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Acoustic Emission Characteristics of Inconel 718 and Inconel 625 Micro Finished by Extrusion Honing Process

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Abstract: Extrusion Honing (EH) is a nontraditional machining process also known as Abrasive flow machining (AFM) that deburrs, clean, polish, remove recast layer and micro cracks by flowing pressurized semisolid abrasive laden visco-elastic media over those surfaces. Inconel 718 and Inconel 625 are nickel base alloys and have a unique position among the materials due to its low thermal diffusive property, high hardness and high strength at elevated temperature. This paper presents ambitious report on acoustic emission (AE) monitoring strategy and the AE characteristics of extrusion honing process using these materials. The results showed AE signals to be a good sensing method for determining the performance of EH for different passage diameters of Inconel 718 and Inconel 625 materials. The energy and amplitude of AE signals were mainly influenced by the surface roughness. It was observed that AE signals are highly dependent on the workpiece passage diameter.

Index Terms: Acoustic Emission; RMS; Amplitude; Extrusion honing; Inconel; Surface finish; Abrasive Flow Machining; Silicone.

1. INTRODUCTION

Extrusion honing (EH) is a nontraditional machining process that was developed in the USA in the 1960s and also known as Abrasive Flow Machining process (AFM). EH can be described as pressurized media passing through the surfaces to reach the desired surface quality. There are mainly three types of EH machines one way, two way and orbital. The media consist of a type of polymeric carrier and abrasive particles SiC, Al_2O_3, diamond etc. EH is used to deburr, polish, radiusing and remove recast layers. Finishing operations in the metal working industries represent a critical and expensive phase of manufacturing process. The quality of surface finish is taken care of by manufacturing processes. Most of existing finishing operations are performed manual, conventional or non-conventional machining processes. Several researches have studied the application of finishing surface by abrasive flow machining.

Rhoades [1-2-3], developed an abrasive flow machine that can be applied to a wide range of applications, from critical aerospace and medical components to high production volumes of parts. The three major elements in extrusion honing are: the machine, abrasive materials, and fixtures. Critical parameters in the process are extrusion pressure and flow of abrasive material. Other parameters are flow speed, media viscosity, media rheology, abrasive size, cross-sectional area of passage and restricting passage length [4]. The developed process consists of two vertically opposed cylinders extrude a semisolid abrasive media back and forth through passages formed by the work piece and tooling. In the study author compares the machining action to a grinding operation as the abrasive media is gently and uniformly hones the surface or edges of the material. Also author reported the process can yield production rates up to thousands of parts per hour. Abrasive flow machining process can be applied to a wide range of predictable, repeatable results. Abrasive flow machining process media is composed of a pliable semisolid carrier and a concentration of abrasive grains called silly-putty [5-6].

R.E.Williams [7], carried out an experimental investigation using Acoustic Emission (AE) on-line monitoring sensing method for determining the performance characteristics of the AFM process. The acquired acoustic emission signals during AFM process revealed the distinct frequency bands, these bands have been related to the different material removal modes in AFM. In present paper the primary AE signal component had a frequency of 160 kHz. This frequency was postulated to be due to the type of work piece material and the formation of AFM flow lines. It was also observed that, as the number of cycles increases, the power spectrum amplitude of this frequency increases. Result reported that AE signal were highly dependent on the characteristics of the work piece surface before AFM process, particularly starting surface roughness R_a. Experimental result also revealed that the root mean square (RMS) voltage of the AE signal found to be very sensitive to extrusion pressure and other AFM process parameters which affect the material removal. Author selected the orifices with smaller inside diameter passages and processed with AFM along with AE monitoring system.

The result shows that very high correlation between RMS AE and the orifice diameter and also RMS AE and volumetric flow rate. Further, author proposed the expression for RMS of the acoustic emission signal and clarified the signal with the findings. Finally, author found that the AE signal generated during AFM process is highly correlated to the passage size, volumetric flow rate of the putty and material removed from the work piece.

Kimberly et al. [8], developed a predictive process modeling system for the abrasive flow machining process. This process is used for polishing and surface removal of work pieces with an internal flow path. The process model is a set of neural network and search algorithm with Visual Basic and Pascal. The model was used to study the process without performing physical experiment by examining the effect on the output variables of small changes to the input variables. This activity enables the engineer to understand and formalize knowledge of the abrasive flow machining process. The model can be used to reduce the development time for new applications and also can be used as a training tool by allowing the trainees to examine the effects of potential machining parameters without performing the trails on sample parts.

Linang Fang et al. [9], studied abrasive particle movement pattern as an important factor in estimating the wear rate of materials, especially, as it is closely related to the burring, buffing and polishing efficiency of the AFM process. There are generally two kinds of particle movement patterns in the AFM that is sliding – rubbing and rolling. In mechanism, AFM grain work piece interaction is taking place in any one or a combination of the possible modes: elastic/plastic deformation by sliding–rubbing grain movement; elastic/plastic deformation by rolling grain movement; chip formation (micro-cutting) by rubbing grain movement; ridges formation by rubbing and rolling grain movement; and low cycle fatigue wear. Therefore, the machining efficiency of a machine part is predominantly depends up on the particle movement patterns. Authors investigated normal load, particle size and hardness of machine parts to understand the involved parameters of particle movement patterns and proposed a computer statistic prediction of particle movement patterns.

It has been found that there are two cases. In case of large–sized particles, the ratio of rolling particles is increased with increasing normal load. For small–sized particles, the ratio of grooving particles is increased with increasing normal load and vice-versa. That influence will be predominant under heavy normal load. Most of the particles will tend to groove when the particle size is below certain value. Hardness of the material and their hardness difference for tribological pairs are other important monitors in predicting particle movement patterns. In this research, increasing hardness of materials results in more rolling particles, which results in much less cutting particles. Experimentally investigated the one-way AFM and developed in process measurement set up in ordered to measure the influence of the applied medium pressure on the (work piece) automotive steel AISI 4140 with the help of an axial force sensor. The media used were high viscous with aluminum oxide as abrasive particles. Their results showed that significant surface improvement in R_a and R_z after 15 AFM cycles. Higher pressure reported that much faster and desired surface finish is obtained. They concluded that sum of axial force increases linearly with passage length and applied piston pressure. They found that the length of the passage of end pieces is leading influence on F_{ax} where passage geometry does not effect. They also concluded that the inlet side of the adapter the core contributes maximum of 74N to the measured value of sum of axial force F_{ax}.

N.L. Murali Krishna and H.P. Raju [10], studied the characteristics of Inconel 625 fabricated by EDM for square shape and observed that a significant improvement in surface finish parameters. Authors claimed that extrusion honing process is capable of removing recast layer and micro cracks effectively.

Some of the researches have studied the effects of process parameters like extrusion pressure, abrasive concentration, grain size and number of cycles with respect to surface roughness and material removal of ferrous and non ferrous metal work piece. Inconel alloys 718 and 625 have wide application areas like chemical industry, heat treatment plant and aeronautical field. However, there is only one study available in the literature [7] regarding the effect of AE signal on EH process parameters.

In the present study, extrusion honing operations were performed on super alloy Inconel 718 and Inconel 625 at laboratory using indigenously built EH set up. A selected grade, polymeric material as medium and silicon carbide as abrasive particles has been used for finishing process. AE signals were captured and extrusion honed surface of Inconel 718 and Inconel 625 have been evaluated in terms of surface finish parameters. Material removal were taken from the work piece before and after the EH process and the results show positive response.

2. EXPERIMENTAL PROCEDURE

Extrusion honing experimentation was conducted in an indigenously built EH set up at laboratory and AE signals were captured and surface parameters, material removal were evaluated after each trial. Surface roughness measurements were taken at different positions both at entry and exit sides.

2.1. Material details

2.1.1. Work material

Inconel® alloys 718 (UNSN07718/W.Nr.3.4856) and Inconel® 625 (UNSN06625/W.Nr.2.4856) is a standard engineering material for applications which require resistance to corrosion and heat. The chemical composition and mechanical properties of Inconel 718 and Inconel 625 is shown in Table 1. The alloy also has excellent mechanical properties and presents the desirable combination of high strength and good workability. The versatility of Inconel 718 and Inconel 625 has led to its use in a variety of applications involving temperature from cryogenic to above 1350°C. The alloys strength and oxidation resistance at high temperature make it useful for many application in the heat–treating industry. In the aeronautical field, it is used for a variety of engine and airframe components. The alloy is a standard material of construction for marine engineering, chemical processing and nuclear reactors.

Table 1 Chemical Composition of Inconel 718, 625 and Mechanical Properties.

Element	**Concentration [wt.%] Inconel 718**	**Concentration [wt.%] Inconel 625**
Nickel	50-55 Max	58.0 Min
Chromium	17-21	20-23
Molybdenum	2.8-3.3	8-10
Niobium + Tantalum	-------	3.15-4.15
Niobium	4.75-5.5	-------
Iron	Balanced	5 Max
Cobalt	1 Max	-------
Aluminum	0.2-0.8	0.4 Max
Ti	0.7-1.15	0.4 Max
Carbon	0.08 Max	0.1 Max
Manganese	0.35 Max	0.5 Max
Silicon	0.35 Max	0.5 Max
Copper	0.3 Max	0.5 Max
Phosphorus	--------	0.015 Max
Sulfur	0.01 Max	0.015 Max
Mechanical properties		
Density	8.2 g/cm^3	8.4 g/cm^3
Tensile strength	965N/mm^2	760N/mm^2
Yield strength	550 N/mm^2	365 N/mm^2
BrinellHardness	≤ 363	≤ 220
Melting point	1340°C	1350°C

2.1.2. Carrier medium

In the present study, a selected grade of polymer was used as working medium and commercially available silicon carbide particles of 36 grit size were used as abrasive. Silicon carbide (40% vol.) was thoroughly mixed with polymer medium using a laboratory built silicone media mixer machine. The details of carrier medium are shown in table 2.

Table 2 Extrusion honing process parameters

Parameters	**Details**
Pressure	60 bar
Volume fraction of abrasive	40%
Temperature	Ambient
Stroke length	650 mm

2.2. Specimen preparation

Inconel 718 and Inconel 625 specimens of Ø25 mm and length of 24 mm were used for experimentation. The specimens were initially prepared by drilling for different hole sizes of 7, 8, 9 and 10mm. Surface parameters were measured initially and the R$_a$values found in the range of 3 to 1 µm. After washing the specimen with acetone, extrusion honing trials were conducted.

2.3. Experiment trials

The experiment setup was designed and fabricated in the laboratory to perform extrusion honing. This set up is a one way type of EH process that is the medium flows in only one direction. It consists of an abrasive media cylinder coupled to a hydraulic cylinder; to control the actuation the directional control valve has been utilized. Abrasive media cylinder is a piston cylinder arrangement with end cap which has a fixture for housing the workpiece. The fixture is designed to mount the workpiece easily to the end cap of the extrusion cylinder. Abrasive media enters the workpiece from one side and extrudes out at the other side. The extruded abrasive media is collected in the collector. The specimen was honed for 15 passes under similar conditions and after each pass surface was cleaned with acetone and surface finish parameters were measured at three different locations on the workpiece. AE parameter i.e., AE energy and amplitude were acquired using AE measuring system. A threshold level was fixed before actually acquiring the AE signal. The threshold level will helps us in avoiding the noise signals getting along with the AE signals. For this dry running of extrusion honing machine was done and the noise level of 30 dB was fixed as threshold. AE signals were captured and the signals were acquired to computer through Peripheral Component Interconnect (PCI)-2. The surface roughness measurements were taken with skidless surface roughness tester, Surfcom 130A with a stylus of tip radius 2µm. The cut-off length chosen for measurement was 0.8 mm with 4 mm traverse length. Care was taken to measure the roughness at the same location before and after the experiments. The material removal was measured before and after the experiments with Afcoset ER-200A electronic balance having a least count of 0.001mg.

3. RESULTS AND DISCUSSION.

Typical observed parametric influence of extrusion honed Inconel 718 and Inconel 625 specimens is illustrated through Fig.1 to Fig.8. Figures 1, 2, 3 and 4 show the surface roughness in terms of R_a at entry and exit sides respectively for Inconel 718 and Inconel 625. It is seen that there is a visible and drastic reduction in R_a values during early phase of extrusion honing for both the materials by 2nd pass signifying macro-irregularity correction and further there will be significant improvement in surface roughness till 10th pass indicating micro-irregularity correction after that there will be reduction in surface roughness indicating surface deterioration. Figure 5, 6, 7 and 8 shows the amplitude and AE energy respectively for Inconel 718 and Inconel 625. It was also observed that for Inconel 718, AE energy value for 7 mm diameter show positive increase in the trend while for 8, 9 and 10 mm diameter shows negative trend, with increases in number of passes. Where as in the case of Inconel 625, AE energy value for all the diameters shows decrease in the trend, with increases in number of passes. These two trends are possibly due to the difference in the composition of the materials.

3.1. Observation of surface roughness

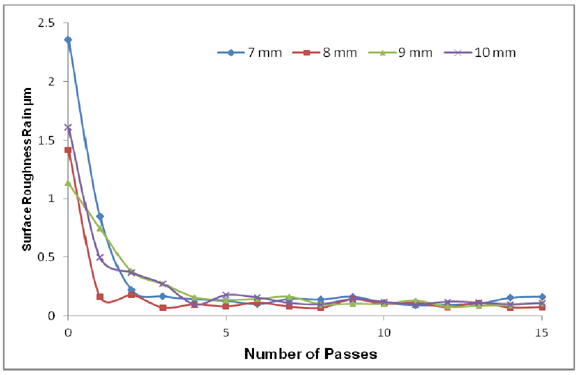

Fig.1 Surface Roughness v/s Number of passes at entry side for Inconel 718.

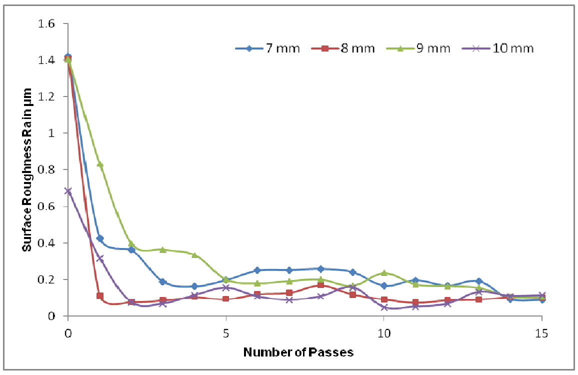

Fig.2 Surface Roughness v/s Number of passes at exit side for Inconel 718.

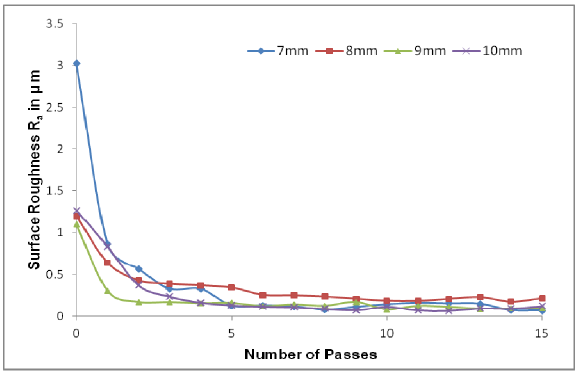

Fig.3 Surface Roughness v/s Number of passes at entry point for Inconel 625.

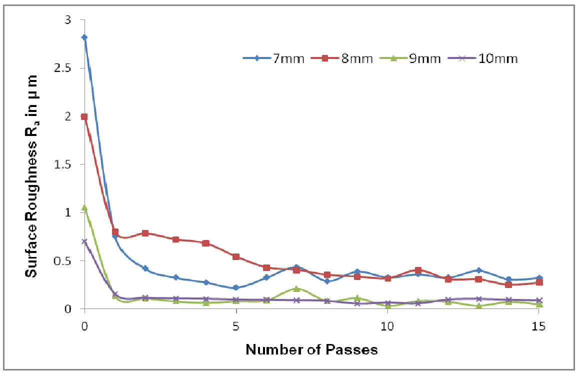

Fig.4 Surface Roughness v/s Number of passes at exit point for Inconel 625.

3.2 *Acoustic Emission Observation*

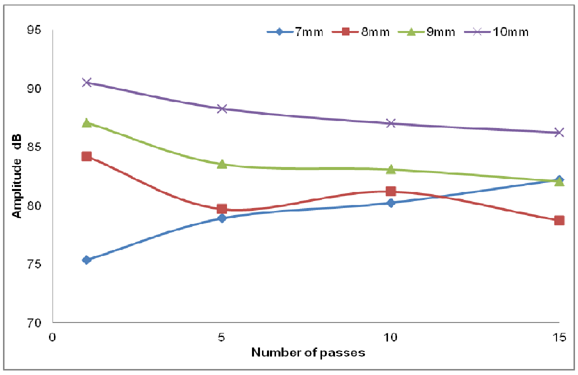

Fig.5 AE Amplitude v/s Number of passes for Inconel 718.

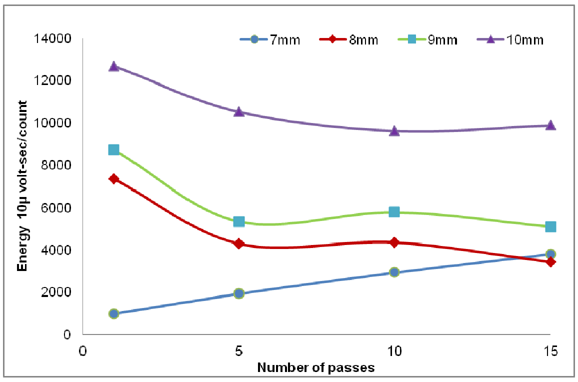

Fig.6 AE Energy v/s Number of passes for Inconel 718.

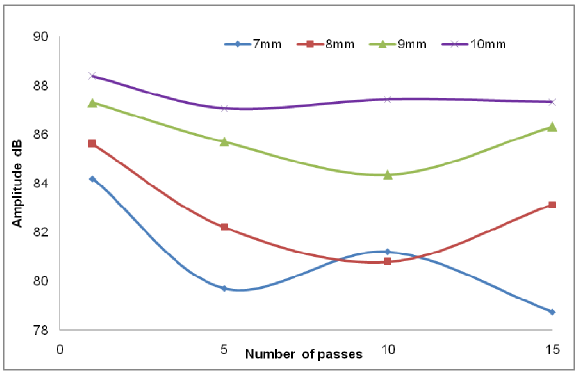

Fig.7 AE Amplitude v/s Number of passes for Inconel 625.

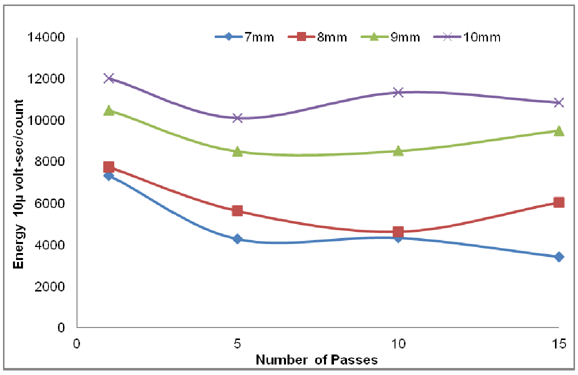

Fig.8 AE Energy v/s Number of passes for Inconel 625.

4. CONCLUSION

In this paper, an investigation has been made to study the AE characteristics of Inconel 718 and Inconel 625 work piece processed by extrusion honing. The samples that were processed with EH have been pre-machined by drilling process. Basic one-way extrusion honing was performed using a silicone polymer with SiC abrasive particles. The surface finish was measured on workpiece at three different locations on entry side and exit side of the abrasive media flow. The results of this study led to the following conclusions:

1. The extrusion honing process with 60 bar pressure, abrasive particle size of 36, volume fraction of abrasive 40% and 15 EH passes shows good results in finishing of Inconel 718 and Inconel 625.
2. At the entry and exit side of the specimen drastic reduction in surface roughness occurs at early stage by 2nd pass indicating macro-irregularity correction. After that there will be steady improvement in surface finish up to 10th pass, signifying micro-irregularity correction indicating honing process, beyond which the surface deteriorating.

3. Surface finish at the exit side is better than the entry side. This may be due to the dead zone formed at entry side wherein the abrasive medium becomes sluggish which results in ineffective abrasion in those regions and at exit side during process the abrasive medium relax quickly as a result makes better contact of the abrasive particles on those regions. This possibly has resulted better surface finish at exit side.
4. It was observed that the AE energy and amplitude were found to be sensitive to the work piece passage diameter.
5. It was also observed that for Inconel 718, AE energy value for 7 mm diameter show positive increase in the trend while for 8, 9 and 10 mm diameter shows negative trend, with increases in number of passes. Where as in the case of Inconel 625, AE energy value for all the diameters shows decrease in the trend, with increases in number of passes. These two trends are possibly due to the difference in the composition of the materials.
6. It can be concluded that AE process is good on-line sensing method to determine the performance characteristics and surface integrity of materials.
7. Also it can be concluded that Extrusion Honing process undoubtedly an alternative, efficient finishing process for small hole / passages and complex shapes.

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