PREFACE

Electro-discharge machining (EDM) is an electro-thermal non-traditional machining process in which electrical energy is used to remove the material by the thermal energy of the spark. Surface integrity is an integrated set of surface characteristics such as geometric fidelity, surface roughness, state of residual stress, hardness profile of the surface layer, phase transformation and cracks. Assessment of surface integrity of manufactured component which is obtained by EDM process is essential as poor surface integrity severely degrades the performance of the component in its service life. Assessment of surface integrity characteristics such as micro-structural changes, variation in microhardness, alteration in surface topography as well nature and magnitude of residual stress can be very accurately estimated on the machined surface using conventional techniques. Micromagnetic technique like Barkhausen Noise (BN), on the other hand, can be applied to assess state of surface integrity in ferromagnetic materials (most of the steels). This technique can be applied in situ with very less measurement time. This can also be a good candidate for integration within the manufacturing environment for assessment of state of stress. However, Barkhausen Noise technique requires calibration, as the micromagnetic response of a ferromagnetic material is dependent on the material composition and microstructure. Over and above, BN gets affected simultaneously by state of residual stress, grain size, plastic deformation and hardness of the work material. For successful measurement, the surface also needs to be relatively smooth and acceptably clean. Barkhausen Noise technique was employed by previous researchers to assess state of stress, microstructure, plastic deformation etc. in different metallurgical and mechanical processes. The present experimental investigation is aimed to study the applicability of Barkhausen Noise technique for assessment of surface integrity of die-steel sample machined at various process parameters by die-sinking EDM under two different polarity conditions using three different tool materials namely; Copper, Copper-tungsten and Graphite. The basic aim of this work i.e. applicability of Barkhausen Noise technique to assess surface integrity aspects in electro-discharge machining. Full factorial design of experiment (2^3 factorial designs) with five added central points was planned to conduct experimental error, which serves as a benchmark to determine whether observed differences in the data are statistically significant or otherwise. ANOVA (Analysis of Variance) analysis was carried out for interpretation and to confirm the adequacy of developed models. Electro-discharge machining parameters pulse current (4, 6 and 9 amp), pulse on time (200, 400 and 750 μs) and voltage (30, 39 and 50 volt) were varied at three level. The experimental run-order (rank) was randomized to reduce the effect of extraneous variables. Such procedure enabled development of second order polynomial models correlating machinability indices and surface integrity characteristics with the three process parameters through regression analysis. The main effect plot showing the effect of variation in process parameters on machinability indices and surface integrity characteristics were also discussed. Material removal rate increases considerably with pulse on time as the increase in pulse length over time increases the expansion of plasma. Negative polarity of tool is more advantageous than positive polarity as it is associated with more energy transfer to the workpiece. The Material Removal Rate (MRR) was higher in case of Cu electrode followed by graphite than Cu-w electrode. This may be attributed to better thermal and electrical conductivity of Cu electrode. Formation of plasma and energy transfer during electro-discharge machining not only causes the workpiece material removal but also results into wear of tool. The tool wear rate increases with material removal rate. During electro-discharge machining heat impulsive forces are generated across the working gap between tool and workpiece. The heat energy between the working gap depends upon pulse current, voltage and pulse on time. Increase in EDM process parameters raises the amount of spark energy (discharged at tool) which in turn results into increase in tool wear rate. Effect of variation of pulse-on time on MRR as well on Tool Wear (TW) was more significant in comparison to pulse current and voltage. The material removal mechanism is responsible for poor surface integrity upon electro-discharge machining. Surface roughness was observed to increase with process parameters as high energy input causes formation of craters in large amount with greater depth. Negative polarity of tool resulted in high crater density comparatively with positive electrode owing to better energy distribution at workpiece, further surface roughness was higher with Cu electrode (under both polarity conditions) due to availability of more free electrons causing more erosion of work material. Pulse-on time was most influential parameters for surface roughness in comparison to current and voltage.

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. In EDM the material removal takes place by melting and evaporating but all the molten metal cannot be flushed by the dielectric fluid. Some portion of the molten metal resolidifies quickly on the machining area during pulse off time. The structure of this resolidify layer (white layer) is quite different from the parent material but the presence of defects in it such as voids, cracks, induced stress etc. cause an overall deterioration of the component's mechanical properties. The white layer is quite hard and non etchable because the molten metal solidifies very quickly leads to martensite formation. Increase in EDM process parameters in both polarity conditions resulted into increase in microhardness. As the spark energy increases more amount of material is melted 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 microhardness with process parameters. Highest microhardness was obtained in case of machining with Cu-w electrode under positive polarity of tool. In the present study, electro-discharge machining resulted into induction of high tensile residual stress.Tensile residual stresses are being induced in the top layer as the expansion and contraction material mainly occurs in the surface layer while the bulk material remains unaffected. Carbon diffusion of the die-electric fluid may also affects the expansion and contraction of surface layer. Induced tensile residual stress when exceeds the material's ultimate tensile strength it leads to formation of cracks in white layers as observed in the metallographic study of machined samples. Micro-magnetic response of the workpiece material upon electro-discharge machining clearly reveals significant effect of process parameters on Barkhausen Noise parameters such as rms and peak value of signal profile. Barkhausen Noise parameters get affected by change in state of stress, grain size, plastic deformation and hardness. Typically, induction of tensile residual stress causes higher amplitude of Barkhausen Noise signal; on the other hand increase in hardness results in reduction in BN parameters. Increase in current, voltage and pulse on time leads to reduction in BN parameters throughout the entire experimental domain of present investigation. It is quite interesting to note that Barkhausen Noise parameters reduced upon electro-discharge machining as compared to as received samples though the observed residual stress was tensile in nature in the entire experimental domain. The regression model developed between machinability indices such MRR, TW and process parameters and among surface integrity characteristics such as roughness and microhardness and process parameters indicates the adequacy of model with significant effect of pulse on time, current and voltage.

Material removal rate and tool wear rate increase with increase in electro-discharge machining process parameters while machining with three different tool materials under both the polarity conditions. Surface finish of electro-discharge machined component is poor due to formation of cracks and crater. Copper tool with negative polarity resulted in highest surface roughness, on the other hand lowest surface roughness value was observed in case of copper-tungsten tool having positive polarity. Microhardness along the depth of machined surface increases with increase in pulse on time, voltage and current. The highest microhardness was observed around 1500 HV in case of copper-tungsten electrode with positive polarity of tool. Electro-discharges machining resulted induction of high tensile residual stress in the surface of machined component throughout the entire experimental domain. Although effect of variation of process parameters on induction of tensile residual stress could not be observed owing to peculiar nature of EDM process. Barkhausen Noise signal parameters namely; root mean square value and peak value were observed to decrease with increase in process parameters with all three tool material as well in both polarity conditions. Any correlation between BN parameters and residual stress could not be observed. Barkhausen Noise parameters get influenced by changes in micro-structure, microhardness alteration and state and magnitude of residual stress. Despite simultaneous occurrence of micro-hardness variation, severe changes in micro-structure, poor surface finish and induction of high tensile residual stress upon electro-discharge machining, a linear correlation could be established between microhardness and BN parameters. Regression models were developed among process parameters and machinability indices and surface integrity characteristics using ANOVA and main effect plots which may be helpful to predict the surface integrity at shop floor of manufacturing industries.