Assessment of Surface Quality in Extrusion Honing Process Using Dimensional Analysis Approach

S. L. N. Jayasimha[1], N. L. Murali Krishna[2] and H. P. Raju[3]

[1&3]Department of Mechanical Engineering, [2]Department of Industrial and Production Engineering,
[1,2&3]P.E.S. College of Engineering, Mandya, Karnataka, India
E-mail: jysmh29simha@gmail.com

Abstract - It is critical to obtain the desired surface quality on the internal and external portions of machined part. The estimated level of surface texture can be induced on the exterior regions using traditional finishing processes such as grinding, honing, and so on. While the problem emerges when processing core miniature components such as micro bores, inlet/outlet valves etc. The EH process overcomes this limitation of conventional finishing method. It is a novel micro machining process that extrudes the pressured flow of carrier media blended with abrasives into the confined passage to generate desired level of surface texture. Owing to abrasion process micro machining occurs by taking away the negligible amount of stock material. The present study focuses on the impact of number of passes at the specimen's entry and exit sides of the carrier media. The improvements in surface finish (R_a) on both side i.e., entry and exit are evaluated as well. A dimensionless expression for R_a is also developed. The relationship is implemented using Buckingham's π theorem and comparison of developed model is performed with experimental results. SEM analysis is made to portray surface texture produced by selected process parameters such as number of passes, volume fraction and grit size of abrasive grains.

Keywords: Extrusion Honing (EH), Surface Finish (SF), Material Removal (MR), Carrier Media, Abrasives

NOTATIONS

R_a	-	mean arithmetic roughness value
C_a	-	abrasive concentration
DA	-	dimensionless/dimensional analysis
E	-	Youngs modulus
EH	-	extrusion honing
F_s	-	flow speed of media
MR	-	material removal
M_e	-	mesh size of abrasives
N	-	number of passes
SF	-	surface finish
VF	-	volume fraction
WP	-	work piece
ρ_m	-	density of media

I. INTRODUCTION

Abrasive flow finishing (AFF) is a deburring technique that develops compressive residual stresses while removing burrs and recast white layer in the premachined component. This approach can process multiple passages at once in one or more components as well as in tapered and stepped parts. This process is now known to be extrusion honing and, in some cases, abrasive flow machining (AFM). This technology covers a wide range of applications that includes nozzles, manifolds, impellers, prosthetic knee joints. Finishing is due to the abrasion reaction of the flow of pressurized polymeric media infused with SiC particles across the constrained path. Throughout this process, abrasive dough is made to flow across substrate to be processed. The AFM technology is regulated by variables such as extruding pressure and flow velocity of media, distribution of SiC inside the media, as well as the number of carrier media passes.

This finishing approach guarantees the process geometric precision, applicability and effectiveness which are crucial for mechanization. For first pass itself this technique accomplishes significant development in surface morphology with changing dimensions. Finishing methods generally acquire 15 % of machining costs in production cycle. While finishing value when reduces below one micron the marginal cost ramps up.

Jain *et al.,* 2000 investigated AFM, which improve surface texture of unreachable areas and effect of parameters such as distribution and size of abrasive grains with media flow speed were performed on brass and aluminium. The investigated SF and MR responses were in agreement with the experimental values [1]. Extrusion honing (EH) is an excellent method for processing stiffer materials having complex profiles. From the available literature it is witnessed that several researchers have tried this method for processing class of materials.

Ravi Sankar *et al.,* 2010 studied abrasion on Al/SiC MMCs by R-AFF method. There is a considerable improvement on R_a when extruding pressure, rotational speed, cycles and % of lubricating oil (wt %) in carrier media are considered [2].

Sudhakara *et al.,* 2020 suggested AFM on hollow cylindrical cavities. These specimens were made of Al 7075/SiC NMMCs produced by stir casting [3].

Mohammad Yunus *et al.,* 2020 sought to anticipate the impact of factors 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 Box Behnken design of RSM [4].

Several scholars repeatedly tried AFM processing on a variety of materials that are softer or harder. For instance, Mejar Singh et al. 2015 carried out studies on Al-6061[5], Amir et al. 2018 and Ibrahim et al. 2014 on stainless steel 304 [6] and low carbon steel [7].

Raju *et al.,* 2005 studied from material viewpoint of this deburring technology which has polished a wide range of materials. Furthermore, out of roundness, bearing area and residual stresses of spheroidal graphite iron have been investigated by the authors [8]. Besides evaluating material removal [9-10] and producing the glazed surface texture in the given ferrous material [11-12]. Furthermore, the authors attempted the existing novel finishing process on other stiff materials like Inconel-600[13], Inconel-718[14], Monel-400[15], Hastelloy-C22[16], Titanium grade-2[17], Nitronic-60[18] and Nickel Alloy A-286[19] for assessing the ultimate surface finish value with influence of given process parameters for different number of passes.

Murali Krishna *et al.,* 2014 validated the use of this EH approach, revealing that irregularities of EDM process such as recast layer was removed. While evaluating the responses this technique gives consistent results that are in alignment with the experimental and theoretical results. Several scientists have attempted to model the EH process which is still in early stage. This is owing to the scarcity of information on the viscoelastic nature of media and type of MR during micromachining [20]. Also, performance of micro machining process was monitored by the acoustic emission technique [21].

Despite, Jain *et al.,* 1999-2004 achieved considerable results using finite element methodologies [22], stochastic simulation [23], neural networks [24], and genetic algorithm [25] technique for evaluating the performance of the abrasive-based finishing method.

Jayasimha *et al.,* 2021-2022 investigated the effect of VF of SiC on R_a, dynamic pressure, and rate of strain on Inconel-625 in one-way EH by employing computational approach [26-27]. Meantime EH process is also modelled and influential parameter among process parameters is determined [28]. To assess the capability of estimation the experimental outcome is estimated using ANN technique [29]. The research is strengthened by contrasting final R_a for aluminium, copper, and titanium-Gr 2 alloy [30]. Moreover, the researcher also emphasized to develop a relation to determine the resulting surface finish [31].

The present study investigates surface finish R_a, surface texture and quantification of R_a by dimensionless modelling by considering passes, grit value and VF of abrasive in the flow media as process parameters.

II. EXPERIMENTATION

The EH passes were executed in an in-house developed experimental arrangement. The various constants and parameters utilized in the study are listed in Table 1. Resulting EH surfaces were finally studied.
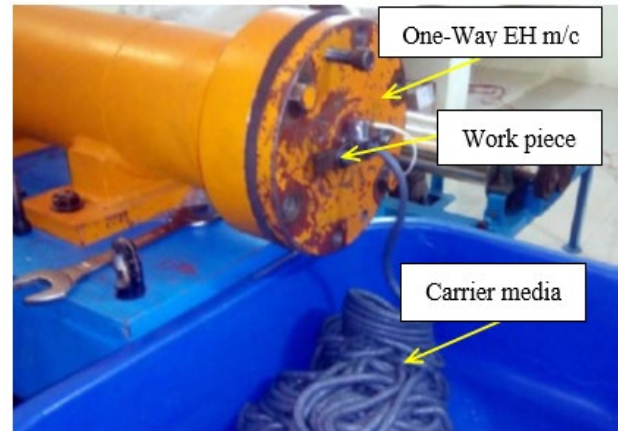

Fig. 1 Extrusion honing machine

The EH equipment is depicted in Fig.1 which incorporates a longitudinal cylinder carrying abrasive dough, flow regulating valve and hydraulically controlled actuator. The current set up is irreversible and media flows only in one direction. Drum at acute end is connected to a fixture to fit WP and fastening is made to grip the specimen, so that it can be simply attached and removed smoothly. Roughness characteristics were measured on the samples after EH experimental trials.

TABLE I EXTRUSION HONING PROCESS PARAMETERS CONSIDERED IN PRESENT STUDY

Sl. No.	Parameters	Value
1	Extruding pressure (bar)	60
2	Flow speed of media(m/min) F_s	0.3
3	Length of stroke (mm)	600
4	Number of passes N	15
5	Volume fraction (Abrasive %) C_a	35
6	Grit size of abrasive (microns) M_e	36
7	Temperature	Ambient
8	Dynamic viscosity of media (Pa.S)	20250
9	Density of media (Kg/m^3) ρ_m	1.13×10
10	Modulus of elasticity (Kg/m^3) E	2×10^{11}

A. Carrier Media

The carrier media in EH process is a blended mix of silicone polymer and silicon carbide grains as shown in Fig. 2. The transporting media is prepared with known VF and grit size of abrasives. Media is proportionately blended and prepared using in house developed media mixing machine as shown in Fig. 2 (d).
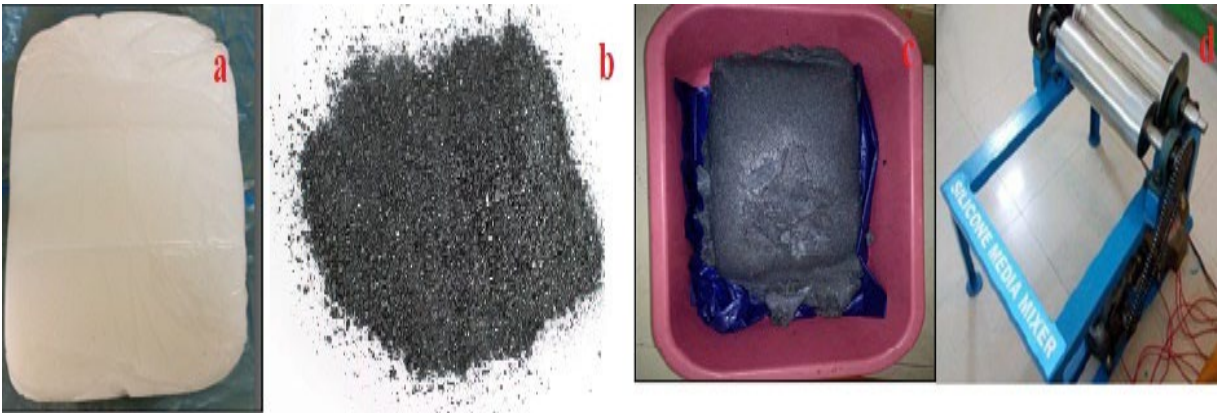
Fig. 2 a. Silicone b. SiC c. Media (Silicone + SiC) d. Media preparing machine

B. Material and Specimens for EH

Inconel-625 is a nickel based alloy which is widely used in elevated temperature and in corrosive environment because of its high resistance to heat and corrosion. The working temperature spans form cryogenic to 1350°C and commonly employed in thermo-mechanical units. The influence of EH trials were performed on the Inconel alloy specimens having the geometry, span 13 mm, inner dia 7 mm, outer dia 20 mm and pre-drilled R_a of 2-3 μm.

C. Evaluation

The resultant surface from the EH trials was wiped and decontaminated using compressed air and acetone. As a consequence, the surfaces were subjected to SEM analysis and surface finish was measured using Surfcom 130A as illustrated in Fig.3.

Fig. 3 Surface roughness computing device (Surfcom 130A)

D. Influence of Number of Passes on Surface Roughness

The specimens were pre machined by drilling, having the bore diameter 7 mm. The EH passes were performed on these passage diameter using the carrier media is a mixture of SiC and silicone. The carrier media having the abrasive size of 36 and VF of 35 % is utilized for conducting experiments.

The pilot tests were performed to identify effective process parameters for all factors and at different levels resulting in better surface finish. The results of these preliminary trials revealed that finishing values after fifteenth pass exhibit higher roughness values. The EH passes were restricted to fifteen passes for all parameters.

The impact of considered parameters such as volume fraction and particle size of abrasive, number of passes and bore diameter for change in roughness characteristics is presented by plotting the corresponding graphs. The consequence of considered process parameters is evaluated in terms of the influence of process factors on roughness parameters and percentage improvement in R_a. The extrusion honed surface is analysed under SEM under suitable magnification. From the studies it is revealed that significant improvement in surface morphology is observed in extrinsic features (surface parameters and texture).

As there are number of factors that decide the quality of surface while in the current study R_a is considered for evaluation. The surface roughness parameters were measured using Surfcom 130A at entry and exit side of carrier media. The surfaces of the specimen after each pass were measured regularly. The surface roughness values were noted initially as well as before and after each pass till fifteenth pass of carrier media.

Fig.4 and 5 depict the changes in R_a, R_z, R_t and R_{pk} at both entry/exit region of carrier media in WP of bore dia 7 mm for the considered process parameters. From the plots, zero pass indicates R_a on pre-drilled bore diameter produced by drilling while the consequent passes are the EH trials with the passage of media. It is evident from the same plots that drilled surface has high roughness values.

Fig. 4 and 5 also illustrates the influence of 36 grit size of SiC in 35 %, volume fraction of SiC on surface roughness parameters on both entry/exit side of specimen for 7 mm passage diameter. It is noticed that when contrasted to entry side the surface roughness parameters for all passage diameter reduces at exit side significantly as shown in Fig. 4 and 5.
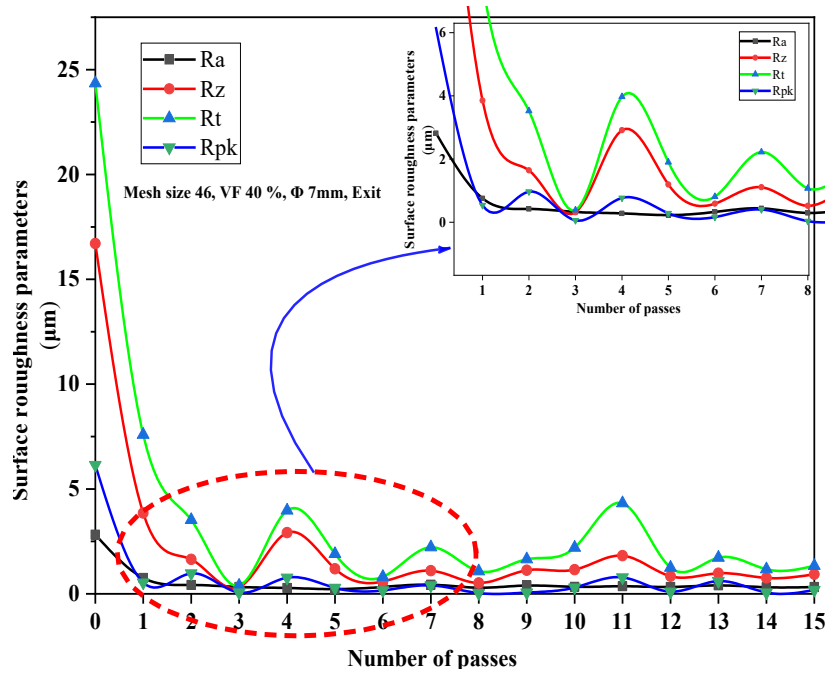
Fig. 4 Effect of number of passes on R_a at entry side

The initial surface induced due to drilling process has a higher value of surface roughness. The surface with enough number of peaks offers more resistance to flow of carrier media and hence most of the peaks get abraded at the early stage of extrusion honing passes. Consequently, it results in high rate of reduction in surface values. Abrasive with higher mesh size means fine abrasives, while smaller abrasives yield lower scratch level and also the intensity of abrasion is also less.

Irrespective of VF and mesh size of abrasives R_a reduces at first pass itself due to macro irregularity correction. It is

presumed that it is because of elimination of leading peak asperities, wear debris, burrs across the passage length. The slow progress of carrier media at entry side creates a dead zone and this result in dull abrasion. As carrier media traverse across the passage the media relaxes rapidly the abrasives makes enough contact at the exit side and yields better surface finish.

It is also concluded from Fig. 4 and 5 significant surface finish values are achieved on both entry and exit side of WP. For WP of Φ 7 mm by 36 mesh size in 35 % VF at exit side of 0.01 µm and entry side of 0.0064 µm is achieved.
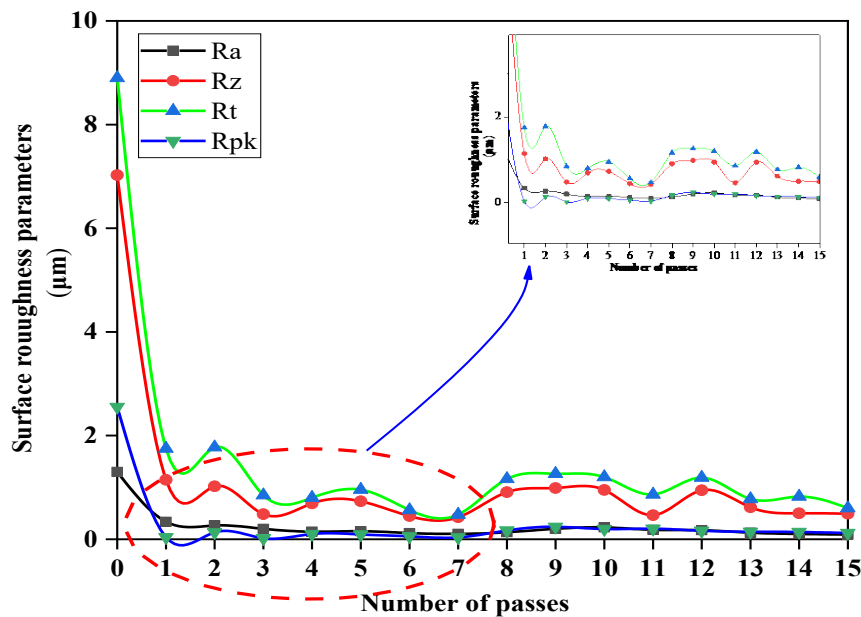

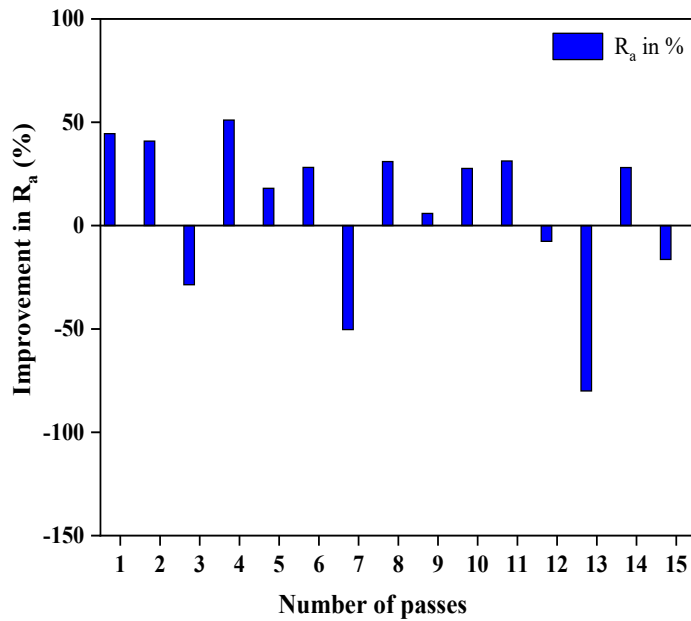Fig. 5 Effect of number of passes on R_a at exit side

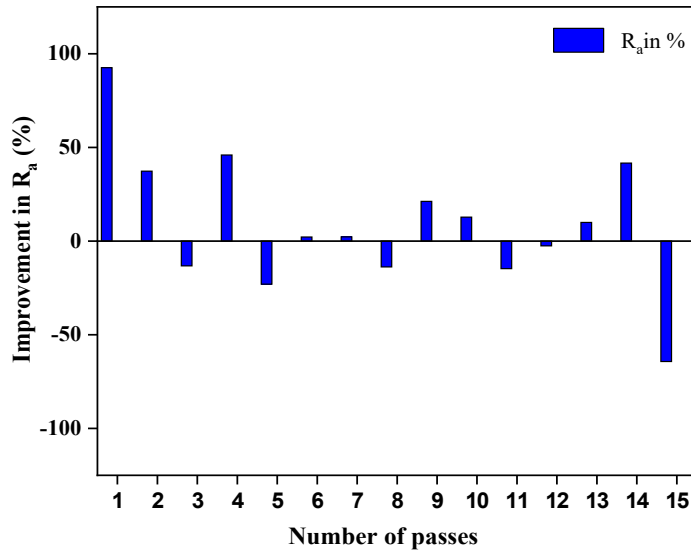Fig. 6 Percentage change in R_a at entry side of carrier media

Fig. 7 Percentage change in R_a at exit side of carrier media

E. Investigation on Percentage Improvement in R_a Values

The resulted surface finish due to EH effect is determined in terms of % improvement in R_a. Fig.6 and 7 shows % improvement in R_a at both entry/exit side of WP. The attained outcome depicts that % improvement in R_a increments greatly for first pass at both entry/exit sides of WP. It is due to shearing of principal peak asperity, removal of remains and burrs on the initial EH surface. With further number of passes, enhance surface abnormalities which are abraded. A considerable hike in percentage improvement in R_a signifies correction in micro irregularity.

With further passes results in material spall out and results in surface drop. This is noticeably indicated by fluctuation in % improvement in R_a after first to second passes and for subsequent passes. It is interpreted that this is due to scratching on material by abrasives on the super finished surface indicating correction in micro irregularities. It is an indication of discontinuation of further EH passes or if continued it attains the phase of material spalling.

It is portrayed in the graphs that % improvement in R_a for all passes is high at exit when compared to exit. It is interpreted that it is because of formation of dead zone at entry due to which carrier media become sluggish resulting in dull abrasion at entry. While at exit side, carrier media relaxes quickly because of better contact between abrasives and abrading surface. Consequently, there is a significant improvement in R_a value at exit side. It is evident from current study, there is 43 % improvement at entry and 95 % at exit part.

III. APPLYING BUCKINGHAM'S Π THEOREM

This method is applied to aggregate entire variables discovered in this study into collection of dimensionless products. Algebraic equations are used to identify required relation among discrete variables. To create a model using the π theorem, select recurring and non-repeating variables. Total number of repeated variables equals the number of fundamental dimensions, according to the π theorem. As a consequence of the criteria stated by π theorem three variables are chosen as repeated variables[32].

The resulting response factor i.e surface finish (R_a) on the specimen is rely on following factors, [31],

$$R_a = f(M_e, N, C_a, F_s, \rho_m, E) \tag{1}$$

Or

The equation (1) can also be expressed as below,

$$f(R_a, M_e, N, C_a, F_s, \rho_m, E) = 0 \tag{2}$$

$n - m = 7 - 3 = 4$ in this study,

Hence three $\pi -$ terms i.e $\pi_1, \pi_2, \pi_3, \pi_4$

Therefore $f(\pi_1, \pi_2, \pi_3, \pi_4) = 0$ (3)

According to law of power indices on either sides of equation,

$$\pi_1 = M_e^a . F_s^b . \rho_m^c . R_a \tag{4}$$
$$\pi_2 = M_e^d . F_s^e . \rho_m^f . N \tag{5}$$
$$\pi_3 = M_e^g . F_s^h . \rho_m^i . C_a \tag{6}$$
$$\pi_4 = M_e^j . F_s^k . \rho_m^l . E \tag{7}$$

According to law of dimensional homogeneity, each π term,

$$\pi_1 = M^0 L^0 T^0 = (L)^a . (LT^{-1})^b . (ML^{-3})^c . (L)$$

By comparing power terms of M, L, T on either sides,

$$a = -1, \qquad b = 0, \qquad c = 0$$

By replacing a, b and c in π_1

$$\pi_1 = M_e^{-1} . F_s^0 . \rho_m^0 . R_a$$

$$\pi_1 = \frac{R_a}{M_e}$$

Similarly, π2, π3 and π4 are,

$$\pi_2 = N \qquad \pi_3 = \frac{C_a}{\rho_m} \qquad \pi_4 = \frac{E}{\rho_m F_s^2}$$

Substituting values of π_1, π_2, π_3 and π_4 in equation (2)

$$f(\pi_1, \pi_2, \pi_3, \pi_4) = 0 \tag{8}$$
$$f\left(\frac{R_a}{M_e}, N, \frac{C_a}{\rho_m}, \frac{E}{\rho_m F_s^2}\right) = 0 \tag{9}$$
$$\frac{R_a}{M_e} = k\left[N, \frac{C_a}{\rho_m}, \frac{E}{\rho_m F_s^2}\right] \tag{10}$$
$$R_a = k\left[M_e \cdot N \cdot C_a \cdot \frac{E}{\rho_m^2 F_s^2}\right] \tag{11}$$
$$R_a = k[M_e^\alpha \times C_a^\beta] \tag{12}$$

A. Analysis of Dimensionless Model

A dimensionless surface polish equation R_a was developed by taking number of passes, flow velocity, media density, grit size, and VF of abrasives on a material while taking its modulus of elasticity into account. The model in this work links the response surface finish (R_a) with the process parameters by taking Young's modulus. The rationale of developed equation is validated by carrying out associated experiments and determining the equation's constants and power indices using the least square method. The basic goal of creating a dimensionless equation is to build a relation among process parameters and output responses.

Fig.8 depicts the surface roughness achieved through experiments and projected by a dimensionless model for various number of passes with 0.35 volume fraction and mesh size 36. The plot clearly shows there is progressive reduction in R_a as number of passes enhances. The curve indicates an error between the experimental and projected outcomes. R_a reduces during early EH passes due to the reduction of peaks from bored surface. After six passes there is a small improvement in R_a, but surface texture deteriorates.
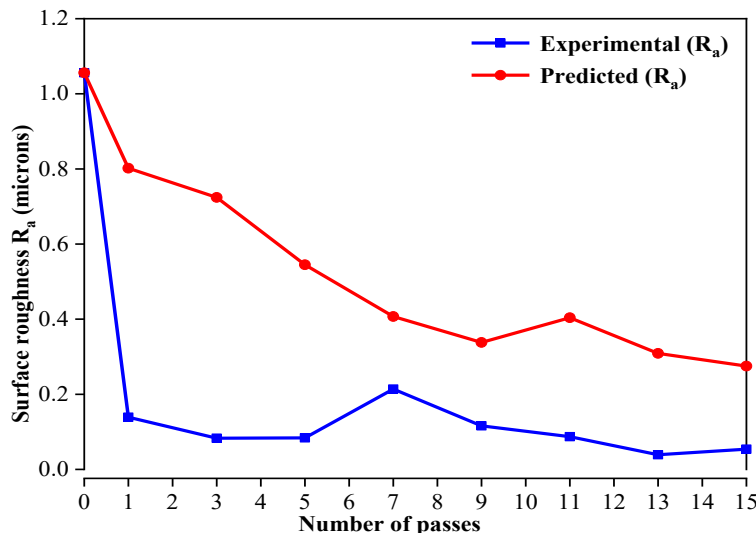

Fig. 8 Plot of experiment and predicted R_a for different EH trials

k is proportionality constants "α" and "β" are dimensionless model's power indices. The coefficient and power indices values must be established. As a result, a series of appropriate experimental trials are carried out. In the current study, regression analysis is employed to find out unknown values of proportionality constant and power terms based on the acquired results. The effect of pass number, grit size and volume fraction of abrasive on R_a is investigated in this study. While performing EH trials the parameters ρ_m and F_s of carrier media are constants. The concluding equation with the value of proportionality constant and power terms is given by eqn (13).

$$R_a = 2.4056[M_e^{-1.5047} \times C_a^{-2.4552}] \times N \qquad (13)$$

IV. SEM ANALYSIS

As drilled and EH textures are investigated for SEM analysis to identify effects of extrusion honing technique on surface texture generated. Fig.9 shows the typical SEM illustrations acquired before and after the EH. A machined mark caused by drilling is apparent and illustrated in Fig.9(a). The macrograph after five pass can be seen in Fig.9(b), which also notifies scrubbing of boring lay, path of particle movement and abrasion dents. Additional trial of EH as shown in Fig.9(c), glazing pattern can produce a fairly consistent texture with a steady lay pattern. With additional EH trials, as seen in Fig.9(d) this materials possess a unique glazing structure and uniform texture after 15 passes.
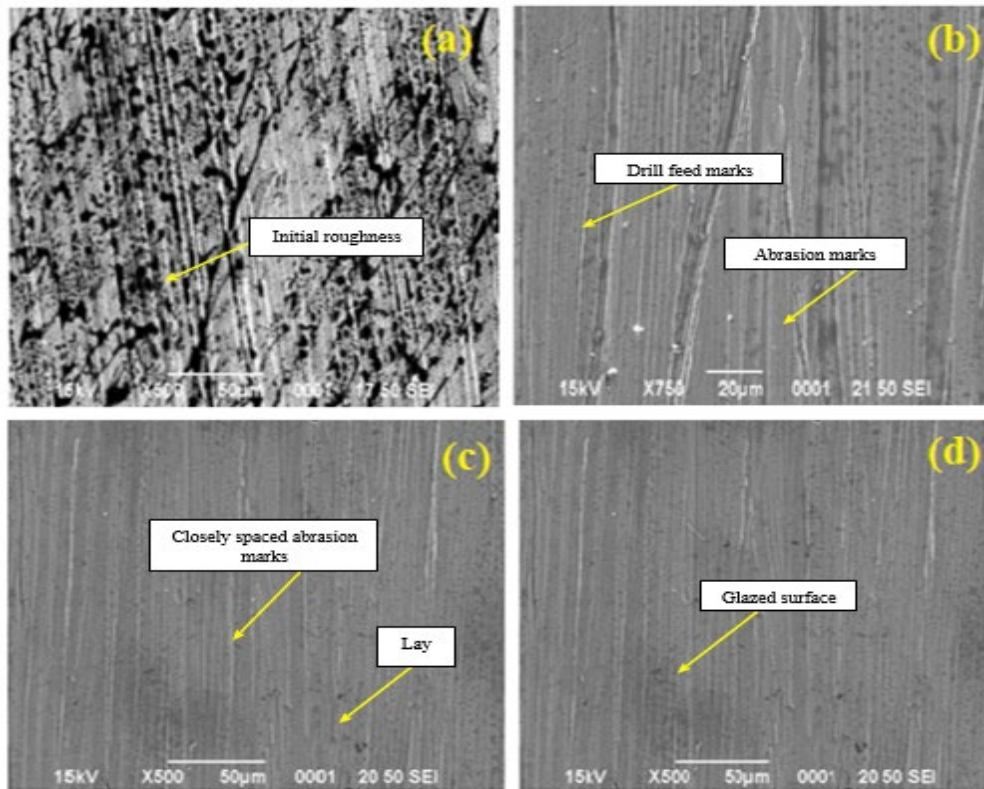

Fig. 9 SEM images of EH textures (a) As bored surface (b) after 5 passes (c) After 10 passes and (d) After 15 passes

V. CONCLUSION

Challenging stiff material like Inconel-625 alloy is finish-machined using EH process by a select grade polymer. It is evident that R_a reduces significantly at the early phase of EH process i.e., at first and second pass itself. This is due to shearing of asperities and surface irregularities. The EH process at pressure 60 bar, abrasive grit size of 36 and 35% VF, 15 number of passes and in 7 mm bore diameter reveal appreciable results when interior surface of Inconel-625 alloy is extrusion honed. EH trials are carried out for given grit number and VF of abrasive for the given passage diameter on both entry/exit sides of carrier media. There is an extreme decline in surface finish. This happens from second pass after which there is a stable improvement in

surface roughness up to fifteenth pass with a diminishing surface with further number of passes. After first pass surface roughness at both entry and exit side exhibits extensive abnormality in the surface texture generated by pre-honing. The sudden reduction in surface quality is because of removal of principal peak asperities at early EH phases. The exit side of abrasive media exhibits better surface finish than at entry side. It is due to formation of dead zone at entry while there is a better contact of abrasive with work surface at exit side.

It is efforted to develop a dimensionless expression to evaluate R_a with the process parameters considered. It is witnessed that predicted results achieved with developed equation are in accord with the experimental results. SEM

photographs of EH surfaces illustrate progress in quality of surface texture and uniform lay pattern of surface texture can be visualized.

REFERENCES

[1] V. K. Jain and S. G. Adsul, "Experimental investigations into abrasive flow machining (AFM)," *International Journal of Machine Tools and Manufacture,* Vol. 40, No. 7, pp. 1003-1021, 2000.

[2] M. Ravi Sankar, V. K. Jain and J. Ramkumar, "Rotational abrasive flow finishing (R-AFF) process and its effects on finished surface topography," *International Journal of Machine Tools and Manufacture,* Vol. 50, No. 07, pp. 637-650, 2010.

[3] D. Sudhakara, S. Suresh and B. Vinod, "Experimental study on abrasive flow machining (AFM): new approach for investigation on nano-SiC in the improvement of material removal and surface finishing," *Journal of Bio- and Tribo- Corrosion,* Vol. 6, No. 01, pp. 1-12, 2020.

[4] Mohammed Yunus and Mohammad S. Alsoufi, "Application of response surface methodology for the optimization of the control factors of abrasive flow machining of multiple holes in zinc and Al/SiCp MMC wires," *Journal of Engineering Science and Technology,* Vol. 15, No.1, pp. 655-674, 2020.

[5] M. Singh and S. Mittal, "Effect of process variables on material removal rate during finishing of Al-6061 alloy using abrasive flow machining," *International Journal of Current Engineering and Technology,* Vol. 5, No. 4, pp. 2449-2453, 2015.

[6] Amir Dehghanghadikolaei, Behzad Fotovvati, Behrouz Mohammadian and Navid Namdari, "Abrasive flow finishing of stainless steel 304 biomedical devices," *Research and Development in Material Science,* Vol. 8, No. 02, pp. 864-871, 2018.

[7] A. F. Ibrahim, "Studying material removal in abrasive flow machining by using SiC," *International Journal of Current Engineering and Technology,* Vol. 4, No. 5, pp. 3420-3423, 2014.

[8] H. P. Raju, K. Narayanasamy, Y. G. Srinivasa and R. Krishnamurthy, "Characteristics of extrude honed SG iron internal primitives," *Journal of Materials Processing Technology,* Vol. 166, No. 3, pp. 455-464, 2005.

[9] H. P. Raju, K. Narayanasamy, Y. G. Srinivasa and R. Krishnamurthy, "Material response in extrusion honing," *Journal of materials science letters*, Vol. 22, No. 5, pp. 367-370, 2003.

[10] H. P. Raju, K. Narayanasamy, Y. G. Srinivasa and R. Krishnamurthy, "Flexible super finishing process for intricate shapes," 2022.

[11] H. P. Raju, K. Narayanasamy, Y. G. Srinivasa and R. Krishnamurthy, "Production of surface texture in extrude honing," *JSME/ASME International conference on materials and processing,* pp. 333-336, 2002.

[12] K. Narayanasamy and H. P. Raju, "Generation of quality surface in extrude honing," 2022.

[13] H. P. Raju, V. R. Devadath and N. L. Murali Krishna, "Extrusion honed surface characteristics of Inconel 600," *International Journal of Engineering Research and Applications,* Vol. 3, No. 06, pp. 1338-1343, 2013.

[14] H. P. Raju, B. N. Shreeraj and N. L. Murali Krishna, "Characteristics study of inconel 718 surface generated by extrusion honing process," *International Journal of Engineering Research in Mechanical and Civil Engineering,* Vol. 2, No. 4, pp. 654-658, 2017.

[15] K. N. Lingaraju and H. P. Raju, "Surface finishing using extrusion honing process on monel-400,"*International Journal of Engineering Research and Application,* Vol. 7, No. 12, pp. 52-56, 2017.

[16] V. R. Devadath and H. P. Raju, "A study of the effects of extrusion honing on hastelloy C22 using SiC abrasive of different mesh sizes," *International Journal of Current Research in Life Sciences,* Vol. 7, No. 02, pp. 1029-1035, 2018.

[17] H. P. Raju and B. Sreenivasa Murthy, "Investigation into the super finishing of hole surface of titanium grade-2 using one-way extrusion honing process," *International Journal for Research in Applied Science & Engineering Technology,* Vol. 7, No. 07, pp. 171-177, 2019.

[18] H. P. Raju and K. S. Abhijith, "Studying the variations of surface roughness parameters of nitronic-60 to extrusion honing process," *International Journal for Research in Applied Science and Engineering Technology,* Vol. 7, No. 07, pp. 449-456, 2019.

[19] A. D. Karthik and H. P. Raju, "Investigation on surface roughness parameters of nickel alloy A-286 by extrusion honing process," *International Research Journal of Engineering and Technology,* Vol. 5, No. 07, pp. 968-973, 2018.

[20] N. L. Murali Krishna and H. P. Raju, "Extrusion honed surface characteristics of Inconel 625 fabricated by EDM for square shape," *International Journal of Engineering Research and Application,* Vol. 4, No. 6, pp. 68-72, 2014.

[21] N. L. Murali Krishna and H. P. Raju, "Acoustic emission characteristics of Inconel 718 and Inconel 625 micro finished by extrusion honing process," *International Journal of research in advent Technology,* Vol. 2, pp. 81-86, 2014.

[22] R. K. Jain and V. K. Jain, "Finite element simulation of abrasive flow machining*," Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture,* Vol. 217, No. 12, pp. 1723-1736, 2003.

[23] Rajendra K. Jain and V. K. Jain, "Stochastic simulation of active grain density in abrasive flow machining," *Journal of Materials Processing Technology,* Vol. 152, No. 1, pp. 17-22, 2004.

[24] R. K. Jain, V. K. Jain and P. K. Kalra, "Modelling of abrasive flow machining process: a neural network approach," *Wear,* Vol. 231, No. 2, pp. 242-248, 1999.

[25] Rajendra Kumar Jain and Vijay Kumar Jain, "Optimum selection of machining conditions in abrasive flow machining using neural network," *Journal of Materials Processing Technology,* Vol. 108, No. 1, pp. 62-67, 2000.

[26] S. L. N. Jayasimha, Ganapathy Bawge and H. P. Raju, "Flow simulation of visco elastic polymer in one way extrusion honing process," *Materials Today: Proceedings,* Vol. 47, No. 10, pp. 2467-2473, 2021.

[27] S. L. N. Jayasimha, K. N. Lingaraju and H. P. Raju, "Experimental and computational simulation of one way extrusion honing process on Inconel-625 alloy," *AIP Conference Proceedings,* Vol. 2421, No. 01, pp. 1-11, 2022.

[28] S. L. N. Jayasimha, K. N. Lingaraju and H. P. Raju, "Modelling of as bored surface of Inconel-625 alloy using unidirectional extrusion honing process," *Materials Today: Proceedings,* Vol. 52, No. P3, pp. 993-997, 2022.

[29] S. L. N. Jayasimha, K. N. Lingaraju and H. P. Raju, "Prediction of surface finish in extrusion honing process by regression analysis and artificial neural networks," *Applications in Engineering Science,* Vol. 10, No. 01, pp. 1-6, 2022.

[30] S. L. N. Jayasimha, Ganapathy Bawge and H. P. Raju, "Surface finish characteristics of distinct materials using extrusion honing process," *Journal of Computational & Applied Research in Mechanical Engineering,* Vol. 12. No. 01, pp. 41-50, 2021.

[31] S. L. N. Jayasimha, N. L.Murali Krishna and H. P. Raju, "Development of semi-empirical model to estimate surface finish of Inconel-625 alloy in extrusion honing process," *Results in Engineering,* Vol. 15, No. 100575, pp. 1-6, 2022.

[32] Nilesh G. Patil and P. K. Brahmankar, "Determination of material removal rate in wire electro-discharge machining of metal matrix composites using dimensional analysis," *The International Journal of Advanced Manufacturing Technology,* Vol. 51, No. 05, pp. 599-610, 2010.