IFERP connecting engineers... developing research
ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 2, Issue 4, April 2017

Estimation and Comparison of Surface Roughness and AE Parameters of P-20 tool steel Material in Wire Electric Discharge Machining using Multiple Regression Analysis and Group Method Data Handling Technique

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Abstract: -- **Wire Electrical Discharge Machining (WEDM) is a specialized thermal machining process capable of accurately machining parts with varying hardness or complex shapes, which have sharp edges that are very difficult to be machined by the main stream machining processes. Selection of process parameters for obtaining higher cutting efficiency or accuracy in WEDM is still not fully solved, even with most up-to-date CNC wire EDM machine. It is widely recognised that Acoustic Emission (AE) is gaining ground as a monitoring method for health diagnosis on rotating machinery. The advantage of AE monitoring over vibration monitoring is that the AE monitoring can detect the growth of subsurface cracks whereas the vibration monitoring can detect defects only when they appear on the surface. This study outlines the machining of P-20 tool steel material using L'16 design of experiment. P-20 tool steel material is used for various large-size plastic mould, precision plastic mould, car accessories, home appliances and electronic equipment plastic moulds. Each experiment has been performed varying different process parameters like pulse-on, pulse-off, current and bed speed. Among different process parameters voltage and flush rate were kept constant. Molybdenum wire having diameter of 0.18 mm was used as an electrode. Simple functional relationships between the parameters were plotted to arrive at possible information on surface roughness and AE signals. But these simpler methods of analysis did not provide any information about the status of the work material. Thus, there is a requirement for more sophisticated methods that are capable of integrating information from the multiple sensors. Hence, methods like Multiple Regression Analysis (MRA) and Group Method of Data Handling (GMDH) have been applied for the estimation of surface roughness, AE signal strength, AE absolute energy and AE RMS. The GMDH algorithm is designed to learn the process by training the algorithm with the experimental data. The experimental observations are divided into two sets: the training set and testing set. The training set is used to make the GMDH learn the process and the testing set will check the performance of GMDH. Different models can be obtained by varying the percentage of data in the training set and the best model can be selected from these, viz., 50%, 62.5% and 75%. The best model is selected from the said percentages of data. Number of variables selected at each layer is usually taken as a fixed number or a constantly increasing number. It is usually given as fractional increase in number of independent variables present in the previous level. Three different criterion functions, viz., Root Mean Square (Regularity) criterion, Unbiased criterion and Combined criterion were considered for the estimation. The choice of criterion for node selection is another important parameter for proper modeling. From the results it was observed that, AE parameters and estimated surface roughness values were correlates well with GMDH when compare to MRA.**

Keywords: ***WEDM, AE, MRA, GMDH***

INTRODUCTION

The wire-cut type of machine arose in the 1960s for the purpose of making of tools (dies) from hardened steel. The tool electrode in WEDM is simply a wire. To avoid the erosion of material from the wire causing it to break, the wire is wound between two spools so that the active part of the wire is constantly changing. The earliest Numerical Controlled (NC) machines were conversions of punched-tape vertical milling machines. WEDM is an alternative competitive process to manufacture complex part geometries.

The present work was carried out for a detailed study on estimation of surface roughness and AE parameters of P-20 tool steel material in WEDM. Process parameters such as pulse-on time, pulse off time, current and bed speed were varied. The measured surface roughness and AE parameters namely signal strength, absolute energy and RMS was compared with predicted values of MRA and GMDH, and estimation of theoretical results and experimental results were compared. P-20 tool steel is used for various large-size plastic mould, precision plastic mould, car accessories, home appliances and electronic equipment plastic moulds. In the past, researchers have

ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
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investigated the effect of parameters on Metal Removal Rate (MRR) for WEDM using High Strength Low Alloy steel as work piece and brass wire as electrode. HSLA used in cars, trucks, cranes, bridges, roller coasters and other structures that are designed to handle large amounts of stress. It is observed that MRR and surface roughness increases with increase in pulse on time and peak current [1]. In general, heat treatments after WEDM improve the quality in terms of microstructures and surface roughness. It can be concluded that the quality of a press die prepared by the high temperature heat treatment after WEDM could be as good as that by traditional manufacturing processes of the method. Cemented carbide, which is about two times harder than high-speed steel, exhibits superior wear- and heat resistance properties [2]. A new polishing method in which surface modification by an oxidizing treatment is combined with flow polishing using abrasives was developed to remove the surface defects generated in cemented carbide with fine holes by WEDM. In this method, although it is desirable to avoid a thermal process if possible, the oxidizing treatment is added to process. Thus, on-the-machine surface modification technology in WEDM has already been developed for the purpose of completely removing the surface defects [3].

Experimental investigation of the machining characteristics of Polycrystalline Diamond (PCD) in micro (μ-WEDM) was carried out. The Taguchi method was adopted to obtain the optimum conditions of parameter settings for cutting width and MRR. The ANOVA analysis has been used to predict the significant machining parameters according to L_{18} orthogonal array and signal/noise (S/N) ratio. The experimental results reveal that the intensity of open circuit voltage (UHP) affects significantly on the amount of cutting width as well as MRR. Additionally, the cutting width is also directly reduced by higher wire tension and lower flushing pressure [4]. One of the main challenges in WEDM is avoiding wire breakage and unstable situations as both phenomena reduce process performance and can cause low quality components. The methodology has been followed as applied to process instability and wire breakage detection in WEDM. First, an acquisition system has been developed aimed at storing an extensive experimental database based on stable and unstable tests. The results of a preliminary analysis of a set of tests have revealed the influence on wire breakage of discharge variables, such as peak current, discharge energy and ignition delay time. Related to these discharge variables, wire breakage indicators have been defined [5]. Machining of Ti-6Al-4V in Wire EDM was considered using three different machine rates which are 2 mm/min, 4 mm/min and 6 mm/min with constant current (6A). The effects of different process parameters on the kerf width, material removal rate, surface roughness and surface topography are also discussed. The best combination of machining parameter viz. machine feed rate (4 mm/min), wire speed (8 m/min), wire tension (1.4 kg) and voltage (60 V) were identified [6]. A simplistic analytical model is used to evaluate the effectiveness of low frequency workpiece vibration during the micro-EDM drilling of deep micro-holes and experimental investigation to validate the model by studying the effects of workpiece vibration on machining performance, surface quality and dimensional accuracy of the micro-holes [7]. AE signal as the frame of reference for determining the acoustic time lag, the proof-of-concept of the applications of AE discharge mapping for the respective identification of electrode length and workpiece height in fast-hole EDM and WEDM are presented. Additional work in terms of acquisition and processing of AE signals is warranted to further develop this technology towards its real-time implementation, as well as its extension to sink EDM [8]. Comparison of electrode wear estimation in WEDM using MRA and GMDH for EN-8 and EN-19 material were studied based on Taguchi's L'_{16} array. Three different criterion functions of GMDH viz., regularity, unbiased and combined have been tried for electrode wear estimation. Different models of GMDH by built by varying the number of data in training set to 50%, 62.5% and 75% of the total data. They have found that the least error of estimation and best fit were found for 62.5% of data in training set for EN-8 material and 62.5% and 75% of data in training set for EN-19 material. Comparison of two theoretical methods for estimation of electrode wear, they have found that regularity criteria function of GMDH has an edge over MRA method [9].

EXPERIMENTAL WORK

The experiments were performed on CONCORD DK7720C four axes CNC WED machine. The basic parts of the WED machine consist of a wire electrode, a work table, a servo control system, a power supply and dielectric supply system. The CONCORD DK7720C allows the operator to choose input parameters according to the material and height of the work piece. The WED machine has several special features. Unlike other WED machines, it uses the reusable wire technology. i.e., wire

ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
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can't be thrown out once used; instead it is reused adopting the re-looping wire technology. To avoid the erosion of wire from the material causing it to break, thus the wire is constantly changing before each experiment. The experimental set-up for the data acquisition is illustrated in the Fig. 1.

The WEDM process generally consists of several stages, a rough cut phase, a rough cut with finishing stage, and a finishing stage. But in this WED machine only one pass is used. The gap between wire and work piece is 0.02 mm and is constantly maintained by a computer controlled positioning system. Molybdenum wire having diameter of 0.18 mm was used as an electrode.

Fig. 1. Experimental Set-up during machining

THEORETICAL ANALYSIS

Multiple Regression Analysis (MRA)

The objective of MRA is to construct a model that explains as much as possible, the variability in a dependent variable, using several independent variables. The model fit is usually a linear model, though some timer nonlinear models such as log-linear models are also constructed. When the model constructed is a linear model, the population regression equation is

$Yi = \alpha + \beta 1\ X1i + \ldots\ldots\ldots\ldots\ldots + \ \beta mXmi + ei$ (1)

Where Yi is the dependent variable and X1i ……… Xmi are the independent variables for ith data point and ei is the error term. Error term is assumed to have zero mean. The co-efficients α, ß1,………ßm are not known and estimates of these values, designated as a, b1…….bm have to be determined from the sampled data. For this least squares estimation is used, which consists of minimizing with respect to each of the co-efficients a, b1…..bm

$$SS=\sum_{i=1}^{n} e_i^{2}=\sum_{i=1}^{n}(Y_i-a-b_iX_{1i}.......-b_mX_{mi})^2 \qquad (2)$$

This will give k+1 equations from which a, b1…..bm, can be obtained. These least squared estimates are the best linear unbiased estimates and hence give the best linear unbiased estimate of the dependent variable.

Y = a + b1X1 + b2X2 +…………+ bmXm (3)

Group Method of Data Handling Technique (GMDH)

One of the widely used methods for empirical analysis of data and model building is the multiple regressions. One of the major problems associated with use of regression has been the need to specify functional formulation. It would be preferable in such cases to use the data to determine both the nature of function and parameters of the function. This is the motivation for the development of self-organizing methods in modeling, GMDH is one such method. Data with the largest variance is put in the training set. The variance for ith data point is given by

$$D_i^2=\sum_{i=1}^{n}(X_{ij}-X_j)^2/\sigma_j^2$$

(4)

Where, Di = measure of variance for ith data point, σj = variance for jth input variable, Xj = mean for jth variable and

$$\sigma_j^2=(1/n)\sum_{i=1}^{n}(X_{ij}-X_j)^2$$

(5)

Initially, an attempt was made to obtain a clear insight involved in the process by plotting measured surface roughness, AE signal strength, AE absolute energy and AE RMS values against machining time.

RESULT AND DISCUSSION

Effect of minimum and maximum pulse on time on signal strength, absolute energy, RMS and surface roughness

Fig. 2 shows the surface roughness (Ra) curves for minimum pulse on of 16 µs with the varying in other process parameters. From the Fig. 2, it can also be observed that at moderate and higher process parameters, the Ra value increases drastically.Fig. 3 shows the absolute energy curves for maximum pulse on of 28 µs

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ISSN (Online) 2456-1290
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with varying in other process parameters. From the Fig. 3 it can also be observed that at maximum pulse on and at higher process parameters the need of absolute energy for machining is more.

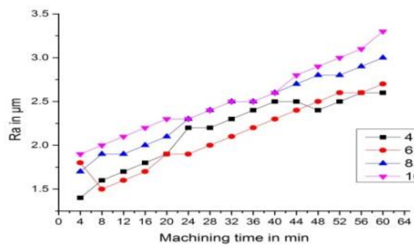

Fig 2 : Measured surface roughness for different machining time at minimum Pulse on of 16µs for P-20 Tool Steel material

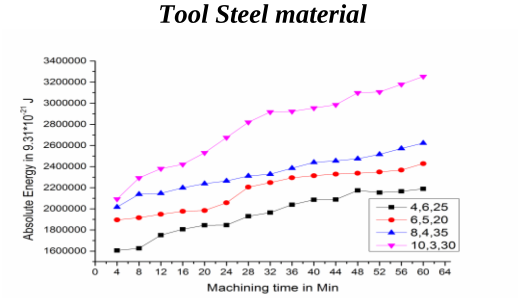

Fig 3 : Measured absolute energy for different machining time at maximum Pulse on of 28µs for P-20 Tool Steel material

Effect of minimum and maximum current on signal strength, absolute energy, RMS and surface roughness

Fig. 4 shows the signal strength curves with machining time for maximum current of 6 amps. The plot reveals that during the machining, the signal strength has little higher gradient with lower process parameters.

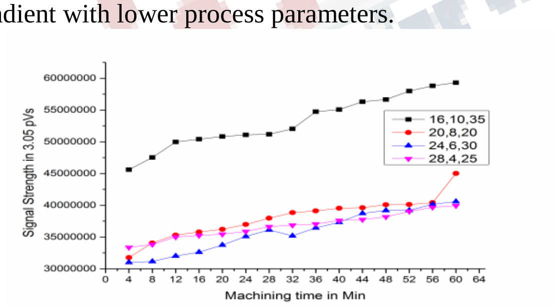

Fig 4 : Measured signal strength value for different machining time at maximum current of 6 amps for P-20 Tool Steel material

Fig. 5 shows the RMS curves with machining time for minimum current of 3 amps. The plot reveals that during the machining, the RMS has little higher gradient with lower process parameters.

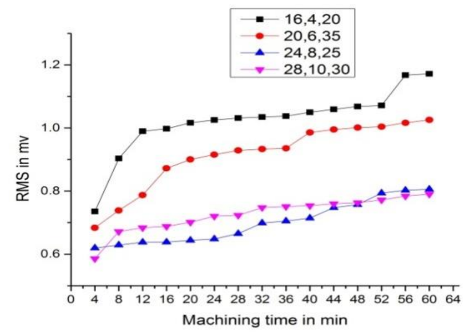

Fig 5 : Measured RMS value for different machining time at minimum current of 3 amps for P-20 Tool Steel material

Estimation of surface roughness, signal strength, RMS and absolute energy by MRA

Multiple regression analysis method is used for the estimation of Surface roughness and AE signals. form of graphs for further discussion and comparison.

Fig. 6 shows multiple regression estimates of surface roughness for various pulse off (4 µs,6 µs,8 µs,10 µs), current(3 amps,4 amps,5 amps,6 amps), bed-speed (20 µm/s,25 µm/s,30 µm/s,35 µm/s) at constant pulse on 28 µs respectively for P20 tool steel material. From the figure, it is observed that the measured value at moderate and higher process parameters correlates well with the estimated value.

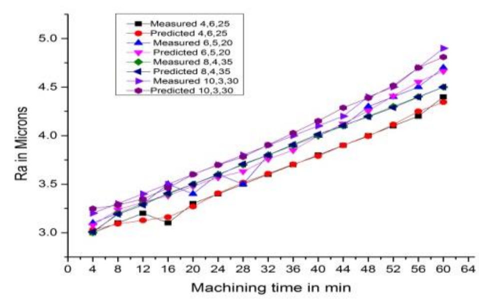

Fig 6 : Regression analysis estimation of surface roughness for various machining time for maximum pulse on 28µs

Fig.7 shows multiple regression estimates of RMS for various pulse on time (16µs,20µs,24µs,28µs),pulse off time(4µs, 6µs, 8µs, 10µs), bed-speed (20µm/s,35µm/s, 25µm/s, 30µm/s) at constant current 3 amps. From the figure, it is observed that the measured RMS value at

ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
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lower and moderate process parameters correlates well with the estimated value.

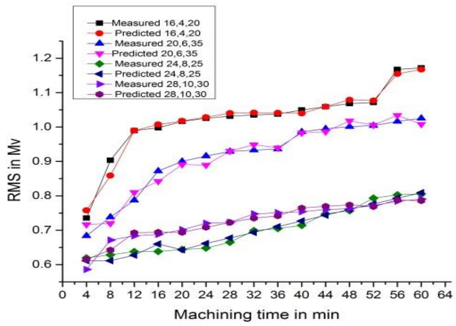

Fig 7 : Regression analysis estimates of RMS for various machining time for minimum current 3 amps

Surface roughness, Signal strength, RMS and Absolute energy estimation by GMDH

GMDH was also tried out for the estimation of surface roughness, signal strength, RMS and absolute energy for various process parameters based on the data obtained from the machining trials on stavax material. The independent variables were used as the input to the GMDH algorithm, which estimated surface roughness, signal strength, RMS and absolute energy (output) as a polynomial function of the supplied input. In designing the GMDH model, it is necessary to determine the number of input nodes and the level at which the output is estimated or the number of layers in between the input and output layer. In the present study, the number of data in the training set was considered to be at least 50% of total experimental data and it was varied in steps of 12.5% up to 75%. Hence, 50%, 62.5% and 75% of experimental data was considered in the training set.

Study of GMDH criterion

Fig. 8 shows GMDH estimation of RMS for P-20 tool steel material from three criteria, for 50% of data in training set for pulse on time 24µs, pulse off time 6 µs, current 6 amps, & Bed speed 30µm/s.Fig. 9 shows GMDH estimation of signal strength for P-20 tool steel material from three criteria, for 50% of data in training set for pulse on time 20µs, pulse off time 6 µs, current 3 amps, & Bed speed 35µm/s.

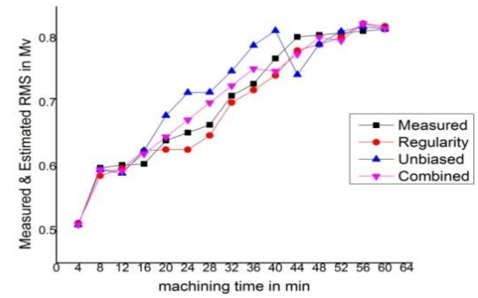

Fig 8 : GMDH estimates of RMS for P-20 tool steel at 50% of data in training set

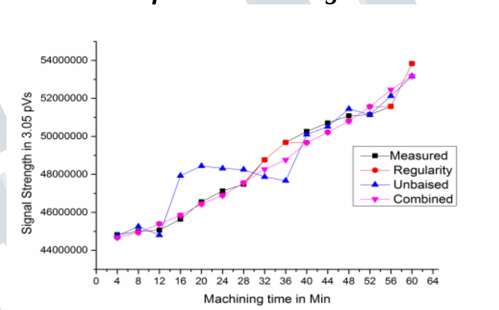

Fig 9 : GMDH estimates of signal strength for P-20 tool steel at 62.5% of data in training set

Referring to the graphs, it was observed that, the RMS and Signal strength obtained by regularity criterion correlates well with the measured RMS and Surface roughness. Estimates from unbiased and combined criterion gave poor results.

Study of percentage of data in training set

Results of GMDH were also studied to identify the best percentage of data in the training set to estimate the surface roughness, signal strength, RMS and absolute energy. Performance of GMDH for various percentages of data in the training set viz., 50%, 62.5% and 75% of data were studied.

Fig. 10 shows the measured and GMDH estimates of absolute energy from regularity criterion, for various percentages of data in the training set of pulse on time 28µs, pulse off time 4µs, current 6amps, bed speed 25µm/s.

ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
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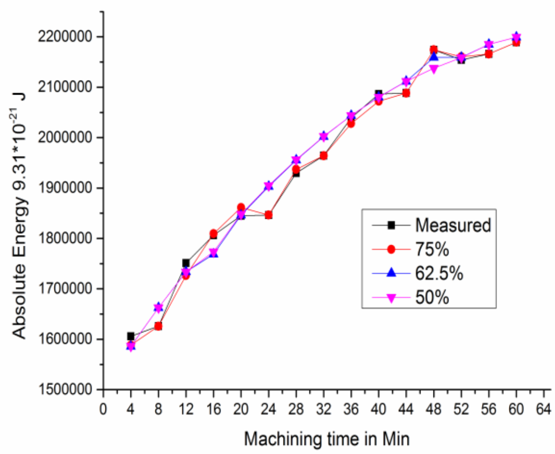

Fig 10 : GMDH estimates of Absolute energy for various percentages of data in training set

From these graph, it was observed that, with the increase in the percentage of data in the training set, the estimation power of regularity criterion also increases and the best results were obtained at 75% training set.

Comparative study of MRA and GMDH

MRA and GMDH were used to estimate surface roughness, signal strength, RMS and absolute energy in WEDM based on the experimentally measured signals, machining time, and cutting conditions. In GMDH, regularity criterion with 75% of data in the training set gave better estimation than the other criteria and percentage of data. Based on the SE obtained the comparison of GMDH and Multiple Regression estimates was for Surface roughness at pulse on time 16µs, pulse off time 4 µs, current 3amps and bed-speed 20µm/s in fig 11. Fig 12 shows the comparison of GMDH and Multiple Regression for signal strength at pulse on time 28µs, pulse off time 10 µs, current 3amps and bed-speed 30µm/s. From the graphs it was observed that good estimation is obtained in both MRA and GMDH models. Among these, regularity criterion of GMDH gave better estimation than MRA. This is because; GMDH is a self-organizing method of modeling, which fits a high degree polynomial using a multilayered network like structure.

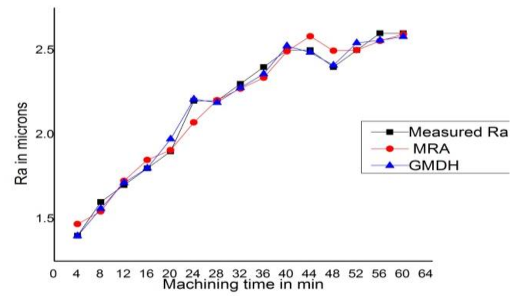

Fig 11 : Comparison of GMDH and multiple regression estimates of Surface roughness

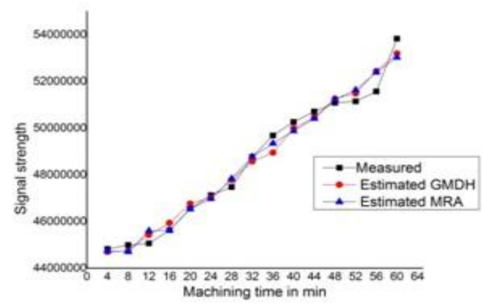

Fig 12 : Comparison of GMDH and multiple regression estimates of Signal strength

CONCLUSION

The present work involves machining of P-20 tool steel workpiece at various process parameters. During machining, different AE signal parameters viz., signal strength, RMS and absolute energy from the workpiece were acquired. Surface roughness was also measured after machining. Both experimental and theoretical approaches were used to estimate surface roughness, signal strength, RMS and absolute energy. Based on the experimental results, the following conclusions were drawn. The roughness plots have increased for maximum process parameters .Signal level of AE parameters increased with the increase in machining time due to increase in load on the workpiece at higher process parameters. Measured surface roughness had a better correlation with the estimated one at lower and higher process parameters, Measured RMS correlates well with estimated one at with lower and moderate process parameters, Measured signal strength correlates well with estimated one at lower and moderate process parameters and Measured absolute energy correlates well with the estimated

ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
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one at moderate and higher process parameters and comparison of the two theoretical methods for estimation of surface roughness, signal strength, RMS and absolute energy, it was found that regularity criterion function of GMDH had an edge over MRA method.

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