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Extrusion Honed Surface Characteristics of Inconel 600

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ABSTRACT
Precision finishing of internal surfaces and complex geometries is always of concern in industry since it is labour intensive and difficult to control. Due to the development of new difficult-to machine materials like Inconel and also complex geometrical shapes of engineering components, the available traditional finishing processes alone are not capable of producing required surface finish and other characteristics. Extrusion honing (EH) is a relatively new non-traditional micro-machining process to debur, radius, polish and remove recast layer of components in a wide range of applications. Material is removed from the work-piece by flowing abrasive laden medium under pressure through or past the work surface to be finished. Components made up of complex passages having surface/areas inaccessible to traditional methods can be finished to high quality and precision by this process. Inconel alloy 600 is a difficult metal to shape and machine using traditional techniques. In this study, extrude honing of Inconel 600 has been performed in an indigenously built hydraulic operated extrusion honing setup using select grade of polymer as a carrier medium and SiC grit of 36 mesh size as abrasive. The internal surface finish results obtained with the use of extrusion honing process are discussed.
Keywords— abrasive, carrier medium, extrusion honing, Inconel, surface finish.

I. INTRODUCTION

Extrusion honing **(**EH**)** also known as abrasive flow machining (AFM) is a process for the production of excellent surface qualities of inner profiles that are difficult to access and outside edges, as well as for deburring and edge rounding. EH process removes small quantity of material by flowing a semisolid abrasive-laden compound called ‘media’ through or across the surface of the workpiece to be finished.Two vertically opposed cylinders extrude media back and forth through passages formed by the workpiece and tooling (Fig.1). Abrasive action occurs wherever the media enters and passes through the most restrictive passages. The media is composed of semisolid carrier and abrasive grains. Most commonly used abrasive grains are silicon carbide, boron carbide, aluminium oxide and diamond. The most commonly used carrier is polyborosiloxane. The unique features of EH such as versatility, efficiency, economy makes the process useful to perform a wide range of precision machining operations in the aerospace and automobile industries, manufacture of dies and medical instruments. Some of the components machined by EH include fuel injector nozzles, turbine blades, combustion liners, dies etc. It can simultaneously process multiple parts or many areas of a single workpiece. Inaccessible areas and complex internal passages can be finished economically and effectively. Inconel 600 is a difficult metal to shape and machine using traditional techniques due to rapid work hardening.

Rhoades [3-4] experimentally investigated the basic principles of AFM process and identified its control parameters. He observed that when the medium is suddenly forced through restrictive passage, its viscosity temporarily rises. Significant material removal is observed only when medium is thickened. Jain and Adsul [5] reported that initial surface roughness and hardness of the work-piece affects material removal during AFM process. Material removal and reduction in surface roughness values are reported higher for the case of softer work-piece material as compared to harder materials. Perry [9] reported that abrasion is high where medium velocity is high. An increase in pressure and medium viscosity increases material removal rate while surface finish value (Ra) decreases. Williams and Rajurkar [10] reported that metal removal and surface finish in AFM are significantly affected by the medium viscosity. Jain and Jain [11] also reported that reduction in surface roughness (Ra Value) increases with increase in extrusion pressure and abrasive concentration, but they also observed that reduction in surface roughness (Ra value) is higher with increase in average grain size.

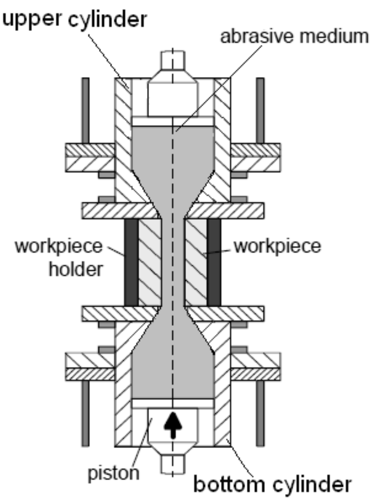

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FIGURE 1 – TWO-WAY EXTRUSION PROCESS

Jain and Adsul [13] reported that MRR is high in the first few cycles due to higher initial coarseness of work-piece surface, and thereafter, it starts slightly decreasing in every cycle. Jain et.al. [14] reported that percentage of abrasives in the medium, grain size and viscosity of the base medium are important parameters that influence stock removal and medium velocity. Gorana et.al. [15-16] reported that depth of penetration of abrasive particle depends on extrusion pressure, abrasive medium viscosity, and grain size. Due to the combined effect of radial force and axial force, the material is removed in the form of microchip.

Some of the researchers have studied the effects of process parameters like extrusion pressure, abrasive concentration, grain size, number of cycles etc. with respect to surface roughness and material removal of ferrous and non ferrous metal work-piece. Inconel alloy 600 has wide application areas like chemical industry, heat treatment plant and aeronautical field. Hardly any information is available in the literature regarding the effect of EH process parameters on surface finish of Inconel 600.

In the present study, extrude honing operations were performed on super alloy Inconel 600 at laboratory using indigenously built EH setup. A select grade of low cost polymeric material as medium and silicon carbide as abrasive has been used for finish process experimentation. The extrude honed surface of Inconel 600 have been evaluated in terms of surface finish parameters and the results show positive response.

II. EXPERIMENTAL PROCEDURE

Extrude honing experimentation were conducted in an indigenously built EH setup at laboratory and the surface finish parameters were evaluated after each trial.

[1] ***A. Material***

1. Work material: Inconel® (nickel-chromium-iron) alloy 600 (UNSN06600/W.Nr. 2.4816) is a standard engineering material for applications which require resistance to corrosion and heat. The alloy also has excellent mechanical properties and presents the desirable combination of high strength and good workability. The limiting chemical composition of Inconel alloy 600 is shown in Table 1. The versatility of Inconel 600 has led to its use in a variety of applications involving temperatures from cryogenic to above 1095°C. The alloy is used extensively in the chemical industry for its strength and corrosion resistance. The alloy's strength and oxidation resistance at high temperatures make it useful for many applications in the heat-treating industry. In the aeronautical field, it is used for a variety of engine and airframe components. This alloy is a standard material of construction for nuclear reactors. [Special metals]

TABLE 1 - CHEMICAL COMPOSITION OF INCONEL 600 WT %

Element	**Concentration [wt. %]**
Al	0.18
Chromium	15.24
Iron	8.50
Carbon	0.08
Manganese	0.21
Ti	0.23
Silicon	0.42
Copper	0.17
Cobalt	0.19
Nickel	Balance
Tensile Strength	550-690 Mpa
Yield Strength	170-345 Mpa
Hardness	85BHN

2. Carrier medium: In the present study, a select grade of polymer was used as working medium and commercially available silicon carbide of 36 grit size was used as abrasive. Silicon carbide (25 vol.%) were thoroughly mixed with polymer medium using a laboratory built mixing device. The details of carrier medium are shown in Table .2

[2] B. Specimen preparation

Inconel 600 specimens of Ǿ 25mm and length 10mm were used for experimentation. The specimens were drilled using carbide drill bit of Ǿ 8mm of Ra value 6-8 microns. After washing the specimens, extrusion honing trials were conducted.

[3] C. Experiment trials

The experiment setup was designed and fabricated in the lab to perform extrusion honing. Fig.2 shows the schematic diagram of the setup for the EH process. This set up is a one way type of EH process, i.e the medium flows in only one direction. It consists of an abrasive media cylinder coupled to a hydraulic cylinder and to control the actuation suitable directional control valve has been utilized. Abrasive media cylinder is a piston cylinder arrangement with end cap which has a fixture for housing the specimen. The fixture helps to mount and dismount specimen easily from the cylinder. Abrasive media enters the specimen from one side and extrudes out at the other side. The extruded abrasive media is collected in the collector shown in fig. 3. The parameters used in the trials are presented in Table. 2. Each specimen was honed for 15 passes under similar conditions and after each pass surface finish parameters were measured at two locations of entry side (side 1)and at two locations of exit side (side 2) of the specimen using Surfcom shown in Fig. 4

TABLE 2 – EXTRUSION HONING PROCESS PARAMETERS

Parameter	Details
Pressure	60 bar
Volume fraction (abrasive)	0.25
Temperature	Ambient
Stroke length	500 mm

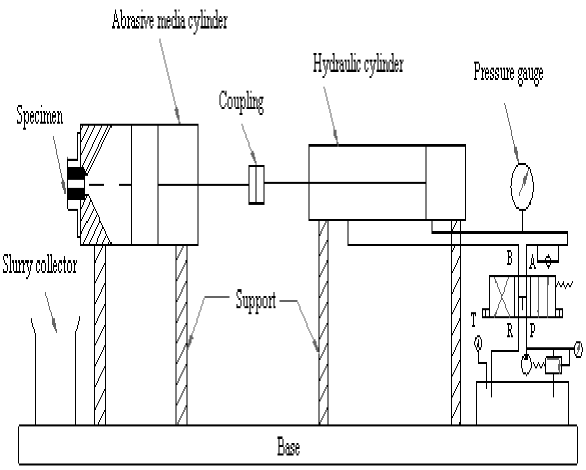

FIGURE 2: SCHEMATIC DIAGRAM OF THE EXTRUSION HONING PROCESS

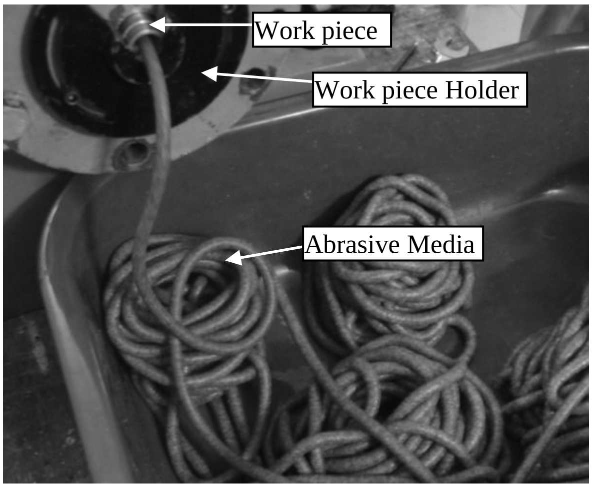

FIGURE 3: EXTRUSION HONING PROCESS

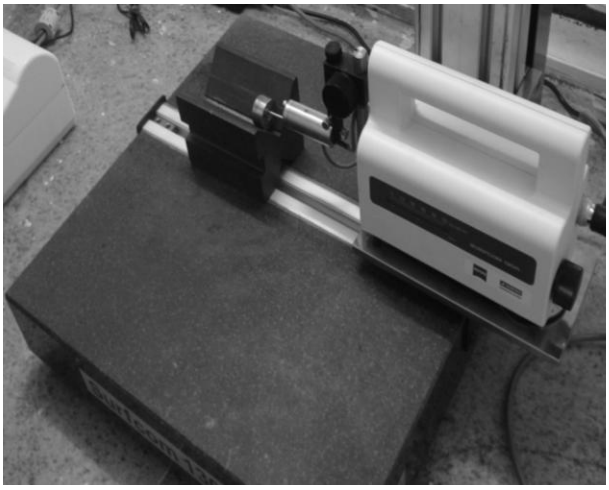

FIGURE 4: SURFCOM - SURFACE ROUGHNESS MEASURING INSTRUMENT

III. RESULTS AND DISCUSSION

The extrude honed surface of Inconel 600 was evaluated in terms of surface finish parameters. Fig. 5,6,7 depicts roughness parameters at entry side first point. Fig.8,9,10 entry side second point Fig. 11,12,13 exit side first point Fig. 14,15,16 exit side second point. Fig. 5 and Fig 8 shows surface parameters at first and second point of entry side. It shows that during the early stages of honing there is drastic reduction in R_z, R_t, R_{pk} values however as the number of passes increases there is progressive reduction in these value. Trend of these values changes after thirteenth pass. There is a progressive reduction in R_a value from initial pass to thirteenth pass later R_a value also increases.

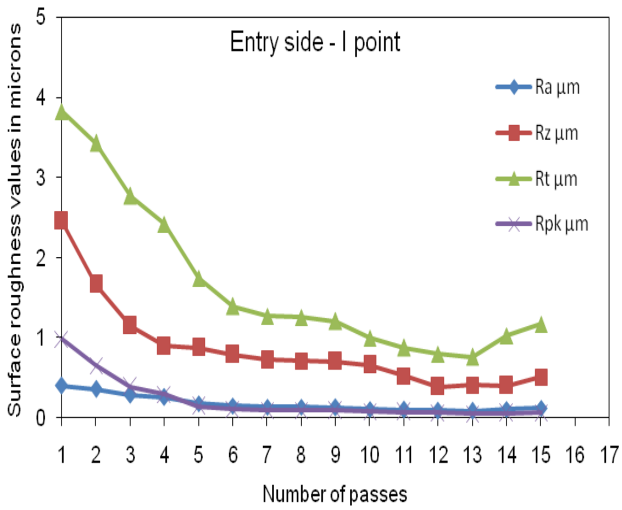

FIGURE 5: SURFACE ROUGHNESS PARAMETERS CHARACTERISTICS AT FIRST POINT OF ENTRY SIDE

It can be observed that after thirteenth pass deterioration of surface texture occurs in both entry and exit side of the specimen as well. Fig. 11and Fig 14 shows surface parameters at first and second point of exit side. It also shows the variation of R_a, R_z, R_t and R_{pk} values similar to entry side i.e. drastic reduction during the early stages of honing, progressive reduction as the number of passes are increased. Trend of all these values increases after the thirteenth pass.

Fig. 6 and Fig. 9 shows the variation of R_t/R_a with number of passes at first and second point of entry side. A steady reduction in R_t/R_a can be seen up to thirteen passes later there is a rise in R_t/R_a. This indicates that the work piece attains core roughness by thirteen passes and later roughness increases. Exit side values at first point and second point shown in Fig. 12 and Fig.15 follow the same pattern.

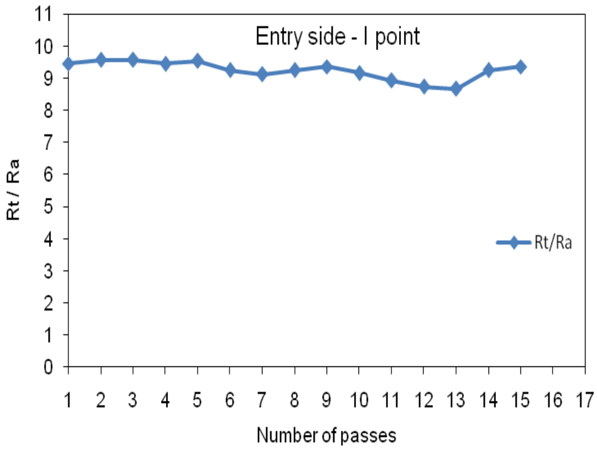

FIGURE 6: VARIATION OF RT/RA AT FIRST POINT OF ENTRY SIDE

Fig. 7 and Fig. 10 shows the percent wise change in roughness characteristics at first and second point of entry side. It is seen that all the characteristics R_a, R_z, R_t, and R_{pk} show a drastic reduction in percentage change in early three passes this maybe due to removal of active asperity over the length the surface. Further honing shows steady change in all the characteristics R_a, R_z, R_t, and $R_{pk.}$ After thirteenth pass all the characteristics show negative values. Exit side values at first point and second point shown in Fig. 13 and Fig.16 also depicts similar variation in percent wise change in roughness characteristics.

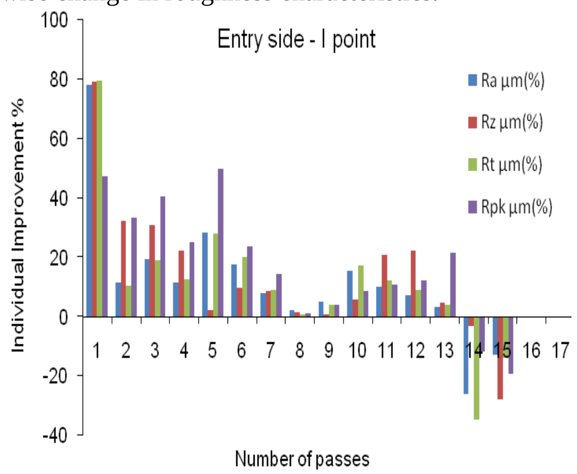

FIGURE 7: PERCENTAGE OF CHANGE IN INDIVIDUAL CHARACTERISTICS AT FIRST POINT OF ENTRY SIDE

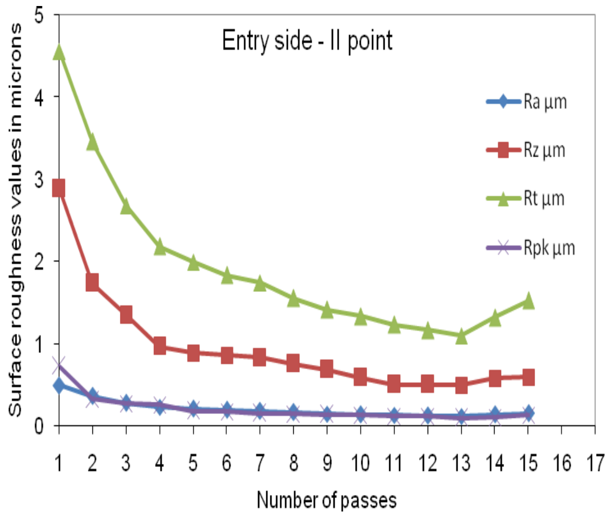

FIGURE 8: SURFACE ROUGHNESS PARAMETERS CHARACTERISTICS AT SECOND POINT OF ENTRY SIDE

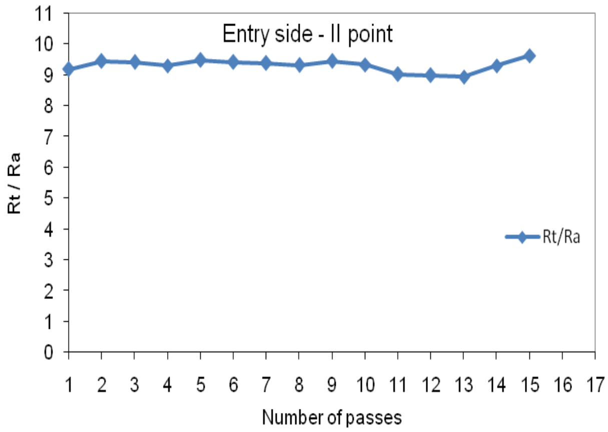

FIGURE 9: VARIATION OF RT/RA AT SECOND POINT OF ENTRY SIDE

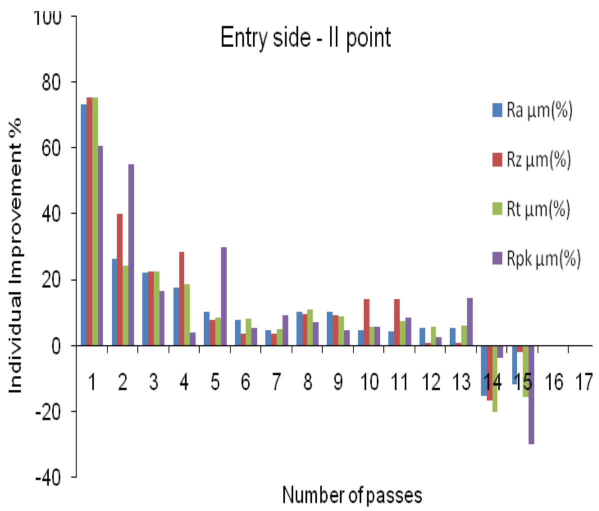

FIGURE 10: percentage of change in individual characteristics at second point Of entry side

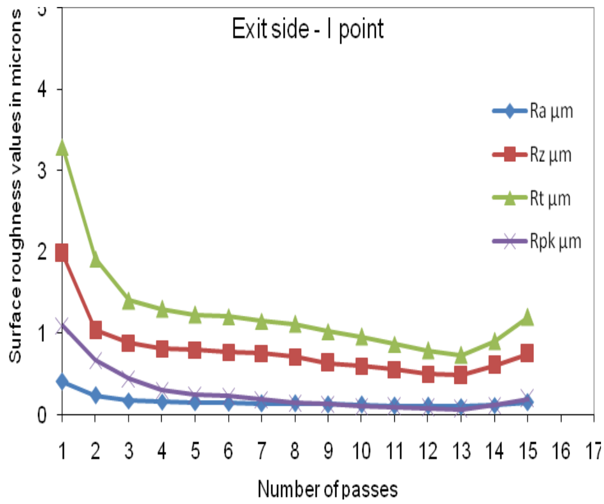

FIGURE 11: SURFACE ROUGHNESS PARAMETERS CHARACTERISTICS AT FIRST POINT OF EXIT SIDE

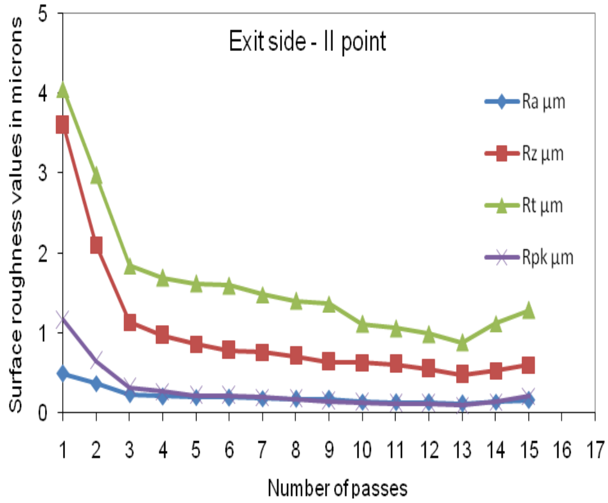

FIGURE 14: SURFACE ROUGHNESS PARAMETERS CHARACTERISTICS AT SECOND POINT OF EXIT SIDE

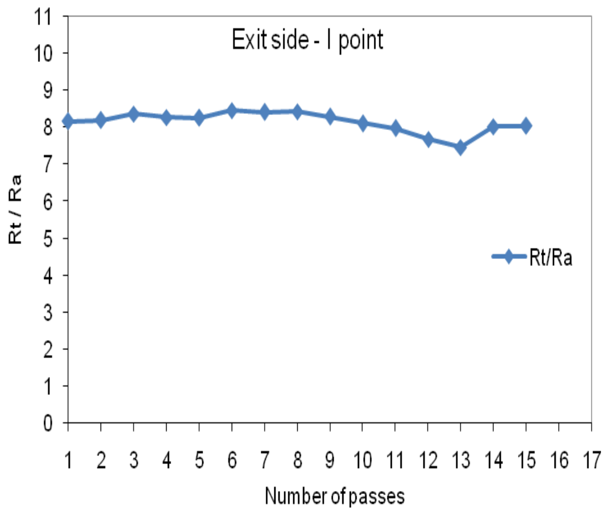

FIGURE 12: VARIATION OF RT/RA AT FIRST POINT OF EXIT SIDE

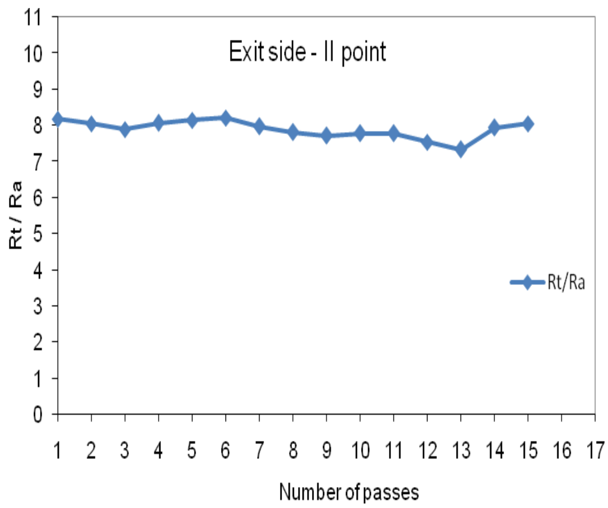

FIGURE 15: VARIATION OF RT/RA AT SECOND POINT OF EXIT SIDE

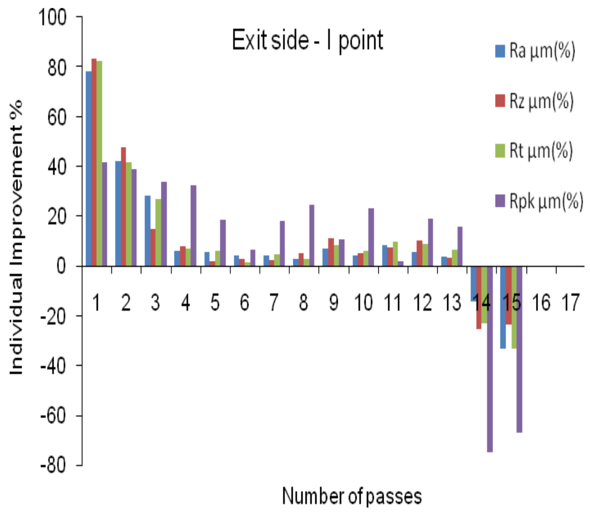

FIGURE 13: percentage of change in individual characteristics AT first point of exit side

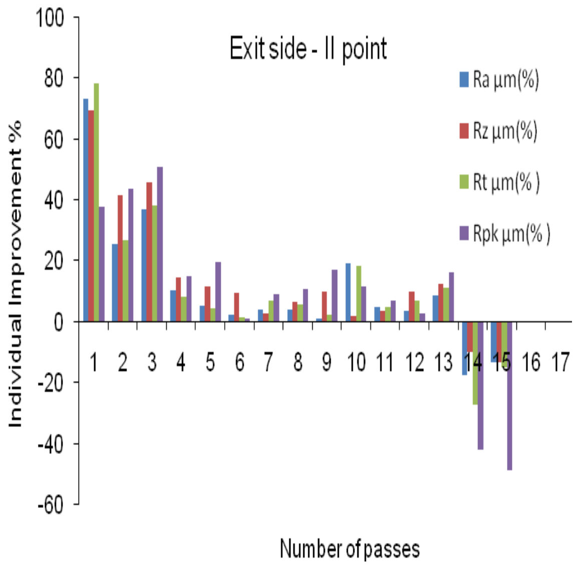

FIGURE 16: PERCENTAGE OF CHANGE IN INDIVIDUAL CHARACTERISTICS AT SECOND POINT OF EXIT SIDE

IV. CONCLUSION

In the present study extrusion honing of Inconel 600 has been carried out using select grade of silicone polymer. The surface finish parameters of Inconel 600 were measured at two locations on entry side and exit side of abrasive media. The conclusions drawn from the study are:

1. The extrusion honing process in 60 bar range shows good results in super finishing Inconel 600
2. The surface finish parameters show a progressive improvement till thirteenth pass in both entry and exit side of the specimen beyond which the surface starts deteriorating.
3. Till thirteenth pass core roughness is achieved and in later passes abrasive particles dig into the surface causing the surface parameters values to increase.
4. At the entry side of the specimen drastic reduction in surface finish parameters occurs till fourth pass later gradual reduction up to thirteenth pass.
5. While at the exit side drastic reduction occurs till third pass only later gradual reduction in surface finish parameters up to thirteenth pass
6. Surface at the exit side is better than entry side due to better contact with abrasive medium.

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