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Monitoring of EDMed surface using Barkhausen Noise Technique

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Abstract

Present experiment efforts a nondestructive evaluation of surface integrity of die steel upon Electrical Discharge Machine (EDM) via Barkhausen Noise (BN) method. The experiments have been performed using copper electrode with negative polarity conditions. The selected machining process parameters were pulse current (4,6 and 9 A), voltage (30,39, 50V) and pulse on time (200, 400 and 750 µs). It was observed that the study of surface integrity aspects of workpiece in terms of Material Removal Rate (MRR), Surface Roughness (SR), micro hardness and residual stress profile with application of Barkhausen Noise (BN) analysis method. A possible relationship have been recognized among the process parameters with MRR, SR, residual stress and micro-hardness measurements. While pulse current (I_P), voltage and pulse on time (T_{on}) were set at higher value, these parameters consequence decrease in BARKHAUSEN NOISE parameters (rms and peak value) through the whole experiment of present study. Typically, the tensile residual stress observed in EDMed surface is one of reasons for larger amplitude of BARKHAUSEN NOISE signal.

Keywords: Electrical Discharge Machine, Surface Integrity, Residual stress, Barkhausen Noise

INTRODUCTION

In general, die steel possess better hardness, strength, wear resistance. It is broadly used in automobile, die and punch industries etc. Machining of these steel with complex geometric shape is beyond the abilities of the conventional machining process like turning, milling or grinding etc. [1]. There are several advanced machining procedures are capable of machining these materials in difficult to cut. The electrical discharge machining process is a thermo- electrical machining process which enable to erode the metal from workpiece by a sequence of repetitive electrical spark. The discharge sparks take place in the inter electrode gap between the tool as well as conductive sample immersed in dielectric medium. The EDM process also improves machining efficiency as well as dimensional precision [2,3]. Metal removal rate shows linear relation with discharge current. In EDM process, higher discharge current improves thermal load which act on both electrodes leads to more MRR. Typically, surface roughness in EDM process is effected by discharge energies, types of electrode and polarity [4]. During machining process, higher value of pulse interval time results more MRR from workpiece but after certain interval it decreases. Due to this long pulse interval, dielectric fluid gets enough time to regain its strength in the sparking zone as well as maintain stable discharges [5]. When T_{on} and I_P are set at higher value, it results more discharge energy and generate powerful explosion on machined surface. This leads to form deep crater on EDMed surface results high surface roughness [6]. The surface roughness drastically improves with rise in peak current due to frequent breaking of dielectric results more melt and vaporization. Because of this, high concentration of debris deposited at machining region leads to more surface roughness [7]. Hardness is one of the significant factor in die and punch making industries [8]. The white layer formed on EDMed surface possess high hardness as well as good wear resistance because of carbon deposition and cooling effect of dielectric fluid [9]. In EDM process, the carbide layer formed on machined surface is composition of the carbon comes from kerosene leads to improve hardness of EDMed surface [10]. During machining of workpiece, the high tensile residual stresses were developed on machined sample form crack result failure of the sample. In EDM operation, the residual stresses are also developed due to sharp temperature gradient of the machined sample as well as plastic deformation. Due to phase change of material and temperature variation, residual stresses take place on EDMed surface leads to cracks formation in recast layer. This residual stress decreases the accuracy as well as operating life of the machining components [11] Consistent performance of components are reliant on quality as well as failure of components in working circumstance. Therefore, Non-Destructive Technique (NDT) is one of sophisticated method to confirm previous quality of components and as well check deterioration of components to overcome early failure of the components. Hence, numerous various NDT method are used R&D and industries dependent on different physical principle. The purpose of NDT is to investigate as well as characterize of anomalies namely defects, stress, microstructure. For this purpose, The NDT information collected from experiments are used for assessment of surface integrity of component [12]. There are various NDT techniques like Eddy Current Testing (ECT) and Barkhausen Noise (BN) are used for characterization of ferromagnetic material like steel. While ferromagnetic specimen is magnetized, the irregular variations in magnetization of the specimen are realized. This variation occurs because of their reversible domain walls motions. As soon as these domain walls faces the obstacle of inclusions, grain boundaries etc. in their route. These variations induce electrical noises which is sensed using pick-up coil nearby the specimen. This noise is called Barkhausen Noise [13-16]. The magnetic responses such as peak as well as permeability resulted from Barkhausen Noise analysis improves with residual stress then it decreases while tensile residual stress is beyond yield strength of material [17]. The microhardness variation of tempered specimen was effectively evaluated with the applicability of Barkhausen Noise method. Furthermore, it is also used to estimate dissimilar phase of tempering in ferritic steel [18]. Now these days, Barkhausen Noise method was significantly used for assessing surface integrity of sample upon milling process. In addition, Barkhausen events were combined of domain wall motion as well as recast layer thickness at nearer surface followed by heat affected zone [19]. The amplitude of Barkhausen Noise signal identifies the residual stress redistribution in the near-surface region due to precise plastic deformation [20]. Despite numerous application of Barkhausen noise in various manufacturing process like heat treatment, grinding, milling and welding etc. There are not enough literatures are available about the applicability of Barkhausen Noise upon EDM process of die steel with copper tool under negative polarity condition for the estimation of surface integrity. Hence, the aim of this experiment is the assessment of surface integrity of machined sample using die sinking EDM in terms of SR, microhardness, residual stress using Barkhausen Noise technique.

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EXPERIMENTAL DETAILS

A. Die-sinking EDM machine and Material

The experiments were conducted on ZNC EDM supplied by Electronica, India. The dielectric liquid was EDM grade 40 oil. The selected rectangular specimen was the high carbon high chromium die steel of given dimensions (10^W x 10^H x 75^L mm) that was broadly used in die and mold Industry. A suitable jet flushing system is attached with EDM. The chemical composition of this specimen was shown in Table 1. The probable more significant experimental condition was selected as per literature survey. All the selected EDM conditions for this experiment was given in Table 2. The tool electrodes used for this work was electrolytic copper (with cross section 10 x 10 mm) and polarity was negative. Design of experiment was used in this experiment. It also decreases the number of experiments and establish optimized the regression models. Full factorial design of experiment (2^3 factorial design) with five added central points was prearranged and conducted to show a prediction of experimental error. The variation of machining process parameters such as I_P, T_{on} and voltage at three level. In order to decrease result of extraneous variables, trial run-order (rank) was randomized. This method facilitates to formulate first order empirical models comparing machinability indices as well as surface integrity characteristics using three process parameters through regression analysis. Response surface presenting the result of variation in process parameters on machinability indices and surface integrity appearances were developed using MATLAB programming.

B. Measurements

Material removal rate of workpiece is measured such as the weight difference of the sample earlier and after the experiment with respect to machining time. For weight measurement of samples, a precise digital electronic balance (least count 0.0001g) is used. The surface quality of machined sample is represented by measuring a most suitable parameter from centre line is known as arithmetic mean roughness (Ra). For that purpose, 2-D surface profiler Mitutoyo SJ-410 manufactured in Japan was used in this experiment. Individually SR value was evaluated by an average of five readings were taken closer to mid-point of workpiece for every stable EDM machining conditions. In this experiment, the SR is highlighted on the established ISO 4287:1977 Standard. Microhardness of the specimen along the cross-section was measured using microhardness tester (Model: Imager Z2m, Germany). Microhardness tests were measured by applying 50 gm load as well as 10 second dwell time on machined surface for every workpiece using an indenter beginning from 25 µm downwards from the edge. Micro-hardness measurement was taken at different distance beneath the edge with an increase distance of 50 µm at every measurement. The hardness measurement was taken by indenting at three spot with same distance bottom to the edge. Each micro-hardness value was calculated by averaging of these three measurements. The Figure 5. shows the microhardness measurement study of machined sample. X-ray diffraction method with Brucker diffractometer was used for the measurement of residual stresses in the machined sample by five inclined angles at range of −45° to +45°. In this work the measured residual stress is uniaxial in nature. On the contrary, Barkhausen Noise was measured using µscan/Rollscan-300 system, Stresses, Finland. As described in literature, a probe is used to appliance external magnetic field and pick-up coil at the midpoint was used to accept the Barkhausen Noise signal. Before measuring the Barkhausen Noise, the EDMed sample was washed properly using isopropyl alcohol. The middle region of workpiece was preferred as place for both Barkhausen Noise as well as XRD measurement. For individually test, three measurements were taken and studied by µ-scan software to record the root mean square (rms) value and peak value of BARKHAUSEN NOISE signal. Barkhausen Noise signal was analyzed by averaging of all measured BARKHAUSEN NOISE parameters. Magnetizing voltage and frequency are selected by undertaking preliminary trials. These voltage and frequency should supply appropriate BARKHAUSEN NOISE signal with no disturbance of the magnetizing signal. The magnetizing frequency as well as voltage were maintained constant during the experimental domain. The BARKHAUSEN NOISE signal is delivered using a band-pass filter.

Table I: Chemical Composition Of HCHCr Die Steel

Elements	C	Cr	Mn	P	Si		Fe
%	1.7	12	0.4	0.02	0.5	0.11	Balance

Table II: Experimental Condition Of EDM Process

Tool material	Copper
Work material	Die steel (HCHCr)
Machining time	20 min.
Voltage	30, 39 and 50 volts
Current	4, 6 and 9 amps.
Pulse on time	200, 400 and750 μs
Polarity	Negative (-)
Dielectric fluid	Hydrocarbon oil (grade EDM40)

RESULTS AND DISCUSSIONS

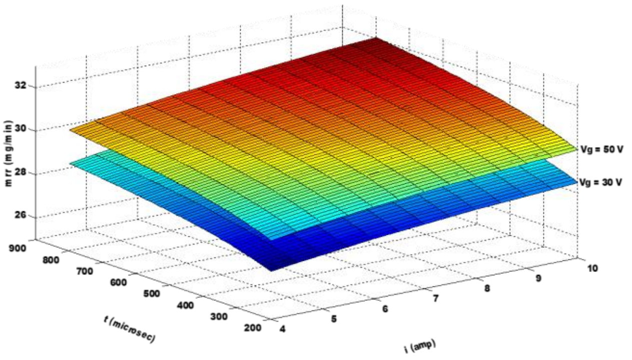

Figure 1: Variation of MRR with process parameters for negative polarity copper tool

Material removal rate was observed to increase with process parameters when the copper tool is connected with negative polarity (refer Fig. 1). As already discussed in literature study that input energy density is directly proportional to I_P; T_{on} and voltage. While I_P gradually improves for constant machining zone, the MRR increases because of erosion of more volume metal from workpiece. But greater T_{on} also allow more heat to sink into EDMed surface results more melting and vaporization along with more MRR. Increase in voltage increases strength of the electrical field which in turn generates elevated temperature condition within the plasma channel. This elevated temperature condition causes a large impulsive force to repel the debris from crater center. Hence, material removal rate increase.

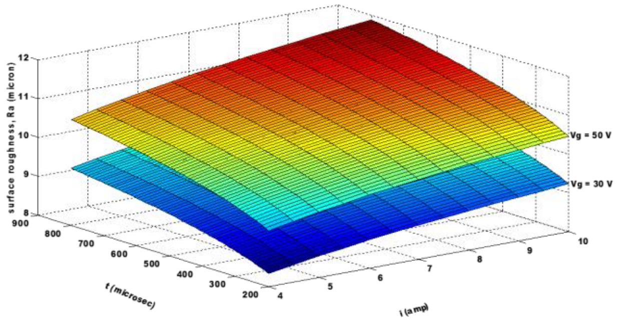

Figure 2: Variation of surface roughness with process parameters for negative polarity copper tool

When copper tool is attached with negative tool polarity, the variation of SR with three process parameters is depicted in Fig. 2. It was observed from the experiments that the value of SR is dependent on I_P and T_{on}. Higher value of I_p or T_{on} degrade the surface finish. Greater value of I_P form deep and wide craters on sample as huge amount material vaporize from sample. Hence, the surface topography of machined sample with high currents is more irregular. In machining process, progressively application of T_{on}, more quantity of spar energy transfers to machine surface leads to decrease the surface finish. The surface roughness shows in increasing trend with increase in voltage. This is basically due to more spark energy strike on workpiece surface and produce bigger crater.

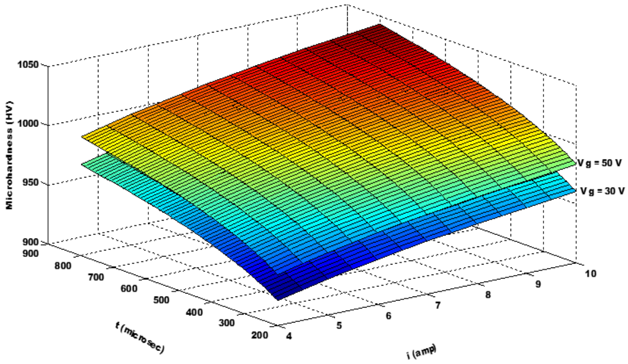

Figure 3: Variation of microhardness with process parameters for negative polarity copper tool

As increase of pulse current, the spark energy increases results more amount of material melts and vaporize. But the amount of metal removed by the dielectric fluid is same so more amount of metal is redeposited on the surface which leads to increase in micro-hardness with I_P. On the other hand, the average recast layer thickness improves with more value of T_{on} at a constant I_P. Higher value of T_{on} permits the electro-discharge energy enter more depth of the material results increase of the white layer thickness. While higher pulse current is supplied, it leads to rise temperature of workpiece and attain the melting point of the metal surface. As a results the average white layer thickness increases. The Fig. 3. shows the variation of microhardness with respect to various process parameters such as pulse current, pulse on time and voltage. In EDM process, the temperature gradient with intense rates of heating and chilling on EDMed sample leads to form the white layer, variation of micro-structural and microhardness. This Figure significantly represents improvement of microhardness with process parameters. In machining process both pulse current and pulse on time increase huge amount of discharge energy as a result quickly melt and evaporate of machined surface and breakdown the dielectric fluid. In EDM process, simultaneously material removal takes place along with white layer forms on the workpiece surface. This white layer is also known as recast layer is hard as well as not etchable as material transform into martensite. Below the 'recast layer' an intermediate layer is exhibited known as heat-affected zone or dark band. Therefore, the combined observation of plastic deformation, white layer and dark band upon EDM of die steel leads to changes in microhardness. While gap voltage is set at higher value, the gap distance across the sparking region increase and more removal of debris occurs. At the same time, more carbon content adheres on workpiece surface assist to variation of phase along with high temperature, which promote the microhardness.

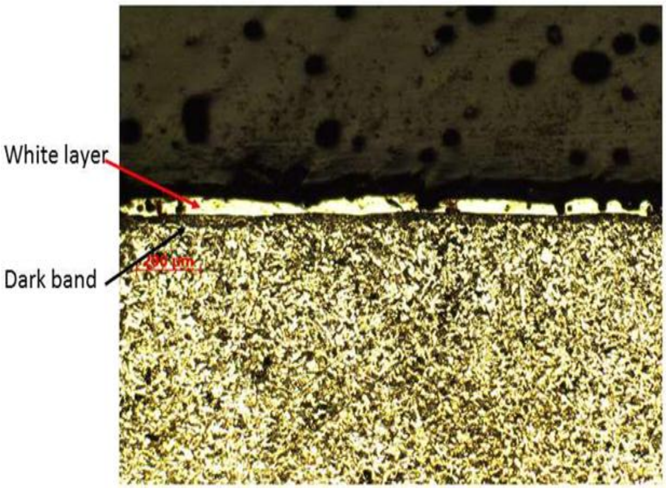

Figure 4: White layer and dark band of cross section of HCHCr die steel machined by EDM

Metallographic study of machined samples clearly depicted quite significant variation in microstructure along the depth in form of thick white layer with presence of cracks. Although the MRR occurs by melting and evaporating but all the molten metal cannot be flushed by the dielectric fluid. Some portion of the molten metal re-solidifies quickly on the machining area during pulse off time. The structure of this re-solidify layer (white layer) is relatively dissimilar as compared to the parent material but voids, cracks, induced stress observed on machined surface degrade of the component. This re-solidify layer is quite hard as well as non-etchable because the molten metal solidifies very quickly leads to martensite formation. Below the 'recast layer' intermediate heat-affected zone is called dark band and shows micro-structural transformations. Severe plastic deformation and development of white layer and dark band leads to changes in microhardness as shown in Fig. 4.

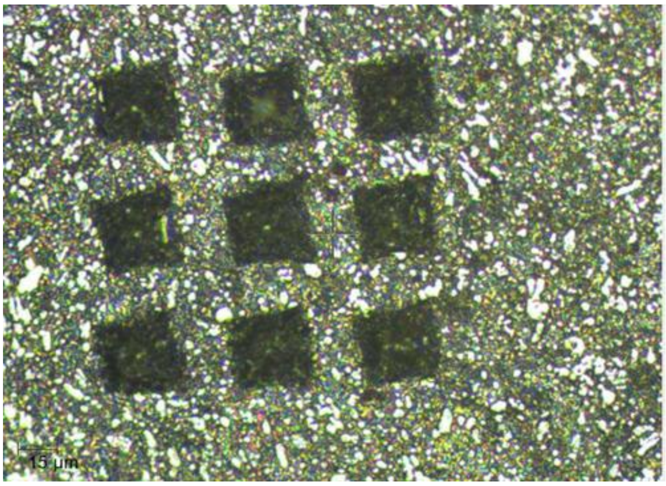

Figure 5: Microhardness measurement of HCHCr die steel machined by EDM.

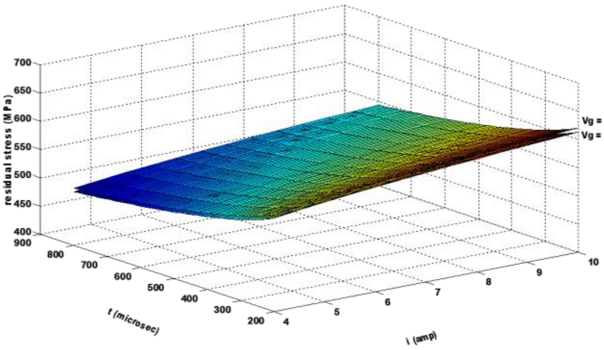

Figure 6: Variation of residual stress with process parameters for negative polarity copper tool

The result of residual stress versus process parameters during machining of die steel under negative polarity with copper electrode is illustrated in Figure 6. In this experiment, high tensile residual stress generates on workpiece surface all over experiment. Usually, tensile residual stresses formed in the upper layer because of the nonuniformity of heat flow as well as phase changes. Moreover, carbon transmission from the dielectric fluid influence the expand and compact of surface level. Cracks were observed in recast layer due to higher value of tensile residual stress as compared to ultimate tensile strength of material. Therefore, cracks were formation in white layers. The induced tensile residual stress rise with respect to T_{on} but it decreases with respect to voltage as well as I_P.

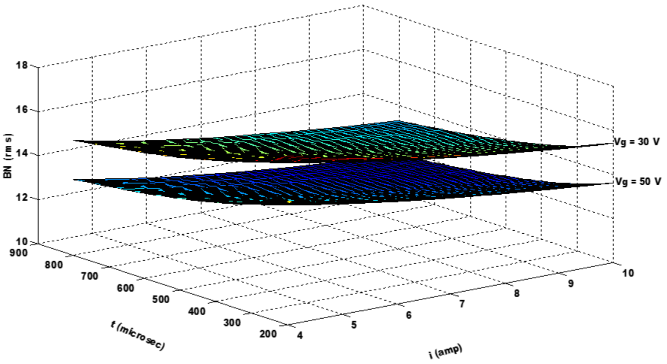

Figure 7: Variation of Barkhausen Noise (rms) with process parameters for negative polarity

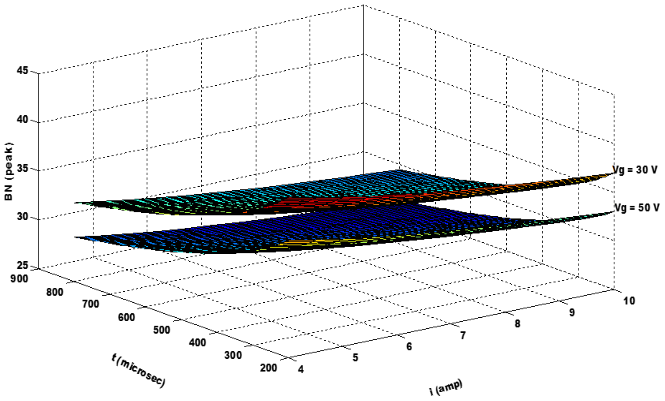

Figure 8: Variation of Barkhausen Noise (peak) with process parameters for negative polarity copper tool

The result of rms value of BARKHAUSEN NOISE signal as a function of process parameters are represented in Fig. 7. The rms value of BARKHAUSEN NOISE signal shows nonlinear relation all EDM process parameters under this study. MRR of workpiece is prime dependent on the spark energy generate plasma channel in EDM process. But MRR linearly increases with I_p, voltage and T_{on}. In EDM operation, MRR also leads to the thermal destruction of the machine workpiece surface and it may be the causes of initiation of high tensile residual stress. Despite linear trend was observed among the process parameters and MRR, but the inverse relation was seen in case of variation of rms value of BARKHAUSEN NOISE signal with process parameters. Usually, BARKHAUSEN NOISE signal profile is characterized by means of rms and peak value. The rms value is more recognized parameter as compared to peak value as concluded from previous literature study. The similar relation of variation of BARKHAUSEN NOISE peak value with respect to process parameters was seen as shown in Fig. 8.

Micro-magnetic response of the machined sample in EDM process represents the significant influence of process parameters on BARKHAUSEN NOISE parameters namely rms and peak value of signal profile. BARKHAUSEN NOISE parameters are the function of residual stress variation, plastic deformation as well as hardness. Typically, the tensile residual stress observed in EDMed surface is one of reasons for larger amplitude of BARKHAUSEN NOISE signal, while improvement of hardness results reduction in BARKHAUSEN NOISE parameters. While current, voltage and pulse on time were set at higher value, these parameters consequence decrease in BARKHAUSEN NOISE parameters through the whole experiment of present study. It is fairly remarkable to describe that BARKHAUSEN NOISE parameters decreases in EDM machining process as compared to obtained workpieces however the perceived residual stress was tensile in all over the experiments. It may be described that improvement of microhardness of EDMed workpiece, which produced more significant result as compared to tensile residual stress.

CONCLUSIONS

Following important conclusions may be summarized from this study:

i. MRR, SR, microhardness and residual stress during EDM significantly affected by process parameters, tool material properties as well polarity conditions.

ii. It was observed hardness of EDMed surface becomes high due to more quantity of carbon content deposited on workpiece. In addition, metal phase transformation occurs in the form of resolidified layer because of high temperatures in EDM process.

iii. After EDM process, tensile residual stress generated on workpiece. The induced tensile residual stress rise with respect to T_{on} but it decreases with respect to voltage as well as I_p.

iv. But investigation of residual stress is difficult to analyse the variant of process parameters because of peculiar nature of EDM procedure.

v. Both rms and peak value of BARKHAUSEN NOISE signal increases with decrease of EDM process parameters such as I_p, T_{on} and Voltage.

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