Estimation and comparison of Cutting Parameters in Drilling of Epoxy Resin Composite Material using GMDH and ANN

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***Abstract*— In this paper, an attempt has been made to estimation of drilling performances using Group Method of Data Handling (GMDH) technique and Artificial Neural Network (ANN). Experiments were carried out on machining the various % weight of Si_3N_4 in Epoxy Resin - Si_3N_4 Composite (ERC) materials, using the HSS tool for various cutting conditions. The input process parameters considered during experiments are viz., % weight of Si_3N_4, Speed, Feed, diameter of drill bit and machining time. The response variables measured for the analysis are Surface Roughness (SR), delamination, circularity, cylindricity and Tool Wear (TW). 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%. The best model is selected from the said percentages of data. 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 50%, 60% and 70% of data in training set using ANN. Estimation and comparison of machining performances were carried out using GMDH and ANN techniques.**

***Keywords*— ERC, Drilling, L_{27}, GMDH and ANN**

1. INTRODUCTION

Drilling is one of the oldest and the most widely used of all machining processes, comprising about one third of all metal-machining operations. Drilling of composite materials is an important and current topic in modern researches on manufacturing processes. Currently, the use of composite materials has increased in various areas of science and technology due to their special physical and mechanical properties such as high specific strength, stiffness and fatigue strength. The quality of the drilled hole depends on the factors such as, speed, feed rate, tool geometry etc. The efficient and economic machining of the materials is required for the desired dimensions and surface finish.

The main goal of this research is to develop tools for practical monitoring and diagnosis of drilled hole status of composite material. The research effort and directions related to the present work will be identified through literature survey. A comprehensive survey of literature helps in establishing the need and scope of the present research work.

An effective approach for the optimisation of drilling parameters with multiple performance characteristics based on the Taguchi method with grey relational analysis was carried out. Taguchi's L_{16}, 4-level orthogonal array has been used for the experimentation. The drilling parameters such as spindle speed and feed rate are optimised with consideration of multiple performance characteristics, such as thrust force, workpiece surface roughness and delamination factor. Response table and response graph are used for the analysis. The analysis of grey relational grade indicates that feed rate is the more influential parameter than spindle speed. The results indicate that the performance of drilling process can be improved effectively through this approach [1]. A new comprehensive approach to select cutting parameters for damage-free drilling in carbon fiber reinforced epoxy composite material were proposed. The approach is based on a combination of Taguchi's techniques and on the analysis of variance (ANOVA). A plan of experiments, based on the techniques of Taguchi, was performed drilling with cutting parameters prefixed in an autoclave Carbon Fiber Reinforced Plastic (CFRP) laminate. The ANOVA is employed to investigate the cutting characteristics of CFRP using HSS and Cemented Carbide (K10) drills. The objective was to establish a correlation between cutting velocity and feed rate with the delamination in a CFRP laminate. The correlation was obtained by multiple linear regression. Finally, confirmation tests were performed to make a comparison between the results foreseen from the mentioned correlation [2]. The cutting parameters (cutting velocity and feed rate) under specific cutting pressure, thrust force, damage and surface roughness in Glass Fiber Reinforced Plastics (GFRP's) were carried out. A plan of experiments, based on the techniques of Taguchi, was established considering drilling with prefixed cutting parameters in a hand lay-up GFRP material. The ANOVA was performed to investigate the cutting characteristics of GFRP's using K10 drills with appropriate geometries. The specific cutting pressure decreases with the feed rate and slightly with the cutting speed, and the thrust force increases with the feed rate. The damage increases with both cutting parameters, which means that the composite damage is bigger for higher cutting speed and for higher feed. The objective was to establish a correlation between cutting velocity and feed rate with the specific cutting pressure, thrust force, damage factor and surface roughness, in a GFRP material [3].

An experimental investigation of a full factorial design performed on thin CFRP laminates using K20 carbide drill by varying the drilling parameters such as spindle speed and feed rate to determine optimum cutting conditions. Have analyzed delamination while drilling CFRP at high spindle speeds using ANN and concluded that spindle speed, feed rate and point angle of the drill affect the delamination of the drilled hole [4]. An experiments were carried out as per the Taguchi experimental design and an L_9 orthogonal array was used to study the influence of various combinations of process parameters on hole quality. ANOVA test was conducted to determine the significance of each process parameter on drilling. The results indicate that feed rate is the most significant factor influencing the thrust force followed by speed, chisel edge width and point angle; cutting speed is the most significant factor affecting the torque, speed and the circularity of the hole followed by feed, chisel edge width and point angle [5]. An experimental investigation of a full factorial design performed on thin CFRP laminates using K20 carbide drill by varying the drilling parameters such as spindle speed and feed rate to determine optimum cutting conditions. Have analyzed delamination while drilling CFRP at high spindle speeds using ANN and concluded that spindle speed, feed rate and point angle of the drill affect the delamination of the drilled hole. It was proposed that a combination of high spindle speed, low feed rate and low point angle would minimize damages that occur due to delamination. The hole quality parameters analyzed include hole diameter, circularity, peel-up delamination and push-out delamination. ANOVA was carried out for hole quality parameters and their contribution rates were determined. Genetic Algorithm (GA) methodology was used in the multiple objective optimization to find the optimum cutting conditions for defect free drilling. Tool life of the K20 carbide drill was predicted at optimized cutting speed and feed [6]. An analysis of delamination behavior as a function of drilling process parameters at the entrance of the CFRP plates were carried out. The delamination analysis in high speed drilling is performed by developing an ANN model with spindle speed, feed rate and point angle as the affecting parameters. A multilayer feed forward ANN architecture, trained using Error-Back Propagation Training Algorithm (EBPTA) is employed for this purpose. Drilling experiments are conducted as per full factorial design using cemented carbide (grade K20) twist drills that serve as input–output patterns for ANN training. The validated ANN model is then used to generate the direct and interaction effect plots to analyze the delamination behavior. The simulation results illustrate the effectiveness of the ANN models to analyze the effects of drilling process parameters on delamination factor. The analysis also demonstrates the advantage of employing higher speed in controlling the delamination during drilling [7].

2. EXPERIMENTAL WORK

The experimental work consists of drilling various % wt. of Si_3N_4 in epoxy silicon nitride composite using HSS drill bit. The machining was carried out in an automatic drilling machine tool. The control factors were chosen based on review of literature, experience and some preliminary investigations. Different settings of controllable factors such as % volume of Si_3N_4, cutting speed, feed rate, diameter of drill bit and machining time were used in the experiments as shown in Table 1.

TABLE 1: MACHINING PARAMETERS AND LEVELS

Machining parameters	Level 1	Level 2	Level 3
% weight	0	6	10
Cutting speed (RPM)	360	490	680
Feed Rate (mm/rev)	0.095	0.190	0.285
Dill dia (mm)	6	8	10
m/c time	30	60	90

3. RESULTS AND DISCUSSION

A. 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)*.

$$Y(x_1, ..., x_n) = a_0 + \sum_{i=1}^{m} a_i f_i \qquad (1)$$

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 *(2)* 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)*.

$$Y(x_1,......x_n) = a_0 + \sum_{i=n}^{n} a_i x_i + \sum_{i=1}^{n}\sum_{j=1}^{n} a_{ij} x_i x_j + \sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{n} a_{ijk} x_i x_j x_k + ... \quad (2)$$

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

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.

The neuron has a bias b, which is summed with the weighted inputs to form the net input *n*.

$$n = w1,1p1 + w1,2\ p2 + ... + w1,RpR + b \quad (3)$$

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 'φ' 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 'φ' to compute activation 'a_n' which is converted into the output 'O_n' via transfer function.

$$a_n = W_n X_n^T + \varphi \quad (4)$$

$$O_n = f(a_n) \quad (5)$$

Since the capability of a single neuron is limited, complex functions can be realized by connecting many such neurons to form layers neuron network. The common type of ANN consists of 3 layers viz., Input layer, hidden layer and output layer. A layer of input units is connected to a layer of hidden units which is connected to layer of output units. Patterns are presented to the networks via the input layer, which communicates to one or more hidden layers where the actual processing is done via a system of weighed connections. The hidden layers then link to an output layer. A layer is defined as group of parallel neurons without and interaction between them.

In the present study outlines the estimation of process parameters in drilling of ERC material. The experiments were performed based on L_{27} orthogonal array. Experiments were done for various %wt of Si_3N_4, speed, feed, dia of drill bit and machining time. SR, circularity, cylindricity, tool wear and delamination were measured. Process parameters are optimized with consideration of multiple performance characteristics, such as workpiece SR, circularity, cylindricity, tool wear and delamination. The verification experiments are conducted using the optimized process parameters and compared with the results obtained from the initial set of readings. The parameters are predicted using mathematical models viz., GMDH and ANN. Comparison of measured values with predicted values with standard error is done to know the behavior.

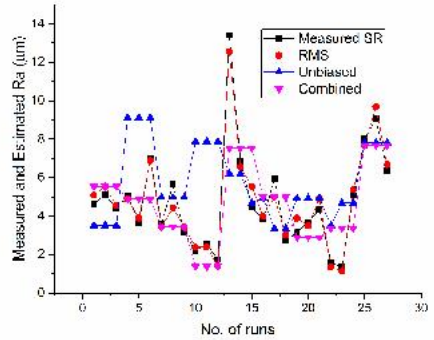

Fig 1. GMDH estimates of surface roughness for various criterions

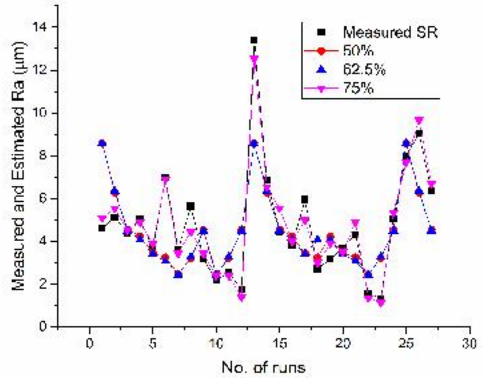

Fig 2. GMDH estimates of surface roughness for various percentages of data

B. Estimation of Performances by GMDH

There are three criterion's viz., regularity, unbiased and combined criteria's were used in GMDH.

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.

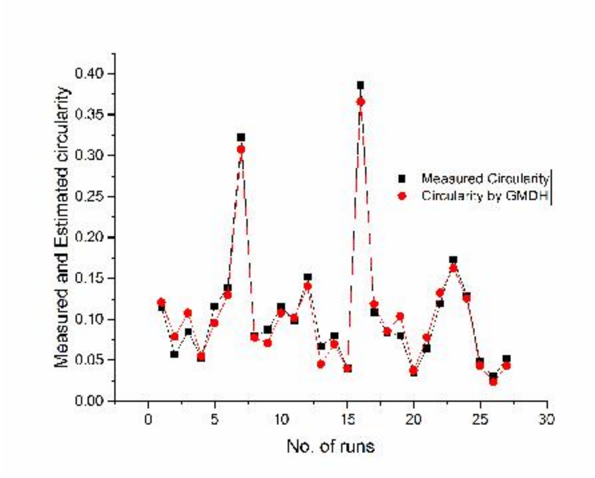

Fig 3. GMDH estimates of circularity

Fig 1 and Fig 2 shows the comparison of experimental and GMDH estimates of roughness from three criterions, for 50%, 62.5% and 75% of data in training set. It is observed that a regularity criterion was correlated to the measured value. The least standard error was 0.3385 from the regularity criteria of 75% training set of data's when compare to other criterions and other two percentage of data in training set. Further estimation was carried out using 75% of data in training set for circularity, cylindricity, tool wear and delamination.

From the Fig. 3, Fig. 4, Fig. 5 and Fig. 6 it is clearly shows that, estimation of 75% of data were correlating well with the measured one for circularity, cylindricity, tool wear and delamination.

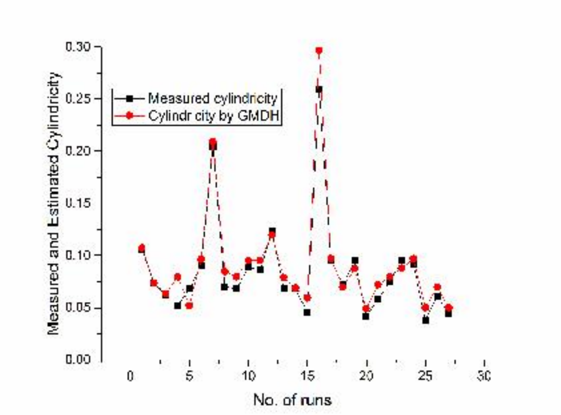

Fig 4. GMDH estimates of cylindricity

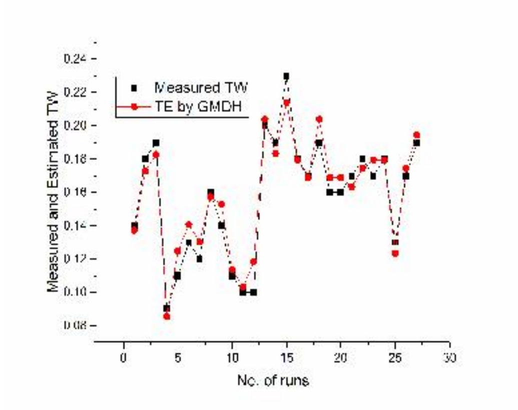

Fig 5. GMDH estimates of TW

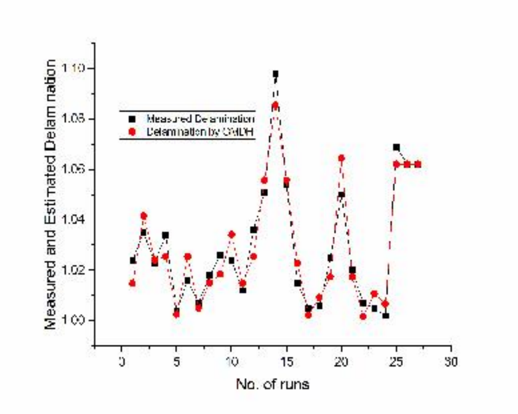

Fig 6. GMDH estimates of delamination

C. Prediction of response for by ANN

The prediction of responses was carried out using neural network fitting tool for various training sets of 50%, 60% and 70%. 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. When compared to 50% and 60% of data in training set, 70% of data was correlating well with the measured one.

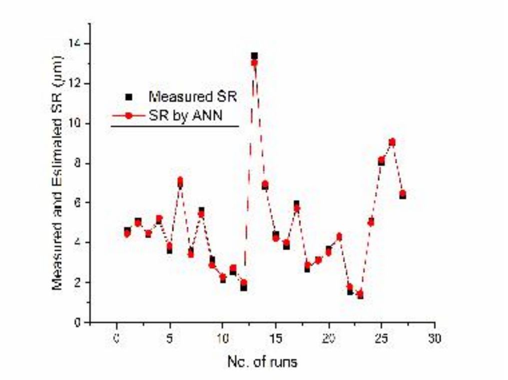

Fig. 7. Comparison of measured and predicted SR

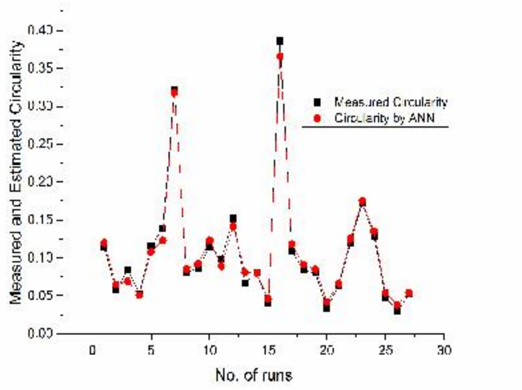

Fig. 8. Comparison of measured and predicted circularity

Fig. 7, Fig. 8 Fig. 9, Fig. 10 and Fig. 11 shows the comparison of measured and predicted surface roughness, circularity, cylindricity, tool wear and delamination of 70% of data sets for ERC material. It is observed from the Fig. 7, Fig. 8 Fig. 9, Fig. 10 and Fig. 11 predicted SR, circularity, cylindricity, tool wear and delamination of 70% of the data set exhibits better correlation with the measured performances.

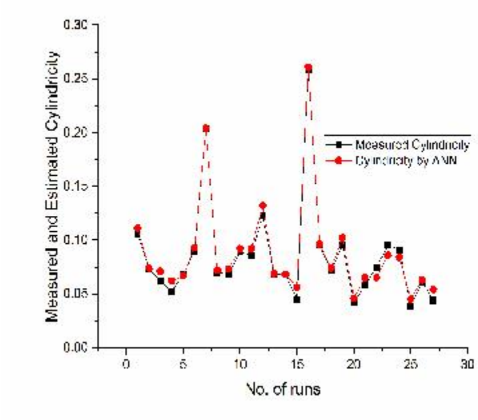

Fig. 9. Comparison of measured and predicted cylindricity

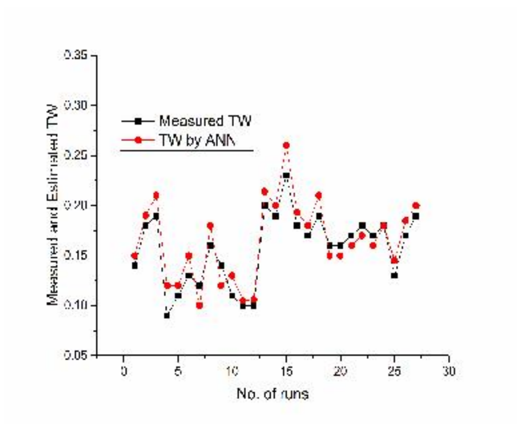

Fig. 10. Comparison of measured and predicted TW

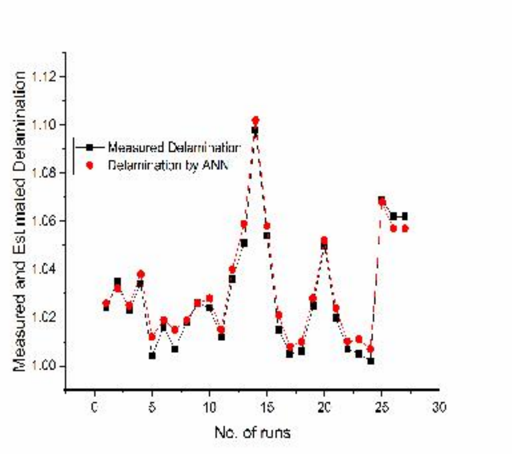

Fig. 11. Comparison of measured and predicted Delamination

D. Comparative Study of GMDH and ANN

GMDH and ANN were used to estimate SR, circularity, cylindricity, tool wear and delamination in machining of ERC alloy. Both methods were found to estimate SR, circularity, cylindricity, tool wear and delamination well discussed in the above sections. From the standpoint of identifying a better method among the two, the results from both the methods were compared. In GMDH, regularity criterion gave better estimation than the other criterions with 75% of data in training set. Hence, it was considered for the comparison.

From Fig. 12, Fig. 13, Fig. 14, Fig. 15 and Fig. 16 observed that the 70% training set of data of ANN is well correlating with the measured SR, circularity, cylindricity, tool wear and delamination than the GMDH. The standard error will be less when compared to GMDH. This is because ANN is a self-organizing method of modelling, which fits a high degree polynomial using a multi-layered network like structure.

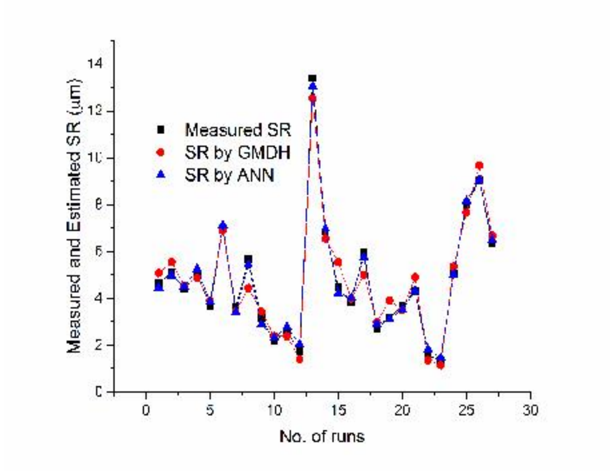

Fig 12. Comparison of MRA and GMDH estimates of surface roughness

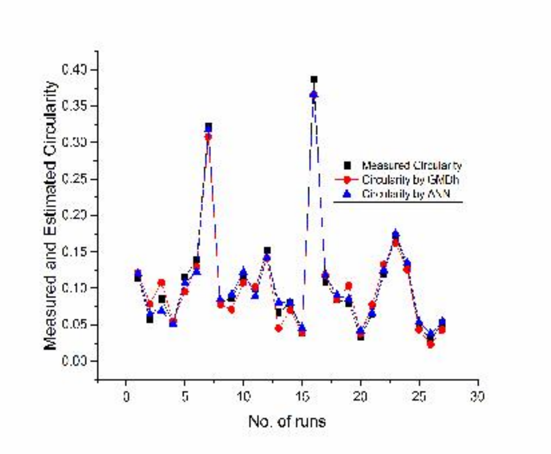

Fig 13. Comparison of MRA and GMDH estimates of circularity

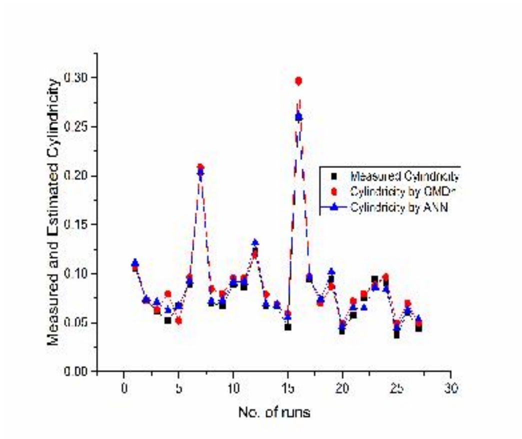

Fig 14. Comparison of MRA and GMDH estimates of cylindicity

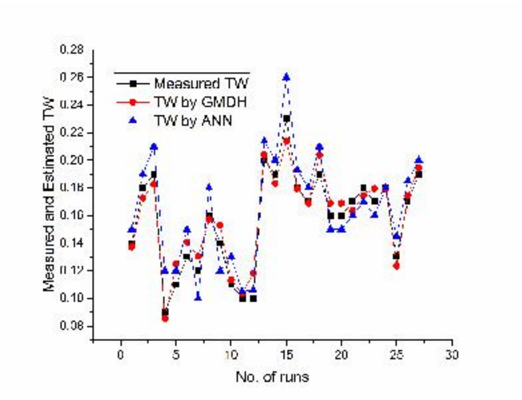

Fig 15. Comparison of MRA and GMDH estimates of TW

4. CONCLUSION

This paper has presented an investigation on the estimation and prediction of machining parameters on SR, circularity, cylindricity, tool wear and delamination in drilling operations. Three different criterion functions of GMDH viz., regularity (RMS), unbiased and combined criterion have been tried for estimation of machining performances. ANN is used to predict the response variable viz., SR, circularity, cylindricity, tool wear and delamination.

The results from the GMDH show that the regularity criteria function with 75% of data provides good estimation than the other function. Comparison of the two theoretical methods for estimation of machining performances, it was found that, artificial neural network fitting function has an edge over GMDH method. 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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