Estimation of Machining Performances using GMDH and ANN in Wire EDM of Cu-1Cr-0.1Zr Alloy

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Abstract: Wire cut Electrical Discharge Machining (WEDM) is a special form of EDM process in which electrode is a continuously moving conductive wire. The material removal is by controlled erosion through a series of repetitive sparks between workpiece and wire electrode. WEDM is a specialized thermo electrical machining process capable of accurately machining parts with varying hardness or complex shapes. Present study outlines the estimation of machining performances in the wire electric discharge machining of Cu-1Cr-0.1Zr alloy using Group Method of Data Handling (GMDH) technique and Artificial Neural Network (ANN). Cu-1Cr-0.1Zr alloy was machined using different process parameters based on Taguchi’s L27 standard orthogonal array. Parameters such as pulse-on time, pulse-off time and current were varied. The response variables measured for the analysis are Dimensional Error (DE), Surface Roughness (SR), Volumetric Material Removal Rate (VMRR) and Electrode Wear (EW). Machining performances have been compared using sophisticated mathematical models viz., GMDH and ANN. The GMDH algorithm is designed to learn the process by training the algorithm with the experimental data. Different GMDH 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% & 75%. Three different criterion functions, viz., Root Mean Square (Regularity or RMS) criterion, Unbiased criterion and Combined criterion were considered for estimation. Machining performances is predicted for 70% of data in training set using ANN. Estimation and comparison of machining performances were carried out using GMDH and techniques.

1. Introduction
Wire Electrode Discharge Machining (WEDM) is a specialized Electrode Discharge Machining process where hard and difficult to machine materials can be machined with complex shapes and forms. It has evolved to be the simple means to make tools and dies with high degree of surface finish and accuracy. One of the main advantages of using this technology is that the marching is occurring without the contact of tool and work. Hence the mechanical load on the work piece during machining is not present. Molybdenum is used in limited areas as wire since it require a high tensile strength to provide a load caring capacity that is reasonable for a small diameter wire. It is most suitable for small wires since it has higher tensile strength and higher melting point. Molybdenum is generally used as
EDM wires for its low electrical conductivity and also low flush-ability. The effect of process parameters on the response factors such as the SR, VMRR, DE and EW to be found out in the present study for the Cu-Cr-Zr alloy selected. A large number of researches are focused on the effect of process parameters but this paper deals with the estimation and comparison of responses. Taguchi’s L_{27} orthogonal array is chosen for design of experiments and ANOVA is performed on the experimental data to find the effect of each input function on the single response function. The responses are predicted by using the GMDH and ANN methods.

Experiments were conducted on high strength armor steel by using Taguchi’s DOE technique and ANOVA was found for the obtained data. Responses that were considered are surface roughness and Material Removal Rate (MRR) by optimizing the input functions namely pulse-on time, pulse-off time, wire feed, flushing pressure, spark voltage and wire tension. Results proved that pulse-on time and pulse-off time and spark voltage are significant variables to the surface roughness and MRR [1]. A study was conducted on HCHCr material by Taguchi’s L_{27} orthogonal array as DOE. The experiments conducted in WEDM to optimize the response function considered SR and VMRR by changing the input functions namely pulse-on time, pulse-off time and bed speed. ANOVA results showed that the pulse on time is having a major significance on the responses SR and VMRR. Verification experiments were conducted by using the optimized factors as input which yielded in better results than before [2]. Artificial Neural Network (ANN) is used to predict the nature of responses in WEDM of stavax material by using Taguchi’s L_{16} orthogonal array as DOE and ANOVA carried out to know the significance of the function on response. Molybdenum wire is used as the electrode. Pulse-on time, pulse-off time, current and bed speed were the input variables for which the dimensional accuracy, VMRR, SR were optimized. ANOVA results showed that current is the most significant factor. BPNN and LMA were used to build and train the network and results for 70% of training set show satisfactory results with measured response variables [3].

Kerf width and material removal rate was optimised in WEDM based on Taguchi’s design and ANOVA conducted to know the nature and significance of input factor namely pulse duration, open circuit voltage, dielectric flushing pressure and wire speed. Regression analysis modeling is carried for the experimental data. Results show that open circuit voltage is three times more significant factor than pulse duration for kerf width. For material removal rate the open circuit voltage is six times more significant factor than pulse duration. Also the proposed statistical technique can be used to predict the nature of the response considered when compared with the experimental data [4]. Study was conducted on Cu-Cr-Zr alloy material to know the role of Zirconium in the alloy system. Microstructure and properties of the alloy were observed by adding different % of Zirconium in Cu-Cr alloy system. It was observed that addition of Zr will result in enhanced tensile and fatigue strength in the Cu-Cr alloy system [5]. Optimization of WEDM by using RSM by using SiCp/6061 Al MMC was studied. Input parameters that were considered for this study were pulse-on time, off time, servo voltage and wire feed rate. Kerf width was studied as the response parameter in ANOVA to find out the significance of each parameter on the response. Mathematical models were also developed and properties of the machined surface are observed under SEM. It was found that servo voltage and wire feed rate are the most significant factor whereas the pulse off is the least significant factor. Also SEM images revealed that to attain fine surface finish combination of lower input parameters is to be used [6]. In a study on 6061 Aluminium alloy on WEDM to find the effect of process parameters on the material removal rate, kerf width, surface finish and EW. Eight experiments were conducted by varying the pulse on time and wire tension. It was found that increase in pulse on time also increases the MRR and effect of wire tension for MRR is negligible for the material considered. Also pulse on does not influence the SR and appearance of material whereas as the wire tension is increased the SR is reduced. It was found that longer pulse on would promote the EW [7].

A study was conducted on SR in EDM of SS316L stainless steel based on grey rational analysis. Copper impregnated graphite electrode was used for this die sinking EDM. Input parameters considered were peak current, servo voltage, servo speed, pulse on time and off time. GRA is used to analyse the data and it has been concluded that pulse on time and servo voltage are the most
significance parameters where as the servo speed, peak current and pulse off time are the lesser significant factors [8]. An experimental study was conducted to know the machining characteristic of PCD by micro-EDM. Taguchi’s experimental design was considered to vary the flushing pressure, wire speed, peak current, open circuit voltage, servo voltage, pulse on time, wire tension and grain size of crystals used to make sintered diamond compact tool. ANOVA and S/N ratio is used to analyse the experimental data obtained. Results show that main factors influencing MRR and kerf width is open circuit voltage. Also MRR increases with the increase in peak current. Optimum conditions were generated and the confirmation experiments were carried out which resulted satisfactory [9].

Modelling, simulation and optimization of WEDM process using RSM along with grey Taguchi technique is discussed. Discharge current, pulse duration, pulse frequency, wire tension, wire speed and dielectric flow rate were varied to know their effect on MRR, SR and kerf width. The data is used to analyse in RSM for each response. Predicted results are used to find out the combination of input parameters which yield in maximum MRR, minimum SR and better accuracy of the product individually. Discharge current, wire speed and pulse duration are the most significant factors contributing to MRR, SR and kerf width. Pulse frequency and wire tension resulted in lesser significant factors to the above mentioned responses. Whereas the dielectric flow rate had no effect on width of cut and MRR but SR reduced with its increase [10]. In a research work to study the machining characteristics of Al-SiC metal matrix composites using rotary EDM with tube type brass electrode is used. The factors that were varied during the experiments are volume fraction of SiC reinforced particles, polarity, peak current, pulse duration, speed of electrode rotation, and hole diameter of the tube electrode to control the response factors SR, EW and tool wear rate. Peak current is the most significant factors which have effect on SR, tool wear rate and EW. GA is used to optimise the result to achieve maximum MRR, minimum tool wear rate and better surface finish [11].

Experiment study was conducted on wire EDM of 5083 aluminium alloy based on Taguchi’s L9 orthogonal array design of experiments were discussed. Input parameters that were considered are pulse-on time, pulse-off time, peak current and wire tension to estimate the significance of each parameter on responses namely SR and wire tension. It was found that pulse-on time, off time and peak current play significant roles in determining the cutting speed and are not dependent on wire tension. Increase in peak current and pulse-on time increases the cutting speed whereas the cutting speed decreases with when the pulse-off time is increased. It was observed that for SR, pulse-on time and peak current are the important process parameters and are independent of pulse-off time and wire tension [12].

Bronze-alumina metal matrix composite was studied in the WEDM base on Taguchi’s L9 orthogonal array experimental design principle. Experiments were conducted to achieve low values of SR on the machined surface and higher values of MRR by varying the input variables viz., pulse off time, pulse on time and wire feed rate. ANOVA has been carried out find the significance of each parameter on the response considered. Results showed that wire feed rate is the most influencing and important parameter for the good surface finish or achieving lower values of SR [13]. Multi quality characteristics of WEDM of High Strength Low Alloy steel (HSLA) with RSM is discussed. Experimental study focused on effect of parameters on MRR with brass wire as electrode. The CCRD was used to conduct the experiments. Results yielded that MRR and SR increases with increase in pulse on time and peak current and the decreases with increase in pulse off time and servo voltage. Also the wire tension has no significant effect on SR and MRR. The RSM method was adopted to optimise the process parameter to responses considered individually by formulating a mathematical model. It was found that RSM model give satisfactory results [14]. They have reviewed the role of EDM process and its process variables in machining of aluminium based MMC materials. They have reviewed that various new techniques like ANN, GA, GRA, RSM etc., for optimization and as well as prediction are used by the researches to find out the best output combinations of the process variables have been successful and yielded in better results. They concluded that to achieve hybrid machining process different methods like electro chemical machining, abrasive jet machining and surface grinding are to be combined [15].
2. Experimental work
The experiments were carried on Concord Wire EDM DK7732 machine on Cu-Cr-Zr alloy material by varying machine parameters which are pulse-on time, off time and current. This machine is 4 axes and controlled by CNC. This machine allows the operator to select the input parameters according to material and height of the work piece. The experimental set-up for the data acquisition is illustrated in the Fig. 1.

One of the major features of this machine is that it uses reusable wire technology. Generally in WEDM two cutting passes are carried out i.e. rough cut and finish cut, but for the present work all cuts are carried out in single pass. The gap between work piece and electrode wire is maintained at 0.02mm and this is constantly maintained by the computer system. Wire electrode used is of 0.18mm diameter and is made up of molybdenum material. These experiments are carried out are according to the DOE plan and the parameters for the trials are set accordingly. The thickness of Cu-Cr-Zr alloy work piece is 40mm. A cut of 10×10mm is planned for each trial. Input levels with levels values are listed in the Table 1 below.

| Machining Process Parameter | Level 1 | Level 2 | Level 3 |
|-----------------------------|---------|---------|---------|
| Pulse-On time, µs           | 25      | 30      | 35      |
| Pulse-off time, µs          | 10      | 11      | 12      |
| Peak Current, A             | 3       | 4       | 5       |

2.1. Group Method of Data Handling
GMDH is a family of inductive algorithms for computer based mathematical modelling of multi parametric datasets that features fully automatic structural and parametric optimization of models. GMDH is used in such fields as data mining, knowledge discovery, prediction, complex systems modelling, optimization and pattern recognition. GMDH algorithms are characterized by inductive procedure that performs sorting-out of gradually complicated polynomial models and selecting the best solution by means of the so called external criterion.
A GMDH model with multiple inputs and one output is a subset of components of the base function (1).

\[ Y(x_1,\ldots,x_n) = a_0 + \sum_{i=1}^{m} a_i f_i \]  
(1)

Where \( f \) are elementary functions dependent on different sets of inputs, \( a \) are coefficients and \( m \) is the number of the base function components. In order to find the best solution GMDH algorithm consider various component subsets of the base function (1) called partial models. Coefficients of these models estimated by the least squares method. GMDH algorithm gradually increase the number of partial model components and find a model structure with optimal complexity indicated by the minimum value of an external criterion. This process is called self organization of models. The most popular base function used in GMDH is the gradually complicated Kolmogorov-Gabor polynomial (2).
\[ Y(x_1, \ldots, x_n) = a_0 + \sum_{i=1}^{n} a_i x_i + \sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij} x_i x_j + \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{k=1}^{n} a_{ijk} x_i x_j x_k + \ldots \]  

GMDH is also known as polynomial neural networks and statistical learning networks thanks to implementation of the corresponding algorithms in several commercial software products.

2.2. Artificial Neural Network

A neural network is an artificial representation of human brain that tries to simulate its learning process. ANN is an interconnected group of artificial neurons that uses a mathematical model or computational models for information processing based on a connectionist approach to computation. The ANN are made of inter connecting neurons which may share some properties of biological neurons. ANN is an information processing paradigm that is inspired by procedure in the biological nervous system. Neural networks are non linear mapping systems that consist of simple processors which are called neurons, linked by weighed connections. Each neuron has inputs and generates an output that can be seen as the reflection of local information that is stored in connections. The output signal of a neuron is fed to other neurons as input signals via interconnections Fig. 2 shows the network architecture of ANN. The neuron has a bias \( b \), which is summed with the weighted inputs to form the net input \( n \).

\[ n = w_1,1p_1 + w_1,2p_2 + \ldots + w_1,Rp_R + b \]  

Various input to the neurons are represented by ‘\( X_n \)’. Each of these inputs is multiplied by a connection weighed, represented by ‘\( W_n \)’ and added to the bias ‘\( \phi \)’ to compute activation ‘\( a_n \)’ which is converted into the output ‘\( O_n \)’ via transfer function. Various input to the neurons are represented by ‘\( X_n \)’. Each of these inputs is multiplied by a connection weighed, represented by ‘\( W_n \)’ and added to the bias ‘\( \phi \)’ to compute activation ‘\( a_n \)’ which is converted into the output ‘\( O_n \)’ via transfer function.

\[ a_n = W_n X_n^T + \phi \]  

\[ O_n = f(a_n) \]

After conducting the experiment, response values are noted down and analysis has been done. The experiment was conducted in the same environmental condition for all the runs so that environmental noise factors can be minimized.

3. Results and Discussions

3.1. Prediction of response variables of Cu-Cr-Zr material

The prediction of responses was carried out using GMDH and ANN, for various training sets of 50%, 62.5% and 75% of data is used in GMDH and 50%, 60% and 70% of data is used in ANN. The three criterion functions, viz., regularity, unbiased and combined were tried out for machining performances. An attempt was made to identify the best criterion and best percentage of data in the training set to estimate machining performances. Identification of the best criterion, best percentage of data and the optimal level of estimation was according to the value of Standard Error (SE) of estimation. The results of GMDH for different machining conditions are presented and discussed. When the training is completed, it is necessary to check the network performance and determine if any changes need to be made to the training process, network architecture or the data sets.
Fig. 3 shows GMDH estimates of DE from various criterions for 75% of data in training set. Referring to the Fig. 3, it was observed that the DE estimate obtained by regularity criterion correlates well with the measured DE. Since the estimate by this criterion closely matches with the measured DE with lesser SE of estimate than the unbiased and combined criterions. Estimate from unbiased and combined criterions gave poor results.

Fig. 3: Measured and estimated DE at various criterions

Fig. 4 shows GMDH estimates of DE from regularity criteria, for various percentages of data in the training set. It was observed from the Fig. 4, that with the increase in the percentage of data in the training set, the estimation power of regularity criterion also increases. Least error and best fit was obtained when 75% of data is used in the training set. The least SE is 0.0073 for 75% of data in training set at level 3. Further GMDH estimation will be carried out for DE and VMRR of Cu-Cr-Zr material.

Fig. 4. Measured and predicted DE at various percentage of data by GMDH

From Fig. 5, it is clearly shows that, the results from the GMDH, least error of estimation and best-fit was found for 75% of data in training set at level 3 under RMS criteria for SR, VMRR and EW. Fig. 6 shows that prediction of responses was carried out using ANN, for various training sets of 50%, 60% and 70% of data in training set is used in ANN.
It is observed from the Fig. 7, Fig. 8 and Fig. 9 predicted SR, VMRR and EW of 70% of the data set by ANN exhibits better correlation with the measured SR, VMRR and EW when compared to the GMDH.
4. Conclusion
This paper has presented an investigation on the estimation and prediction of machining parameters on DE, SR, EW and VMRR in WEDM. Three different criterion functions of GMDH viz., regularity (RMS), unbiased and combined criterions have been tried for estimation of machining performances Cu-Cr-Zr. ANN is used to predict the response variable viz., SR, VMRR, EW and accuracy. The results from the GMDH show that the regularity criteria function provides good estimation than the other function. Different models of GMDH were built by varying the number of data in the training set to 50%, 62.5% and 75% of the total data. It was found that the least error of estimation and best-fit was found for 75% of data in training set at level 3 under RMS or regularity criteria for DE, SR, VMRR and EW. Comparison of the two theoretical methods for estimation of machining performances, it was found that, ANN fitting function has an edge over GMDH method. It is observed that neural network trained with 70% of the data in training set gives good prediction results when compared to the 50% and 60% of data in training set. Thus, predicted response variables of 70% training set correlates well with the measured response variables. ANN function gave better prediction than GMDH.

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