ANFIS based model to forecast the Wire-EDM parameters for machining an Ultra High Temperature Ceramic composite

S Mandal¹*, A Pramanick¹, S Chakraborty², P P Dey¹

¹Department of Mechanical Engineering, IIEST, Shibpur, Howrah, West Bengal, India
²Central Glass and Ceramic Research Institute, Jadavpur, Kolkata, West Bengal, India

E-mail: saikatmandal1992@gmail.com

Abstract: In this work, a ZrB₂ based ceramic composites with 25 wt. % B₄C sintered in spark plasma sintering furnace at 2000°C for 10 min under 50 MPa pressure has been machined with Wire electrical discharge machine (WEDM) and can readily be cut to intricate shapes to meet the requirements of industry. The adaptive neuro fuzzy inference systems (ANFIS) has been used to generate mapping relation between input parameters and output responses. ANFIS is a neuro fuzzy technique where the fusion is made between the neural network and the fuzzy inference system. Also the ANFIS models have been tested by a confirmative test and the results shows minimum root mean square error (RMSE) as 0.0416 for kerf width and 0.9605 for machining speed. This verification indicates that ANFIS modeling can be used to forecast the responses.

1. Introduction:

Ultra high temperature ceramics (UHTCs) are the compound that contain one metallic part which is a transition metal (Zr, Hf, Ta etc.) of periodic table and one nonmetal part, mainly boron (B) and carbon (C). These UHTCs can withstand high temperature (~3000°C), also have high hardness, scratch resistance and good chemical stability [1–4]. Zirconium di-boride (ZrB₂) is one of the most important member of the UHTCs family which is a promising candidate for application in the hypersonic vehicle, rocket propulsion, thermal protection structure, re-entry vehicles [5,6]. Apart from its numerous valuable properties the sinterability of pure ZrB₂ is low and density relatively high. To overcome this problem boron carbide (B₄C) as an additives can be mixed with ZrB₂ matrix. The sintered ZrB₂-B₄C composite possesses high hardness and brittleness which makes the machining of these material quite difficult. In these research an intelligent system, based on ANFIS has been made to predict the Wire EDM machining responses for machining ZrB₂ ceramics with 25 wt. % B₄C in ZrB₂ Matrix sintered by using SPS furnace at 2000°C for 10 min under 50 MPa.

2. Methodology

2.1. Machining

The Sample of ZrB₂ with 25 Wt. % B₄C composite was machined by using a wire EDM(Electronica, EUROCut 734-Mark-I, India) with brass wire of 0.25 mm diameter as electrode (cutting tool) (figure 1 ). The machining performance has been evaluated in terms of kerf width and machining speed. The machining time has been recorded by using a stopwatch. A non-contact type surface profilometer

* Corresponding author.
(Contour GT-K, Bruker USA) was used to measure the kerf width of cut (figure 2). Machining speed has been calculated by using formula.

\[ \text{m/c speed} = \frac{lxd}{t} \text{ mm}^2/\text{min} \]  

(1)

Where \(l\)=cutting length, \(d\)= thickness of sample, \(t\)= cutting time.

In this study the process parameter considered are Shown in Table 1.

| Level | \(T_{on}\) (\(\mu\)sec) | \(T_{off}\) (\(\mu\)sec) | IP (A) | WP (kg/cm\(^2\)) | SF (mm/min) |
|-------|----------------|----------------|--------|-----------------|-------------|
| 1     | 120            | 54             | 140    | 6               | 2100        |
| 2     | 122            | 56             | 150    | 7               | 2200        |
| 3     | 124            | 58             | 160    | 8               | 2300        |

The experiments were designed by Plackett-Burman Design for those 5 factor. According to the design it’s contain 16 base run 16 total run with 4 centre points [7]. Another 11 random run with varying those five input parameter were conducted and responses were recorded for verification of the ANFIS network.

| Exp. No. | Kerf width (mm) | Machining Speed (mm\(^2\)/min) |
|----------|----------------|-------------------------------|
| 1        | 0.3161         | 17.195                        |
| 2        | 0.3350         | 18.884                        |
| 3        | 0.3367         | 12.051                        |
| 4        | 0.3210         | 18.391                        |
| 5        | 0.3390         | 13.869                        |
| 6        | 0.3310         | 13.558                        |
| 7        | 0.3284         | 16.719                        |
| 8        | 0.3337         | 13.015                        |
| 9        | 0.3379         | 12.297                        |
| 10       | 0.3303         | 12.638                        |
| 11       | 0.3390         | 13.484                        |
| 12       | 0.3344         | 14.147                        |
| 13       | 0.3304         | 12.332                        |
| 14       | 0.3330         | 12.478                        |
| 15       | 0.3310         | 13.689                        |
| 16       | 0.3313         | 13.137                        |
2.2. ANFIS

Adaptive neuro fuzzy inference system (ANFIS) is a fuzzy based system implemented on the framework of neural network [8]. The concept of fuzzy set come from that at a point of extend it is not possible to take decision by using only yes or no criteria. The advantage of the fuzzy inference system (FIS) is that it can deal with linguistic expressions and the advantage of a neural network is that it can be trained so that it can self-learn and self-improve [9,10]. Integration of this two system makes ANFIS a capable of good learning and easily interpreting system and a framework more systematic and less reliant on expert knowledge. The ANFIS is a non-statistical technique which has the ability to approximate a large class of dynamical nonlinear systems, which is widely applied in fields such as intelligent control and time series prediction [11,12]. Basically the ANFIS architecture is consist of five layer and each layer has several nodes (figure 3). The rule base contain Sugeno type fuzzy if then rule [13].

If f(x, y) is taken to be a first order polynomial a first order Sugeno fuzzy model is formed. For the first-order Sugeno fuzzy model, a typical rule set with four fuzzy if-then rules can be expressed as

Rule 1: If \( x \) is \( A_1 \) and \( y \) is \( B_1 \) then \( z_1 = p_1 x + q_1 y + r_1 \) (2)

Rule 2: If \( x \) is \( A_1 \) and \( y \) is \( B_2 \), then \( z_2 = p_2 x + q_2 y + r_2 \) (3)

Rule 3: If \( x \) is \( A_2 \) and \( y \) is \( B_1 \), then \( z_3 = p_3 x + q_3 y + r_3 \) (4)

Rule 4: If \( x \) is \( A_2 \) and \( y \) is \( B_2 \), then \( z_4 = p_4 x + q_4 y + r_4 \) (5)

![Figure 3. ANFIS Architecture](image)

In the figure 3 the circular node are the fixed type and square node are adaptive node.

3. Result and Discussion

3.1. Training of ANFIS network

Two different ANFIS model has been developed by using ANFIS tool box in MATLAB 7.10.0 for kerf width and machining speed. Prediction of response of Wire-EDM by ANFIS consists of two main stages, training and testing. Hence, in this research work, all 16 data sets have been selected as training data to train a primary ANFIS network. In the second stage, the trained network has been tested by other 11
additional data sets, which has not contributed in the main design matrix. Then, value of RMSE (Root mean square error) has been calculated for testing data. These stages have been repeated under various types and number of membership function (MF) for input parameter ($T_{on}$, $T_{off}$, IP, WP, SF) to get least RMSE with constant type output MF. value of RSME of all this run are shown below (table 4, 5) During the training of the network the error goal was set as 0.0001 and iteration number was 50 epochs which means the training epochs are continued, until the RMSE fell below 0.001 or the epochs go up to 50 (figure 4). For the ANFIS, the inputs are $T_{on}$, $T_{off}$, IP, WP and SF and the output are kerf width and machining speed. The ANFIS info for all the run are shown in table 3.

![Figure 4. ANFIS training error for 50 Epochs](image)

| Table 3. ANFIS info |
|--------------------|
| Number of          | Triangular MF | Generalized bell MF | Gaussian MF | Trapezoidal |
|                   | 2 MF   | 3MF   | 2 MF   | 3MF   | 2 MF   | 3MF   | 2 MF   | 3MF   |
| Rule               | 32     | 243   | 32     | 243   | 32     | 243   | 32     | 243   |
| Premise parameter  | 30     | 45    | 30     | 45    | 20     | 30    | 20     | 30    |
| Consequent parameter| 192    | 1458  | 192    | 1458  | 192    | 1458  | 192    | 1458  |

| Table 4. Values of RMSE in testing of kerf width for various type and number of MFs |
|-----------------------------------|
| Type of Membership function | Tested RMSE with 2 MF of each input parameter | Tested RMSE with 3 MF of each input parameter |
| Triangular                      | 0.0416                                      | 0.2322                                      |
| G. bell                         | 0.066                                       | 0.2218                                      |

| Table 5. Values of RMSE in testing of machining speed for various type and number of MFs |
|-----------------------------------|
| Type of Membership function | Tested RMSE with 2 MF of each input parameter | Tested RMSE with 3 MF of each input parameter |
| Triangular                      | 0.9605                                      | 9.4709                                      |
| G. bell                         | 2.567                                       | 9.0019                                      |
3.2. Testing of ANFIS network

It is clear from table 4 and 5 that triangular type with 2 MF for both the responses (kerf width and machining speed) has shown the lowest RMSE with respect to the other types and number of membership function.

Figure 5 and 6 depicts a graphical results from comparison between measure and predicted value of machining speed and kerf width in 11 testing data set. It can be inferred from this figure that there are superior agreement between experimentally measured values and predicted values by ANFIS.

| Membership Function | RMSE (Kerf Width) | RMSE (Machining Speed) |
|---------------------|-------------------|------------------------|
| Gaussian            | 0.0635            | 2.6785                 |
| Trapezoidal         | 0.0979            | 3.6504                 |
|                     | 0.223             | 9.0295                 |
|                     | 0.23224           | 9.4709                 |

4. Conclusion

ZrB$_2$-B$_4$C (25 wt. %) ceramic composite was machined by Wire EDM with a Plackett-Burman design of experiment with 16 number of total run by using $T_{on}$, $T_{off}$, IP, WP, SF as input parameter of the machine and machining speed and kerf width were recorded as responses. This 16 number of data set were used to train an ANFIS network for mapping between input and output parameter. Separately 11 new Experiment were conducted for testing the ANFIS model. Eight different ANFIS model were created and tested for both the responses by using triangular, Generalized Bell, Gaussian and Trapezoidal type membership function (MF) with 2 and 3 number of MF of each type. From testing of all this model it can be concluded that the triangular type membership function with 2 number perform better for both the responses (kerf width and machining speed).

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Acknowledgement

The author (SM) would like to thank the Director, CSIR-CGCRI for given permission of his M.Tech dissertation work. Thanks are also due to NOCCD for the sample sintering and preparation.