injectors of internal combustion engines, and hydraulic cylinders. EH is a polishing method having the potential to tackle the challenges encountered during finishing. It is a novel micromachining process developed to remove burrs, shining surfaces, and remove recast layers. The polishing method involves the pressurized flow of abrasive media through or across the workpiece producing compressive residual stresses, which enhances fatigue strength of the material. Also, the process dominates by processing inaccessible areas, multiple holes, stepped passages, tapered holes, slots, contours, and cavities of the specimen. This method utilizes a polymer having viscoelastic properties blended with silicon carbide (SiC) as abrasives to abrade the surface. The silly putty is extruded across a constrictive tunnel with the aid of hydraulic pressure. The media performs as a self-modulating abrasive medium and functions as a flowing grinding wheel. Abrasion takes place at that location where the flow of polymeric laden is restricted and other regions stay unpolished. There are several governing factors responsible for the performance of the EH process such as extrusion pressure, stroke velocity, number of passes, grit size, and concentration of abrasives. Also, the EH process is commonly known as abrasive flow machining/finishing (AFM/AFF). In the current study, efforts are made to prepare the carrier media, evaluation of surface roughness characteristics such as R_a, R_z, R_{max}, and R_{max}/R_a, and also the quality of surface texture induced by SEM analysis as a result of the EH trials.

2. Literature review

Rhoades [1] investigated the fundamental law of AFM, process parameters, and tooling to direct the media flow. Further findings have been developed to understand the impact of size, edges of abrasives, and extruding pressure on the depth of cut. The number of indentation strikes made by the abrasives positioned on the exterior surface of the slug at one pass is a function of slug length, size, and concentration of abrasives in the polymeric media. To know the mechanism of material removal and to impart the effect of surface finish on a given material, it is essential to understand the type of forces. These induced forces, i.e., axial force and radial force produced during the abrasion process in AFM are measured using transducers. It has been concluded by Rhoades that both calculated and measured surface finish and material removal are in agreement with each other [2].

The class of machining process and cutting tools used to fabricate the specimen for AFM considerably influence the variations in surface texture. Loveless et al. [3] noticed that MR and surface texture obtained from wire electric discharge machining (WEDM) and conventional machining process was unique. They advised having AFM cycles for WEDM surfaces. AFM experiments have been performed on brass and aluminum (Al) specimens. The dominating process parameters were concentration of grains followed by grit factor of abrasives, number of cycles, and velocity of media [4].

In addition to MR and texture of surface, bearing area fraction and out of roundness have been evaluated by this process. Raju et al. [5] further investigated that silicone polymer can be utilized to finish spheroidal graphite cast iron at a lower pressure range (10 bar) yields anticipated outcomes instead of using polyborosiloxane. A dynamic advance in R_a is realized up to the seventh pass after that the texture initiates to decline. Enhancement in the bearing region is significantly credited by the investigator. The principle of the AFM process is that it utilizes sharp edges having irregular geometry for having required texture by abrasion between wall surface and abrasives. By producing thin-chips while abrading results in fine tuning and control of surface texture, close tolerance has been achieved. The process gained importance by finishing hard and difficult to machine materials [6, 7]. The output response R_a, R_{max} and MR on steel cylinders has been efforted by rough honing using cubic boron nitride as abrasive. The designed parameters mesh size, abrasive density, cylinder lateral velocity, honing head velocity, and extruding pressure of abrasives has been formulated by central composite design [8].

The flexible honing has been executed on crankcase cylinders made of gray cast iron used in Hermite compressors. The result of grain size factor (400 and 200) of abrasives and tool stroke iterations (1, 3, and 5) on roughness parameters has been studied by building a 2 × 3 factorial design [9]. The candidate material for any automotive and aerospace application is Al metal matrix composite (MMC). It has been efforted to finish Al MMC containing SiC from 0 to 15%. Focused on the mechanism of MR and finishing of pure alloy and MMC. Responses have been determined by taking the factors extrusion pressure, a number of cycles, and media mixed with hydraulic oil [10].

It is evident from the literature that nanocomposites fabricated by stir casting can also be finished by AFM. For instance, Al 7075/SiC nano MMCs [11] with reinforcement ranging from 1 to 4%. The influence of process parameter extrusion force, grain size, and stroke iterations on ΔR_a and MR were analyzed. Further, by including another parameter, concentration of abrasives, has been efforted on Al-6061 material [12] for MR as a response. A disc type of dynamometer has been employed to estimate the intensity of radial force and axial force in AFM. Emphasis was to know the effect of extrusion pressure, abrasive size and concentration on surface finish, material removal, cutting forces, and active grain density. The study has been made by factorial design to know the contribution of each factor, main effect, and its interaction. Finally, surface texture has been examined by SEM [13]. The experiment has been designed using Taguchi L27 orthogonal array and ANOVA for predicting the importance of input parameters. The optimization of the process parameters has been performed by box Behnken design (BBD) of response surface methodology (RSM) with desirability function to minimize R_a and maximize MR. The work has been further extended by taking extrusion pressure and SiC (20, 40, and 60%) in Al alloy [14].

Finishing hardened tool steel [15] samples, which were pre-drilled by electric discharge machining (EDM) method is unique as that of turning and milling. The impact of the AFM process constraints results in modification of the surface texture and the initiation of residual stresses. The investigator [16] extended the utilization of AFM process for plastic gears and recognized the improvement of R_a from 0.68 to 0.08 µm in 120 sec.

Raju et al. evaluated the effect of a number of passes on surface roughness values on Inconel 600 [17], Monel 400 [18] and monitored the process performance by acoustic emission technique. Murali Krishna et al. [19] further extended their interest in removing the recast layers/microcracks formed during the EDM process by simultaneously deburring the surface. Williams et al. [20] proposed that affecting variables in this finishing method are expulsion pressure, the volume of medium flow, grit structure, and type of specimen. This procedure shines interior sections of engine heads and exhaust system that gives uniform streamlined flow ways. Polishing by this method upgrades the fuel effectiveness thus cost reduction in the internal combustion engine.

Sandeep Chouhan et al. [21] efforted AFM on AISI D2 (Die steel) workpiece by using Taguchi analysis by considering the process parameters and viscoelastic properties of the polymer, a number of passes, and mesh size of abrasives on MR. It was concluded that difficult-to-reach areas can be processed, and the influencing parameter is the abrasive concentration when compared to the number of cycles and grain size of abrasives.

Vijay et al. [22] suggested L16 orthogonal array having the process parameters such as number of cycles, velocity of media, mesh size and concentration of abrasives which influences the interior surface quality of nozzle. They depicted mathematical relation between the response and designed parameter. The optimization of the process parameter optimization has been performed by analysis of variance (ANOVA) and identified the hierarchy by analytic hierarchy process.

Mali et al. [23] explained AFM to deburr the component made from Al/SiC MMC having a cylindrical surface. The result of AFM parameters on the quality of surface and MR were studied. The regression models for R_a, R_{max}, ΔR_a, ΔR_{max}, and MR were also developed to evaluate the result of AFM-dependent factors.

Sushil et al. [24] studied AFF on MMCs having an excess percentage of SiC (ranging from 20-60% in the Al MMC). The results of input parameters like extrusion force, amount of oil in abrasive laden, mesh size and concentration of abrading grains, nature of workpiece material, number of passes on MR, and variation in ΔR_a and surface quality were studied.

From the simulation perspective, the AFM process has been simulated while finishing swaging die and considering different viscosities of media to understand the influence of viscosity factor [25]. Furthermore, stochastic simulation is achieved to determine the dynamic grains involved in the abrasion process [26].

Prediction of the response parameters in AFM is efforted using neural networks and genetic algorithm approaches [27-30].

3. Experimental details

The finishing trials were executed on a laboratory setup EH machine. After each trial, the samples were evaluated for surface roughness parameters and surface texture.

3.1. Work material

The selection of a particular alloy/material for a scientific study depends on its availability, properties, and applications. In the current study, aluminum, copper, and titanium samples were considered for EH trials to investigate the influence of finishing cycles. The considered materials find wide application in aerospace, automotive, biomedical, and defense sector.

Aluminum (Al) is a popular engineering material, which can be melted, cast in molds, formed into the required shape, and machined easily. One of the significant properties of aluminum is lightweight and highly ductile. Al is a good conductor of heat and electricity; hence Al is preferred in high power transmission grids. Apart from these, Al finds enormous application in aerospace and automotive because of its lightweight, as stated earlier [32].

Copper (Cu) as a material is known to mankind since ancient time. It possesses good electrical and thermal conductivity apart from this it is easily machinable and resistant to corrosion. Copper finds its application as wire in electrical cables, power collectors in solar heaters and as integrated circuits in electronics. One of the major advantages of copper is that it can be easily welded, brazed and soldered [33] .

Titanium (Ti) is a standard engineering material which demand for high resistance to corrosion and heat specifically in chemical, nuclear reactors, petroleum oil refineries. The alloy has excellent mechanical properties associated with good workability. The intense strength and resistance to oxidation at elevated temperature enables it for diverse uses in industries. This alloy is widely used in structural, airframe and engine parts in aerospace and aeronautical applications [34]. The mechanical properties of Al, Cu and Ti G-2 material is in Table 1.

3.2. Carrier Medium

It is a flexible polymeric medium. In the current investigation, silicone was selected, and SiC of 36 mesh size and volume fraction of 40% was thoroughly blended with the silicone by mixing machine, as shown in Fig. 1. Table 2 details the properties of the carrier medium.

The silicone polymer is soft which is chemically inactive and stable. The polymer is unaffected by the changes in extreme environmental conditions. It is a polymer having alternating Si and oxygen atom that makes the polymer flexible, which can be deformed effortlessly in the direction of induced loads.

SiC as the abrasive has multiple cutting edges of irregular orientation. These randomly present shearing edges in the abrasives aid by abrading the irregularities present on the surface.

Table 1. Mechanical properties of Al, Cu and Ti.

Prop.	Density g/cm^3	Yield strength N/mm^2	Melting point ºC	Youngs modulus Gpa
Al	2.7	276	660.3	68.9
Cu	8.96	220	1085	117
Ti G-2	4.51	410	1350	120

Fig.1. (a) Silicone polymer, (b) SiC, (c) Carrier medium (silicone + SiC), and (d) Medium prep m/c.

Table 2. Details of carrier medium.

Property	Values
Appearance	Translucent
Density (Kg/m^3)	1.13×10^3
Viscosity (Pa.S)	20250
Durometer hardness	40 JIS A
Williams plasticity	180

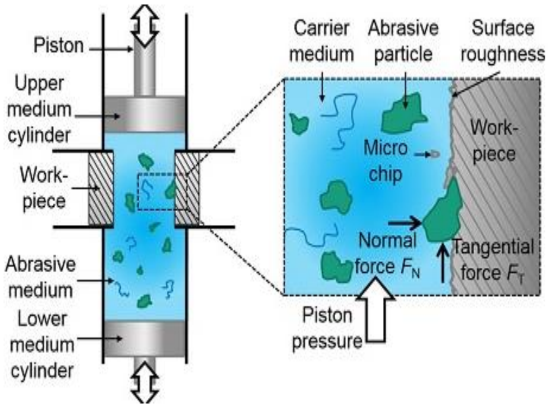

Fig. 2. Schematic illustration of extrusion honing arrangement [31].

3.3. Specimen preparation

Al, Cu, and Ti specimens of 15 mm length with 12 mm internal diameter and 24 mm external diameter geometry were considered for EH trials. The entire specimen had a R_a of 2 to 3 µm range. The specimens were previously drilled by carbide drill bits and washed thoroughly using acetone to remove burrs and debris.

3.4. Setup trials

The principle involved in two-way EH and how the material gets abraded is depicted in Fig. 2. An indigenously designed and fabricated one-way extrusion honing machine was set up to conduct the finishing trials. Fig. 3 shows the setup for conducting EH trials. The equipment consists of a cylinder containing abrasives laden in series with a hydraulic actuator controlled by a proper direction control valve.

The only difference between one-way EH and two-way EH is that in the case of one-way EH the carrier medium reciprocates in one direction and takes the exit on the other end. While, in the case of two-way EH, the carrier medium reciprocates in both directions inside the abrasive cylinder, as shown in Fig. 2. The EH equipment has a piston coupled with a cylinder arrangement with a fixture for holding the workpiece. As stated earlier the arrangement is unidirectional, i.e., the media can flow only in a particular direction. Easy removal and mounting of the work piece are enabled by a unique fixture held across the abrasive cylinder. The specimens were processed for 10 passes of medium flow under the same experimental constraints represented in Table 3. Test pieces after each trial were dismantled from fixtures for offline measurement.

3.5. Evaluation

After each trial, the polished surface was cleansed with acetone to expel the clogged particles to evaluate surface roughness characteristics, bore geometry and texture. A suitable location for measuring roughness characteristics was randomly selected at a distance of 2-5mm from the exit/entry side of carrier media and towards the inner region of the specimen. The changes in roughness values are measured for an evaluation length of 4 mm and cut off a length of 0.8 mm after each trial

The surface finishing parameters of R_a, R_{max}, and R_z were measured in a direction perpendicular to the induced surface pattern using a stylus of tip radius 2 µm in a Surfcom 130A profilometer, as shown in Fig. 4, and surface texture of polished surface was evaluated by SEM photographs.

In addition to the evaluation of roughness features, the out of roundness was evaluated using the standard form tester. Since the finishing involves MR, it is a fact that residual stresses are induced is witnessed by the X-ray diffraction technique [5].

Table 3. Particulars of extrusion honing process parameters.

Factor	Values
Extrusion pressure (bar)	60
Media velocity (m/min)	0.3
Stroke length (mm)	600
Radius of media cylinder (mm)	110
Volume fraction (abrasive %)	40
Mesh size of abrasives	36
Temperature	Ambient

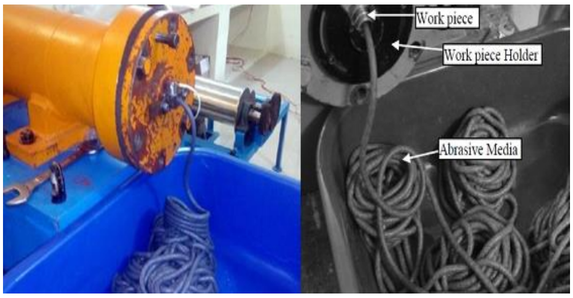

Fig. 3. Indigenously developed one way extrusion honing machine.

Fig. 4. Surface roughness measuring instrument (Surfcom 130A).

4. Results and discussion

EH has been executed to remove surface irregularities present in aluminum, copper, and titanium pre-drilled specimen surfaces. In addition, to investigate the influence of a number of passes on R_a, R_{max}, R_z, and R_{max}/R_a. Fig. 5 depicts the result of a number of passes on mean surface finish R_a for different materials considered. It's noticeable that as the number of cycles increases, means surface finish value R_a decreases. Surface finish varies randomly as well as non-linearly with increment in the number of passes regardless of material type either soft or hard.

Initially, drastic escalation in finish values is experienced, after that gradual decrement in finishing is attained with increasing the number of passes. This is mainly due to the sharp edges contained in the initially predrilled surfaces, when polymeric laden flows across these edges, the edges are sheared due to abrasion. After a few passes, the number of edges declines, and the surface attains saturated value. The R_a values for Al reduced from 3.7 µm to 1.7 µm, in case of copper, from 2 µm to 0.5 µm, and for Ti, from 0.67 µm to 0.13 µm, respectively.

From the EH trials, it is evident that this method is effective for fine finishing of materials irrespective of the soft or hard, and the required level of finish can be achieved in a few cycles for soft materials as compared to hard materials.

Fig. 6 illustrates the result of a number of passes on maximum roughness depth R_{max} for dissimilar workpiece materials. The R_z decrements gradually for all the material considered after EH trials. The R_z values for Al reduced from 32 µm to 16 µm, in case of copper, from 13.5 µm to 1.6 µm, and for Ti, from 11 µm to 0.34 µm, respectively.

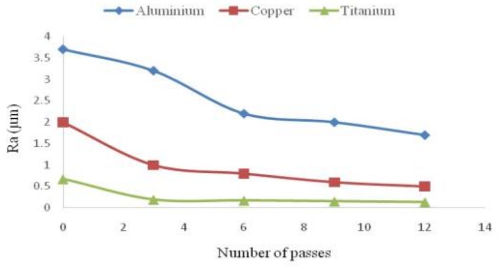

Fig. 5. Passes Vs average surface roughness R_a.

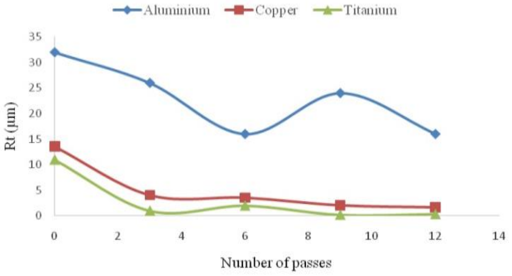

Fig. 6. Passes Vs maximum roughness depth R_{max}.

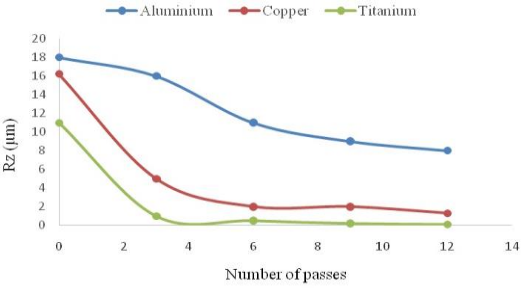

Fig. 7. Passes Vs average maximum height R_z.

In the same way, as the number of passes escalates, a decrement in the average maximum height of finish profiles was obtained on different material surfaces. Fig. 7 explains the effect of carrier media passes on average maximum height. The R_z values for Al reduced from 18 µm to 8 µm, in case of copper, from 16.2 µm to 1.3µm, and for Ti, from 11 µm to 0.1 µm. The examination of changes in R_{max}/R_a for a number of passes is shown in Fig. 8 . It is noticed that up to the fourth pass, there is a constant and gradual decline in R_{max}/R_a. From the data collected, the change in roughness characteristics with each pass was assessed. The modification in roughness is mainly due to the existence of abnormality in surface texture, and the steady decline in the surface characteristics R_a, R_{max}, and R_z is because of the elimination of the macro irregularity on the interior surface of the hole by the EH process.

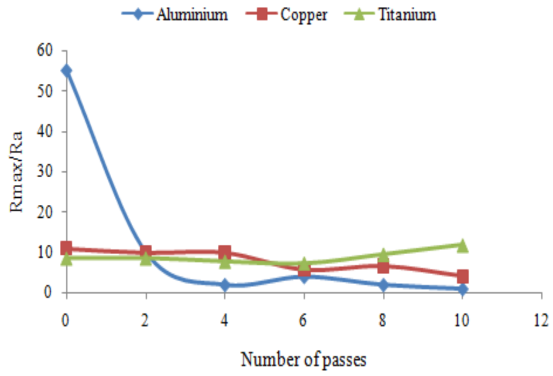

Fig. 8. Passes Vs ratio (R_{max}/R_a).

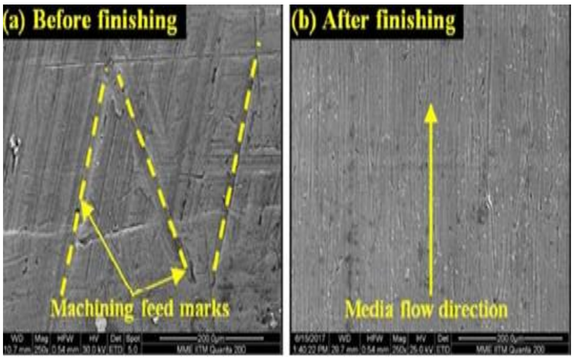

Fig. 9. SEM images of aluminium workpiece [32].

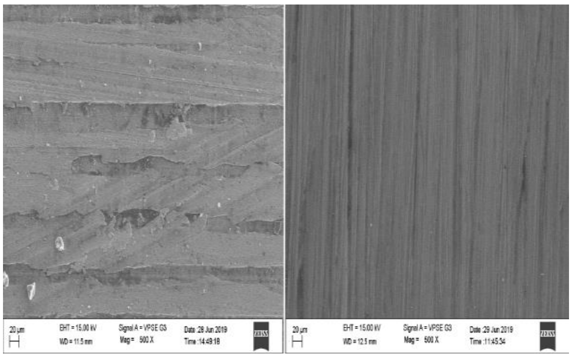

Fig. 10. SEM images of copper workpiece.

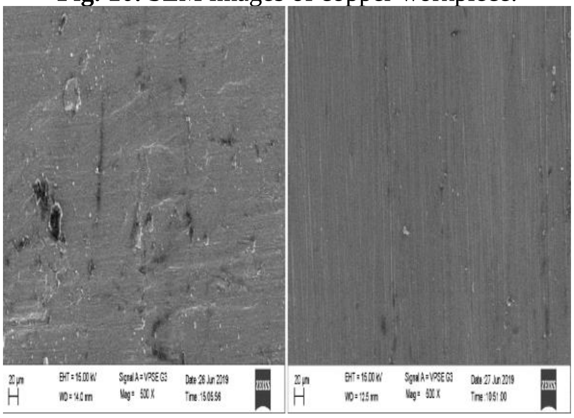

Fig. 11. SEM images of titanium workpiece.

From the EH of Al, Cu, and Ti alloys, it is found that the peaks on the surfaces are abraded by the abrasives at the initial stages of finishing with crest leveling accompanied by glazing of the surface. Consequently, with further passes, depreciation of the glazed surface takes place due to spalling.

The surface characterization of samples was examined using an SEM. For analysis, the influence of this process on surface quality was performed by taking images of prior and post EH trials.

Fig. 9 exhibits the SEM images of the Al sample before and after finishing. The images reveal deep machining feed marks and a rough surface on the workpiece before EH. After finishing, a substantial reduction in these feed marks on finished surfaces is observed, as shown in SEM photographs [32].

Fig. 10 reveals the SEM images of the Cu workpiece before and after polishing. From the SEM images, more surface irregularities are observed. After finishing, trials surface texture is free from abnormalities in the texture, and drastic change in finishing is observed.

Fig. 11 is the SEM images of the Ti workpiece before and after EH. From, the SEM images, it is evident that more pits and feed marks are observed. After EH, the pits are abraded, and uniform unidirectional lay patterns are obtained.

5. Conclusions

Extrusion honing is a micromachining technique in which base material is abraded by abrasive action using pressurized viscoelastic polymer blended with SiC to polish inaccessible regions. In the present study, EH trials were executed on Al, Cu, and Ti samples to exhibit the efficacy of the process While finishing the category of considered materials of study. Also, the influence of finishing effect on surface texture was examined. A study on modeling and optimization was highly desirable, and following conclusions are withdrawn,

- The opted polymeric laden is utilized as a carrier medium for abrasive while finishing inaccessible regions.

- The extrusion honing process is a remedial finishing method for polishing the materials Al, Cu, and Ti at lower pressure.
- Irrespective of materials, i.e., Al, Cu, and Ti materials considered, a drastic reduction in R_a is witnessed at the early stages of finishing. Only negligible progress in surface texture is perceived for more cycles, after which surface begins to deteriorate.
- The R_a values for Al reduces from 3.7 µm to 1.7 µm, in case of copper, from 2 µm to 0.5 µm, and for Ti, from 0.67 µm to 0.13 µm, respectively, after EH trials. In the same manner, R_{max} and R_z also decline. This change in R_a is due to the chopping of peaks by abrasive grains.
- From declined R_a for the category of metals under consideration, it is evident that extrusion honing is a reliable process for fine finishing of soft and hard metals.
- It is noticed that the surface texture in the central interior region is better than the arrival and depart region because of better interaction with the abrasive medium.
- The number of crest and troughs on the machined profile is eliminated after finishing by the process of abrasion.

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