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ENHANCING SURFACE FINISH: EXPLORING THE IMPACT OF EXTRUSION HONING PROCESS ON TITANIUM GRADE-2 ALLOY

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Abstract

Conventional finishing processes such as grinding, honing and lapping lag in processing intricate and inaccessible regions such as through holes, internal cavities, fuel injectors, etc. A new abrasion-based finishing process, such as extrusion honing, is developed to overcome this drawback. In this process, media, i.e., a blended mixture of silicone polymer, which is visco-elastic in nature, and SiC abrasive of known % of volume fraction and grit size, is employed. This media is considered a flowing grinding wheel and flexible in nature. The current work explores the influence of parameters such as the number of passes and bore diameter of the specimen in the extrusion honing process. The experimental study has been carried out on titanium grade-2 alloy. Experimental data is collected by constructing L9 OA for the factors considered and is verified with multiple regression analysis. The experimental plan has been executed by considering two factors, i.e., the number of passes and bore diameter involving three different levels. The study of variance (ANOVA) found that the number of passes is a significant contributing factor to the response parameter Ra, which is found to be 58.97 %. Multivariate regression analysis is performed to predict the surface finish (Ra) of the specimen within the operating range of the process by validating with extrusion-hunting trials. Finally, the current paper contrasts the result of extrusion honing trials, i.e. surface Ra, with the developed model and agrees with the established result.

Keywords: *Extrusion Honing (EH), Surface finish (Ra), Roughness and Abrasives.*

1. Introduction

Finishing and deburring operations in any machining-oriented manufacturing process are laborious and uneconomical, which significantly accounts for the cost of manufacturing. EH can overcome the potential solution for such time-consuming and unavoidable actions. It is a flexible finishing technique for inducing superior surface texture, which is ideal to approach, especially in interior regions, and simultaneously deburrs and removes recast layer and radius surfaces. The process gained familiarity because of the cutting tool's inaccessibility in the machined surface regions. The aggressive action of the abrasives leads to the removal of burrs because of the pressurised flow of media across the constrained section of the workpiece. The potential applications of EH are diverse in automotive, aerospace, tool and die-making, surgical, etc. The domain applications include manifolds of IC engines, fuel injector nozzles, turbine blades, impellers and diffusers. The significant parts of an EH system include the machine, tooling and media. The EH machine is a hydraulically actuated setup designed and fabricated indigenously. The fixture grasps the work piece firmly and permits the pressurised stream of abrasive media across the confined channel. Media is the blended mixture of abrasives and the polymer possessing the semi-viscous property, which holds the abrasives rigidly. The commonly used polymer is silicone, which acts as a flexible tool. Appreciable surface textures have been obtained with the effects of several passes, the volume fraction of abrasives, mesh size of abrasives, passage area of media on surface finish and material removal on ferrous alloys, non-ferrous alloys and MMC. The peculiarity of this finish machining process is that it involves minimal material removal from its parent material in terms of grams. The principle involves the pressurised flow of viscous media across the constricted passages demanding finishing action due to abrasion between the abrasives and surface texture shearing of the peaks on the surface, resulting in uniform surface integrity. The potential application of this process is that it not only finishes the surface but

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also effectively polishes and eliminates the re-solidified layer formed during pre-processing by EDM and another thermal-based machining process. Some authors call this deburring technology abrasive flow machining/ abrasive flow finishing. This finishing process finds its intense application in engineering and diverse uses in processing bio-medical and orthopaedic implants.

The uniqueness of this process is that it not only finishes the surface but also removes the material in small amounts, which acts as a tertiary process simultaneously. This method can process any material, irrespective of hardness, from soft materials like Al to rigid materials like W, Ti and Ni alloys. One of the fascinating features of this process is that it does not possess any cutting tool; instead, it is a flexible tool assuming the shape of the profile to be processed. The higher surface roughness values (R_a) are reduced to much nominal and lower values of R_a at a minimal number of passes in this abrasive-based process [27-29]. Further, the potential capability of this process is that the component surface subjected to abrasive action can be employed directly to the intended application without further inspection.

2. Literature Review

Rhoades [1] studied the AFF technique and determined its control factors. The author found that when the media is quickly constrained across an unaffordable cross-section, the viscosity of the media rises momentarily. An appreciable amount of material is evacuated due to abrasion, which relies on viscosity, flow rate and pressure. Each parameter finally alters the intensity of abrasive grains collaborating with the workpiece and the force developed on an abrasive particle. The high medium volume enhances the abrasive grains interacting with the workpiece; thus, enough material removal is achieved.

Jain and Adsul [2] detailed existing waviness and resistance of the work piece impacts material expulsion in AFF method. Material expulsion and decrease in waviness are more significant if there is an accessible workpiece material. Enriched material evacuation and decreased surface roughness increments when the percentage of abrasive grains in the medium increments. Of all the factors considered, the most influential is the concentration of abrasives chased by grit size and strokes.

Raju HP [3] clarified that silicone could be used to finish SG Cast Iron at a lower pressure range (10 bar), yielding anticipated outcomes instead of polyborosiloxane. A dynamic advance in surface texture is realised up to the seventh pass. After that, the texture begins to decline. The investigator claims that enhancement in the bearing region is significant. Further, the author continued his studies on other nickel-based alloys such as Inconel-600 [4], Inconel-718 [5], Monel-400 [6], Nitronic-60[7], Nickel Alloy A-286 [8].

Williams and Rajurkar [9] proposed that the variables that affect this finishing method are expulsion pressure, volume of medium flow, grit structure, and type of specimen. This procedure shines interior sections of engine heads and exhaust systems that give uniform, streamlined flow. Polishing delivered by this method upgrades fuel effectiveness, thus reducing the cost of the IC engine.

Harlal Singh Mali and Alakesh Manna [10] explained that AFM should deburr the component made from Al/SiC MMC, which has a cylindrical surface. The results of the AFM parameters on the surface and MR quality were studied. The regression models for R_a, R_t, ΔR_a, ΔR_t and MR were also developed to evaluate the result of AFM-dependent factors.

Jayasimha et al. studied the effect of extrusion honing parameters such as grit number and percentage of abrasive on the class of materials such as Al, Cu and titanium alloy [11]. The author emphasised the response factor R_a and material removal for the experimental conditions. Further studies were accelerated by modelling [12] the abrasive-based finish-machining process, and also the simulation study of the extrusion honing process was attempted [13-14].

Ravi Sankar et al. studied abrasion on Al/SiC MMCs using the R-AFF method. There is a considerable improvement in R_a when extruding pressure, rotational speed, cycles and % of lubricating oil (wt %) in carrier media are considered [15].

Murali Krishna et al. validated using this EH approach, revealing that irregularities of the EDM process, such as the recast layer, were removed. While evaluating the responses, this technique consistently aligns with the experimental and theoretical results. Several scientists have attempted to model the EH process, which is still in the early stages. This is owing to the need for more information on the viscoelastic nature of media and the type of MR during micromachining [16]. Also, the performance of the micromachining process was monitored by the acoustic emission technique [17].

Despite this, Jain et al. achieved considerable results using finite element methodologies [18], stochastic simulation [19], neural networks [20], and genetic algorithm [21] technique to assess the application of this novel two-way abrasion-based method to determine the impact of process factors on the brass and aluminium alloys.

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Sudhakara et al. experimented with AFM on hollow cylindrical cavities. These specimens were made of Al 7075/SiC NMMCs produced by stir casting [22].

Mohammad Yunus et al. sought to anticipate the impact of factors like extruding pressure, grit size and number of cycles on responses R_a and MR. Al/SiC particulate MMC with a high SiC % has been considered by constructing the Box Behnken design of RSM [23]. Several scholars repeatedly tried AFM processing on various softer or harder materials. For instance, Mejar Singh et al. conducted studies on Al-6061[24].

Devadath et al. have also developed a feed-forward back propagation neural network to foresee material removal in Hastelloy C22. The simulated results obtained by ANN modelling are concurrent with test results with an error range of ± 10 % [25]. Ibrahim et al. attempted to study the AFM process by considering SiC as an abrasive involving significant process parameters [26].

3. Experimental trials

The current study was carried out in an indigenously developed unidirectional extrusion honing arrangement [11-12], as shown in Fig.1. The particulars related to the preparation of carrier media and its proportionate with abrasives and evaluation of the response parameters are detailed in the previously published research papers [11-12]. Nevertheless, the preparation of the specimen, the geometry of the job, initial roughness conditions, relevant standards, experimental conditions, material properties and process principles are explained in the preceding literature [11].

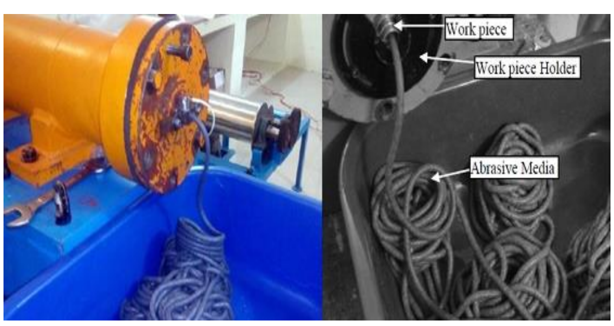

Fig. 1 Indigenously developed unidirectional extrusion honing machine [11].

4. Modelling by regression analysis

The optimal conditions for evaluating surface quality by extrusion honing of Ti Gr-2 alloy is obtained by using L9 orthogonal array methodology to experiment. The two control factors, the number of passes (A) and the bore diameter of the specimen (B), are considered in three different trials. The machining is performed for nine individual independent combinations of process parameters selected. Table No.1 lists the factors and levels selected for extrusion honing trials.

Table 1 Selected Input Process Parameters considered for experimentation.

Factors	Symbol	Levels		
No. of Cycles	A	2	4	8
Diameter (mm)	B	6	8	10

The design matrix used in this study and the corresponding results of surface finish R_a are shown in Table No.2. Taguchi's L9 OA is an efficient technique to assess the results governed by multiple inputs. This approach lowers the number of iterations necessary to develop the response factors. The current study establishes a regression model for evaluating the relationship among input and output variables. The capability of the suggested model has been verified by collecting data through experiments designed using L9 OA and ANOVA.

Table 2 L9 orthogonal array of experimental design and response R_a with S/N ratio.

SL.No	Cycles	Diameter (mm)	R_a (μm)	S/N R_a
1	2	6	0.16	15.9176
2	2	8	0.15	16.4782
3	2	10	0.14	17.0774
4	4	6	0.16	15.9176
5	4	8	0.15	16.4782
6	4	10	0.15	16.4782
7	8	6	0.16	15.9176
8	8	8	0.17	15.3910
9	8	10	0.18	14.8945

ANOVA results achieved for R_a are shown in Table No.3. It is evident from the table that Ra is primarily affected by the number of passes followed by bore diameter respectively. The percentage contribution of several passes, bore diameter and interaction between several passes and bore diameter on Ra was 58.97 %, 2.75% and 38.271 %, respectively, as given in Table No.5. From ANOVA, it is revealed that Ra is notably

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influenced by several cycles and its interaction with bore dia.

Table 3 Analysis of Variance for Surface Finish R_a

Source	DOF	SS	MS	% Contribution
A	2	2.02059	1.01030	58.970
B	2	0.09449	0.04724	2.757
A*B	4	1.31134	0.32783	38.271
Total	8	3.42642		100

This study developed a multiple regression equation for the dependent variable Ra as an output response for several passes and bore dia. The predictive equations obtained from the regression analysis are (R^2 = 98.73%, R^2-Adj = 96.61%). The potential of the model has been verified by using the R^2 value. The R^2 value fluctuates between zero to one. An excellent fit exists among the dependent and independent variables when the value is close to one. In this case, the R^2 value for the established regression model for R_a is 98.73 % respectively. The coefficients existing in the predicted model have been verified using the residual plots. If the residual plot takes the linear form, residual errors are normally distributed, and coefficients are significant. Fig.2. represents the residual plot for the response factor R_a.

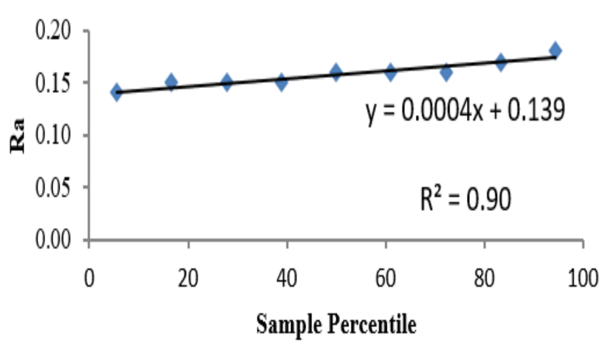

Fig. 2 Residual Plot for the response factor R_a

A conformation test is performed to endorse the established model, and the corresponding values are presented in Table No.4. From the test, it was noticed that predicted and experimental values were in concurrence with each other, as shown in Fig. 3.

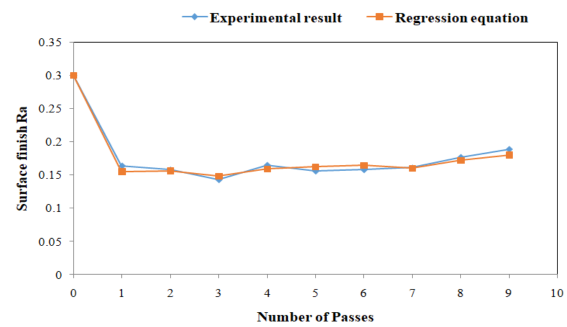

Fig. 3 Comparison of R_a from experiment and regression model

Table 4 Conformation results for the developed model

Exp.No	Experiment R_a(μm)	Regression R_a(μm)	Residual R_a(μm)	% Error
1	0.16	0.14	0.02	12.5
2	0.15	0.15	0	0
3	0.14	0.15	-0.01	7.14
4	0.16	0.15	0.01	6.25

5. Conclusion

The EH process can effectively polish the finish-machining of Ti Gr-2 alloy, and subsequent conclusions have been made from the present investigation.

This study studied the effect of several cycles and bore diameters on the honing of Titanium Grad-2 alloy using an L9 orthogonal array. A significant surface finish of 0.14 - 0.18 µm is achieved from 0.35 µm at a low number of cycles, i.e. two cycles and for a bore diameter of 6 mm, respectively. From ANOVA, it is evident that surface finish significantly affects the number of cycles, dia of the bore and its interaction with a contribution of 58.97 %, 2.75 % and 38.27 %, respectively. From the developed regression model for R_a, an appreciable relationship evolves between the predicted and experimental values, with R2 adj=96.61 %. Hence, the established relation can be utilised to choose the right factors for evaluating surface texture quality. The validation of the model is confirmed using a prediction model and experimentation by randomly selecting the parameter combination and comparing the result. The model demonstrates that the predicted and experimented results are in good agreement and assures that the regression model is acceptable for prediction.

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