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An Experimental Investigation on Surface Topography of Miniature Spur Gear by WEDM of Inconel 718

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Abstract

The traditional machining process such as grinding, milling and drilling, etc. are failed to machine geometrically difficult or complex shaped and sized products. One of the most frequently used precise non-conventional material removal processes is Electrical discharge machining. This paper deals with the investigations on some important aspects of surface integrity and surface topography of the miniature spur gears made by WEDM process. Moreover at high discharge energy the thick white layers are mainly non-uniform and discontinuous in nature. It is seen that high Micro voids are confined but micro cracks do not exist in the sub-surface. The miniature gears explored in the present context for the best quality of surface finish and dimensional accuracy are used as one of the criteria for the progression appraisal. RSM is applied on the experimental data to optimize the output variables for all responses such as material removal rate and surface roughness. In this study ANFIS is used to generate the intelligent model for developing the performance parameters.

Keywords: WEDM, Material Removal Rate (MRR), Surface Roughness, Surface Topography, Surface Integrity, ANFIS, SEM

1. INTRODUCTION

Inconel 718 is basically a Nickel-based super alloy and is broadly used in nuclear, chemical and aerospace industries because of its outstanding chemical and mechanical properties at elevated temperatures. Uses of Nickel based super alloys in Aerospace industries are very common. It has been observed that components like blades, combustor, turbine disk etc. of a gas turbine engines prone to hot working condition are composed by these materials [1].

During machining there is an increase in thermal effects due to low thermal conductivity and it is the most significant challenge that has been faced while working with the material. Work hardening also exhibit in a strong manner along with a high adhesion characteristics on the face of the tool and thus alternating completely the process parameters. The machined surface of the finished product may produce unsatisfactory results due to the presence of carbides and hard abrasive particles [2, 3].

Miniature gears are termed as the gears having outside diameter less than 10mm. Meso gears and micro gears are the classification of miniature gears. The diameters within the range of 1-10mm are meso gear and diameter less than 1mm is micro gear [4, 5]. Scientific applications, industrial and domestic purpose miniature gears are extensively used. Gear extrusion, powder metallurgy, dies casting, gear stamping and gear hobbing are the conventional process for manufacturing meso gear but there are certain limitations for all this processes. Competitive and viable process to generate miniature gear is WEDM. The tribological behavior as well as the functional characteristics widely affected by the parameters of the surface integrity. Thus during the service life there should be a better aspects of surface integrity for best operating performance. Surface integrity parameters are broadly classified into two categories- i) External features of the surface i.e. surface morphology, surface roughness, waviness, form errors etc. ii) Mechanical and metallurgical properties such as residual stresses, micro hardness, microstructure etc. [6].

From the past work very few references are available regarding the surface integrity study of the miniature gears that has been manufactured by WEDM. For the present research work the miniature gears are manufactured by using EZEECUT PLUS Wire Cut EDM. Irregular shaped craters are the vital cause for poor surface integrity. The high discharge energy parameters are the cause of the generation of violent sparks as well as the deviation of the wire from its original path known as wire lag [7]. The input parameters related to generate high discharge energy deteriorate the surface of the electric discharge machined parts by generating recast layer, generations of cracks, rippled surface, and heat affect zone [8, 9].

An extensive study on the effect of process parameters has been studied to find out the creation and the characteristic of recast layer in WEDM of Inconel 718 alloy [10]. The average thickness of the recast layer has also increased with the increase of pulse current duration, discharge of peak current and energy per pulse. Recast layer has been found of an average thickness of 5 & 9µm. On average recast layer Spark cycle and wire diameter has no significant effect. The hardness should be low in the recast layer and the layer should also include a plane of tensile residual stresses along with elastic modules. The surface roughness has been increased with higher per spark energy, slightly along with the wire diameter. Thus, this study comprehensively aims to investigate the development of the surface integrity in terms of surface finish, surface topography as well as microstructure.

2. EXPERIMENTAL PROCEDURE AND OPERATING PARAMETERS

In the present investigation Peak current, Wire feed, Gap voltage, Pulse-on-time and Pulse-off-time are selected as a machining input parameter. The different input parameters along with their ranges are discussed with the help of Table 1.

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Master Brass wire (CuZn37) is basically selected as the cutting tool is selected of 0.25mm diameter due to its high tensile strength and vapor pressure rating. Ionized water to oil ratio (40:2) is used as dielectric/coolant fluid. The manufactured gear has a module 0.7, pressure angle 20º, addendum diameter 8.4mm, tooth thickness 1.1mm, dedendum diameter 5.4mm, number of teeth cut is 10 and the thickness of the plate is 3.94mm. The total cutting length of the gear that is achieved from the CNC WEDM is 47.005mm.

Table I: Selection of Process Parameter and Their Levels

Coded names	Controllable parameters	Levels/Limits				
		-2	-1	0	1	2
A	Wire feed rate (m/min)	30	45	60	75	90
B	Peak current (A)	1	2	3	4	5
C	Pulse-on-time (µsec)	20	30	40	50	60
D	Pulse-off-time (µsec)	3	5	7	9	11
E	Gap voltage (Volts)	40	50	60	70	80

In this research RRAPT software has been used to create the profile or part geometries. The generation of spur gear through RRAPT software has been illustrated in Fig. 1.

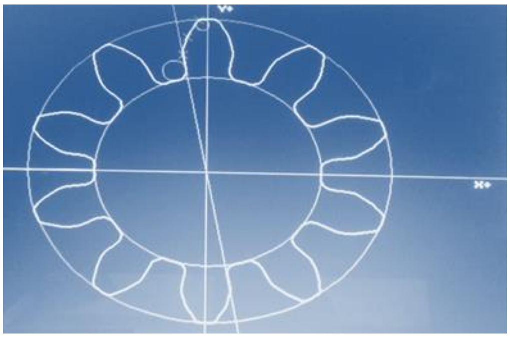

Fig. 1 Spur Gear Profile Shown in RRAPT Software

RRAPT is a CAD/CAM software system for generating NC program for the EZEECUT PLUS wire cut EDM machine. To define the profile in RRAPT, three simple steps have to be followed- (i) Profile creation (ii) Path definition (iii) NC program generation. With the help of part programming, the spur gear profile is generated with the above dimensions.

3. RESULTS AND ANALYSIS

The investigations on physical and geometrical aspects of surface integrity of miniature gears of WEDM have been discussed in the following sections.

3.1 Geometrical Aspects of Surface Integrity

3.1.1 Sphericity Error Evaluation of flank surface topography

Investigation on profile features of a gear tooth shows the presence of burrs, nicks, peak, valleys or asperities on the surface of the flank which is very important to forecast the running-in period, tribological behaviour, and service life of gear [11]. The surface characteristics of the spur gear have been shown in the Fig 2.

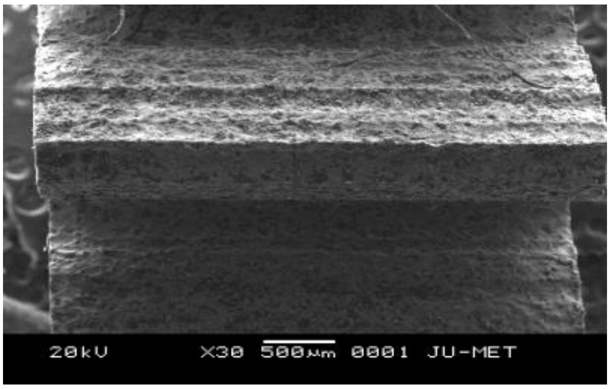

Fig. 2 Surface topography of the sample having maximum surface roughness.

The mathematical model equation has been obtained by using RSM (Response Surface Methodology) for surface roughness.

$$RA = 12.439 - 0.02611\,W.F - 1.6649\,Ip + 0.06312\,Ton - 0.9370\,Toff - 0.1786\,GV + 0.000368\,W.F * W.F + 0.17663\,Ip * Ip + 0.000255\,Ton * Ton + 0.04661\,Toff * Toff + 0.001472\,GV * GV - 0.000150\,W.F * Ip - 0.000343\,W.F * Ton + 0.000073\,W.F * Toff - 0.000119\,W.F * GV + 0.016629\,Ip * Ton + 0.03304\,Ip * Toff + 0.000933\,Ip * GV - 0.004868\,Ton * Toff - 0.001212\,Ton * GV + 0.007051\,Toff * GV \quad (1)$$

It has been observed the white thick recast layer and voids occurs when the peak current is 5A (maximum), pulse on time (Voltage discharging time) is 40µs, pulse off time (Voltage charging time) is 7 µs, and gap voltage is 60V. The above proved so. The wire feed is not important parameters in achieving the best miniature gear.

3.1.2 Evaluation of surface roughness and MRR

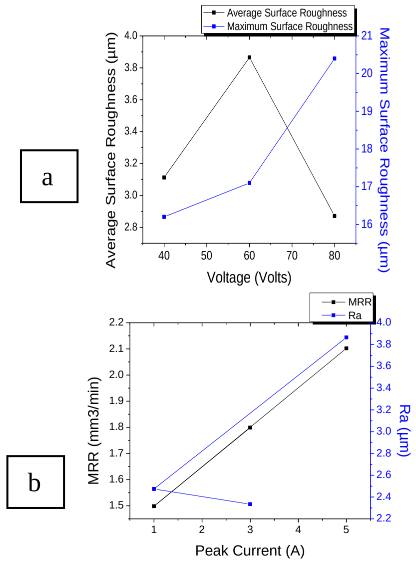

Fig. 3 (a) Effect on the surace roughness Vs voltage (b) Effect on the MRR and surface roughness Vs voltage

From the experimental output values the graphical represantation (Fig. 3) that has been obtained states the average surface roughness is least if the gap voltage is maximum.

Simultaneously there is an increase in MRR linearly with the increse in Peak Current and also the maximum surface roughness has been obtained at maximum value of the peak current.

3.2 ANFIS

The fuzzy logic and fuzzy inference system technique is mostly used to recognize and control of multipart non-linear systems. Both are predominantly interesting methodology to resolve problems in the absence of exact mathematical approaches. Adaptive neuro-fuzzy inference system is a combination of ANN and fuzzy logic soft computing method which is implemented in the structure of an adaptive neural network. ANFIS can create an input-output relation mapping based on both human-knowledge by using a hybrid learning practice. In ANFIS learning, two methods are used for updating membership function. One is steepest descent method and another is hybrid method consisting of back-propagation for the parameters which generates least squares estimation frequently for the input parameters related to the output membership functions. In this way the training error is decreased during the learning process. There are five network layers used in ANFIS architecture i.e. fuzzification, Knowledge base (data base construction, rule base construction), decision making, and defuzzification. Modelling of surface topography is a complex process and it is difficult to solve in conventional process as the final result shows significant disparity between simulation data and experimental data. To overcome such kind of problems, neuro fuzzy technique is applied in this study.

Most commonly used neural network methodology is known as Adaptive Network based fuzzy interface system which is helped to solve estimation problems. It also provides the graphical relation between input parameters and output parameters to obtain best distribution functions [11]. In the present work an ANFIS model has been established to predict surface roughness. In this study Peak current, Wire feed, Gap voltage Pulse-on-time, and Pulse-off-time are chosen as an input parameter.

ANFIS is carried out with MATLAB and sample experimental data of 52 no. is taken for testing. Among all the membership functions, gaussian membership function gives the lower error, which is applied in the present work. In the ANFIS architecture 50 numbers of epoch is used and 52 fuzzy rules are generated from input and output data on sugeno fuzzy model. It is seen that average error for surface roughness is 2.82×10^{-3}.

In Figure 5, peak current gap voltage and Pulse on time have more effect on surface roughness. While peak current as well as gap voltage is increased then surface roughness is increased, as in Fig. 5(a). Figure 5(b) is showed that surface roughness is increased if pulse on time and peak current both are increased. When peak current is increased at the same gap voltage is decreased then it shows the major effect on surface roughness (i.e. higher RA), as in Fig 5(c). The ANFIS model has been shown that higher surface finish is achieved at lower peak current and pulse on time parameters setting, also at higher gap voltage.

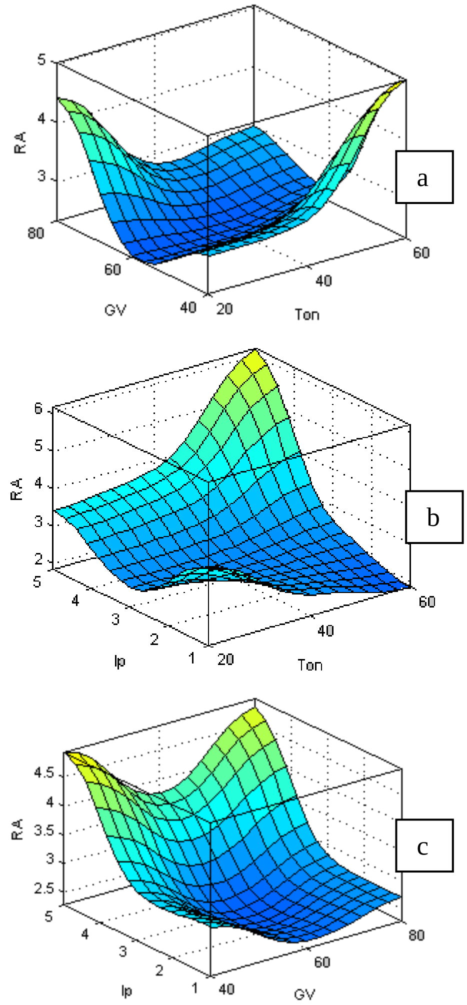

Fig. 4 ANFIS model for surface roughness (a) RA changes with GV and Ip (b) RA changes with Ip and Ton (c) RA changes with GV and Ton

3.3 Physical Aspects of Surface Integrity

3.3.1 Microstructure characterization

The machined samples are cleaned with the help of cold water by ultrasonic cleaning for 5minutes and it is dried in the air. After 24 hours as soon as the residual water gets vaporised, the measurement of the surface topography is performed with the help of Scanning Electron Microscope (SEM).

In Fig. 5(a) the sample has been operated at maximum peak current (5A), wire feed is 60m/min, pulse on time is 40µs, gap voltage is 60V and pulse off time is 7µs. Thus the molten materials at high discharge energy have been splashed from the plasma channel by high bubble pressure. Deionised water partially flushes out the splashed materials. The rest materials resolidified and quenched on the surface and results in the formation of irregular debris along with "coral reef" microstructures.

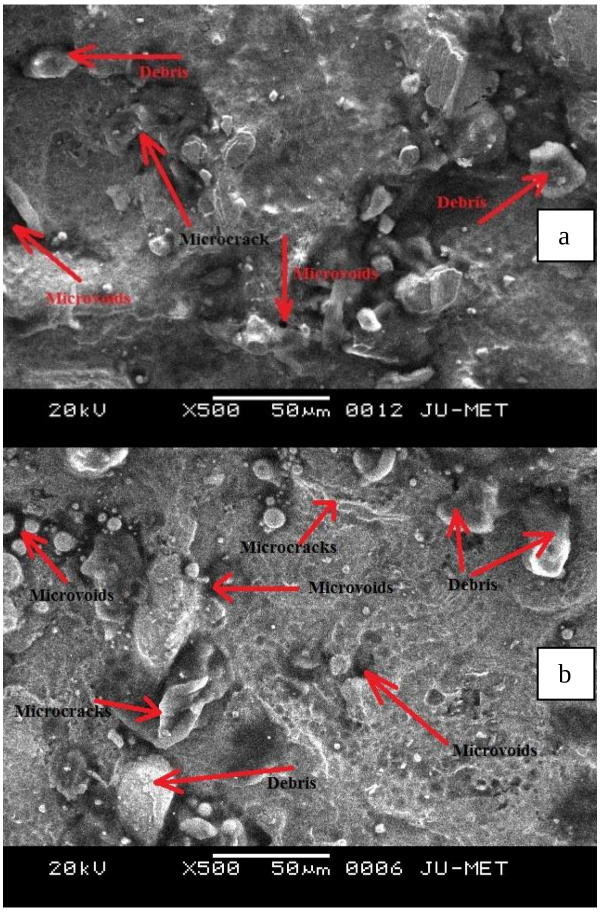

Fig. 5 (a) Sample having least surface roughness of 2.135µm (b) Sample having maximum surface roughness of 3.865 µm

In Fig. 5(b) the sample has been operated at peak current (2A), wire feed is 75m/min, pulse on time is 50 µs, gap voltage is 70V and pulse off time is 5µs. Instead of being flushed away or splashed the molten material stays on the surface at the condition of relative low discharge spark energy. Minimum thermal impact takes place on the material surface at the lowest discharge spark energy. The molten material resolidifies and generates a uniform discharge craters.

4. CONCLUSION

In terms of surface roughness the surface of WEDM is always isotropic. The surface roughness of WEDM has been reduced from 3.865 µm to 2.135 µm. The key finding has been summarized in the present study as follows:

- At high discharge energy white layers are relatively non-uniform and predominantly discontinuous.
- In the thick white layers micro voids has been confined at high discharge energy.
- A uniform, continuous and free from micro voids thin white layer has been achieved at low discharge energy.
- Thus to reduce surface alloying the discharge energy has to be reduced.
- ANFIS is successfully adopted for generating the relation between input-output relation and it can be used to predict achievable surface finish in WEDM process.
- The surface integrity of the miniature gear produced by WEDM are affected by the presence of main factor like heat affected zone, wire lag, recast layer and irregular shaped craters and combination of the high discharge energy parameters governs all these factors. For better outcomes such as micro structure, accuracy, and surface finish, low discharge energy parameters such as short pulse on time and low voltage are very much essential.

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