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# Modeling of Abrasive Water-Jet Machining (AWJM) for Machining Fibre Reinforced Polymer (FRP) by using Taguchi method and ANFIS model

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**Abstract - Abrasive Water-Jet Machining (AWJM) is advanced non-traditional machining process used for cutting polymer composites. In this project experimental investigations are conducted to assess the influence of abrasive water jet machining (AWJM) process parameters on surface roughness (Ra), kerf characteristics and Material Removal Rate (MRR) for machining Fibre Reinforced Polymer (FRP). The approach was based on Taguchi's method to optimize the AWJM process parameters for effective machining. It was found that the abrasive material flow rate, stand-off distance, size of focusing tube and feed rate are the significant control factors. The Taguchi analysis successfully predicted the MRR, surface roughness and kerf characteristics of an AWJM machined FRP material. Verification of the improvement in the quality characteristics had been made through confirmation test with respect to the chosen reference parameter setting.**

***Keywords- Abrasive Water-Jet Machining (AWJM), Material Removal Rate (MRR), Surface Roughness (Ra), Fibre Reinforced Polymer (FRP).***

## I. INTRODUCTION

This work deals with the process optimization of Abrasive Water Jet Machining (AWJM) for machining of Fibre Reinforced Polymer (FRP). For process parameter optimization it's essential to study various parameters of AWJM which affects the machining quality of FRP material. Abrasive waterjet machining is a mechanical, non-conventional machining method in which abrasive particles such as Silica sand, Garnet, Aluminium oxide, Silicon carbide etc. are entrained in high-speed waterjet to erode materials from the surface of material. About 90% of machining is done by using garnet as abrasive particle. In AWJM material removal take place by erosion induced by the impact of solid particles. Material removal occurs by cutting wear and deformation wear, cutting wear defines erosion at smaller impact angle. Deformation's wear occurs by repeated bombardment of abrasive at larger impact angle. Abrasive waterjet machined surface is grouped into three sections which are Initial Damage Region (IDR), Smooth Cutting Region (SCR) and Rough Cutting Region (RCR). Main applications of pure waterjet machining include cutting paper products, wood, cloths, plastics etc. composites materials with high strength, low weight, resistant to heat, hard etc. increase its use and applications.

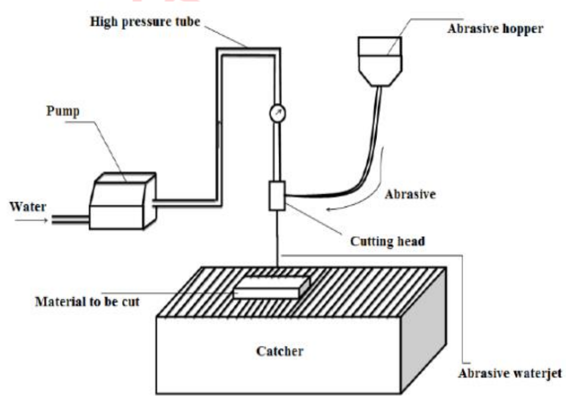


**Fig 1. Set-up of AWJM.[10]**

## II. LITERATURE SURVEY

**Azmir et al. (2008)** presented a paper on 'Investigation on Glass/Epoxy Composite Surfaces Machined by Abrasive Water Jet Machining' in which he conducted experiments to assess the influence of Abrasive Water Jet Machining (AWJM) process parameters on surface roughness (Ra) of glass fibre reinforced epoxy composite. His approach was based on Taguchi's method and Analysis of Variance (ANOVA) to optimize the AWJM process parameters for effective machining. It was found that the type of abrasive materials, hydraulic pressure, standoff distance and traverse rate. A Mathematical model was developed by him and his team using linear regression analysis to predict the performance of Ra in terms of the cutting parameters of AWJM. His model successfully predicted the Ra of an

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AWJM machined glass/epoxy laminate within the limit of his study.[1]

**Srikanth et al. (2014)** presented a paper on 'Metal Removal and Kerf Analysis in Abrasive jet drilling of Glass Sheets' in which he carried out drilling of glass with different Stand of Distances, Pressures and different Nozzle Diameters by Abrasive Jet Drilling process (AJD) in order to determine its machinability under different controlling parameters of the AJM process. While conducting experiments Abrasive Jet Machine (AJM) removed material through the action of focused beam of abrasive laden gas. He optimized process parameters of Abrasive Jet Machining of glass by Taguchi methodology. The Values obtained in Taguchi Analysis were compared with the Analysis of Variance (ANOVA). Various levels of Experiments were conducted for both analysis of MRR and KERF. His research presented ample results by changing pressure, nozzle tip distance, SOD on different thickness of glass plates. The effect of their process parameters on the material removal rate (MRR) was analysed by using Taguchi Method and compared this by using Analysis of variance (ANOVA). [2]

**Khan et al. (2007)** presented a paper on 'Performance of Different Abrasive Materials During Abrasive Water Jet

Machining of Glass' in which he investigated different types of abrasives used in abrasive water-jet machining such as garnet, aluminium oxide, olivine, silica sand, silicon carbide etc. His work gave a comparative analysis of the performance of garnet, aluminium oxide and silicon oxide during abrasive water-jet machining of glass. His study showed that the width of cut increases as the stand-off distance of the nozzle from the work increased which was due to divergence shape of the abrasive water-jet. [3]

**Leema et al. (2002)** presented a paper on 'Study of Cutting Fibber-Reinforced Composites by Using Abrasive Water-Jet with Cutting Head Oscillation' in which an experimental and theoretical research work on Abrasive Water-Jet (AWJ) oscillation cutting of Glass Fiber Reinforced Polymer (GFRP) composite materials was conducted at the Water-jet Laboratory of the Industrial Research Institute of Swinburne (IRIS). The objective of his research work was to conduct a comparative study of the oscillation and normal (without head oscillation) cutting of GFRP composite materials and compare the performances of these two processes.[4]

**Menelaos Pappas et al. (2011)** This work presents a hybrid approach based on the Taguchi method and the Artificial Neural Networks (ANNs) for the modeling of surface quality characteristics in Abrasive Water Jet Machining (AWJM). The selected inputs of the ANN model are the thickness of steel sheet, the nozzle diameter, the stand-off distance and the traverse speed. The outputs of the ANN model are the surface quality characteristics, namely the kerf geometry and the surface roughness. The data used to train the ANN model was selected according to the Taguchi's design of experiments. The acquired results indicate that the proposed modelling approach could be effectively used to predict the kerf geometry and the surface roughness in AWJM, thus supporting the decision-making during process planning.[5]

**S. Babajanzade Roshan et al. (2013)** This paper work deals with experimental investigation, modeling, and optimization of friction stir welding process (FSW) to reach desirable mechanical properties of aluminum 7075 plates. Main factors of process were tool pin profile, tool rotary speed, welding speed, and welding axial force. Also, main responses were tensile strength, yield strength, and hardness of welded zone. Four factors and five levels of central composite design have been utilized to minimize the number of experimental observations. Then, adaptive neuro-fuzzy inference systems (ANFIS) have been used to generate mapping relationship between process factors and main response using experimental observations. Results indicated that the tool with square pin profile, rotary speed of 1,400 RPM, welding speed of 1.75 mm/s, and axial force of 7.5 KN resulted in desirable mechanical properties in both cases of single response and multi response optimization. Also, these solutions have been verified by confirmation tests and FSW process physical behavior. These verifications indicated that both ANFIS model and simulated annealing algorithm [6]

## III. METHODOLOGY

### *A. Working of Abrasive Water-Jet Machining (AWJM)*

Abrasive waterjet machining is a mechanical, non-conventional machining method in which Abrasive particles such as Silica sand, Garnet, Aluminum oxide, Silicon carbide etc. are entrained in high-speed waterjet to erode materials from the surface of material. About 90% of machining is done by using garnet as abrasive particle. In AWJM material removal take place by erosion induced by the impact of solid particles. Material removal occurs by cutting wear and deformation wear, cutting wear defines erosion at smaller impact angle. Deformation's wear occurs by repeated bombardment of abrasive at larger impact angle. Abrasive waterjet machined surface is grouped into three sections which are Initial Damage Region (IDR), Smooth Cutting Region (SCR) and Rough Cutting Region (RCR). Main applications of pure waterjet machining include cutting paper products, wood, cloths, plastics etc. composites materials with high strength, low weight, resistant to heat, hard etc. increase its use and applications. The traverse speed is most effective parameter for MRR. Abrasive flow rate is also an important parameter for increasing MRR. But beyond some limit with increase in abrasive flow rate and traverse speed the surface roughness decreases. Increasing traverse speed also increase the kerf geometry. Traverse speed is directly proportional to productivity and should be selected as high as possible without compromising kerf quality and surface roughness. So, it is required to find optimum condition for process parameter to give better quality of cutting surface. These days AJWM process is being applied

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into the cutting and drilling of hard-to-cut materials such as advanced composites.[7]


**Figure 2. Working of AWJM**

### *B. Design of Experiments (DoE)*

Design of Experiments (DoE) table was prepared by Mini-Tab software by considering input parameters such as Abrasive Material Flow Rate (AMFR), Stand of Distance (SOD), Focusing Tube size (FT) and Feed Rate (FR) and considering output parameters such as Material Removal Rate (MRR) and kerf width (KW). the experiments are been analysed in 3 steps by L36 Taguchi Array.[8]

### *C. Process Parameters*

**Water Jet pressure**

Relationship between pressure and depth of cut for different abrasive flow rates and nozzle diameters will observe on experimental work. The effect of water jet pressure on the depth of cut for various abrasive flow rates makes an observation

**Water flow rate**

In abrasive jet machining where gas (usually air) is used as a propelling fluid, only small mass flow rates of abrasives can be achieved. In AWJM, water is used as a propelling fluid which enables high abrasive flow rates to be achieved, and makes it possible to accelerate abrasives to high velocities.

**Abrasive particle size**

Commonly used abrasive size ranges from 100150 grit. There is an optimum particle size for a particular work piece material and also for a particular nozzle mixing chamber configuration Mesh size 60 is more effective for relatively shallow depth of cut.

**Abrasive material**

Garnet, silica and silicon carbide are commonly used abrasive in AWJC. Type of abrasives to be used is determined after knowing hardness of the work piece material. Higher the hardness of the work piece material, harder should be the abrasives to be used.

**Stand-off-distance**

An increase in Standoff distance rapidly decreases machined depth. This has been explained by arguing that the liquid phase of the jet breaks up into droplets resulting in free abrasive particles..

### *D. Taguchi approach*

**Taguchi Method**

Taguchi Method Taguchi design of experiment is one of these techniques which are used widely. The Taguchi method involves reducing the variation in a process through robust design experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting and the levels at which they should be varies.[8]

Taguchi method focuses on Robust Design through use of

a) Signal-To-Noise ratio
b) Orthogonal arrays

**Steps in Taguchi methodology**

Basic procedure of Taguchi method as following.

a) Determine the Quality Characteristic to be Optimized
b) Identify the Noise Factors and Test Conditions
c) Identify the Control Parameters and Their Alternative Levels
d) Design the Matrix Experiment and Define the Data Analysis Procedure
e) Conduct the Matrix Experiment
f) Analyze the Data and Determine the Optimum Levels
g) Predict the Performance at these Levels

**Table 1 Technical Specification of AWJM Set-up**

| Sr. No. | Parameters | Values |
|---|---|---|
| 1 | Abrasive Type | Garnet |
| 2 | Abrasive Grain Size | 80 Mesh |
| 3 | Hydraulic Pressure | 60,000 Psi |
| 4 | Size of Machining Table | 3x1.5 m |
| 5 | Stand of Distance | 100 mm |
| 6 | Abrasive Material Flow Rate | 0.25-1.5 Lbs/min |

**Table 2 Fixed Parameters of AWJM Machine**

| Sr. No. | Parameters | Values |
|---|---|---|
| 1 | Pressure | 50 KPsi (345 MPa) |
| 2 | Abrasive Type | Garnet |
| 3 | Abrasive Material Grain Size | 80 Mesh |

**Table 3 Level of Parameter of AWJM Machine**

| Parameters | Level-1 | Level-2 | Level-3 |
|---|---|---|---|
| | Low | Medium | High |
| Abrasive Material Flow Rate (Lbs/min) | 0.25 | 0.875 | 1.5 |
| Focusing Tube (mm) | 1.016 | 0.534 | - |
| Stand of Distance (mm) | 0.5 | 0.75 | 1 |
| Feed Rate (mm/min) | 100 | 124 | 147 |

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**Table 4 DoE Table**

Thus, Final DoE can be formulated as;

| Sr. No. | Focusing Tube (mm) | Abrasive Material Flow Rate (Lbs/min) | Stand of Distance (mm) | Feed Rate (mm/min) | MRR (g/sec) | MRR S/N Ratio | Average Surface Roughness (µm) | Average Surface Roughness S/N Ratio |
|---|---|---|---|---|---|---|---|---|
| 1 | 1.016 | 0.25 | 0.5 | 100 | 1.14 | 1.14 | 6.605 | -16.40 |
| 2 | 1.016 | 0.875 | 0.75 | 124 | 0.75 | -2.50 | 10.48 | -20.41 |
| 3 | 1.016 | 1.5 | 1 | 147 | 0.75 | -2.50 | 15.11 | -23.59 |
| 4 | 1.016 | 0.25 | 0.5 | 100 | 0.91 | -0.82 | 9.72 | -19.75 |
| 5 | 1.016 | 0.875 | 0.75 | 124 | 0.91 | -0.82 | 10.14 | -20.12 |
| 6 | 1.016 | 1.5 | 1 | 147 | 0.99 | -0.09 | 8.51 | -18.60 |
| 7 | 1.016 | 0.25 | 0.5 | 124 | 0.99 | -0.09 | 11.17 | -20.96 |
| 8 | 1.016 | 0.875 | 0.75 | 147 | 0.79 | -2.05 | 15.33 | -23.71 |
| 9 | 1.016 | 1.5 | 1 | 100 | 0.79 | -2.05 | 12.09 | -21.65 |
| 10 | 1.016 | 0.25 | 0.5 | 147 | 0.97 | -0.26 | 10.55 | -20.47 |
| 11 | 1.016 | 0.875 | 0.75 | 100 | 0.97 | -0.26 | 9.11 | -19.19 |
| 12 | 1.016 | 1.5 | 1 | 124 | 1.07 | 0.59 | 8.79 | -18.88 |
| 13 | 1.016 | 0.25 | 0.75 | 147 | 1.07 | 0.59 | 8.23 | -18.31 |
| 14 | 1.016 | 0.875 | 1 | 100 | 0.93 | -0.63 | 10.37 | -20.32 |
| 15 | 1.016 | 1.5 | 0.5 | 124 | 0.93 | -0.63 | 13.20 | -22.41 |
| 16 | 1.016 | 0.25 | 0.75 | 147 | 0.98 | -0.18 | 10.93 | -20.77 |
| 17 | 1.016 | 0.875 | 1 | 100 | 0.98 | -0.18 | 10.10 | -20.09 |
| 18 | 1.016 | 1.5 | 0.5 | 124 | 1.05 | 0.42 | 8.63 | -18.72 |
| 19 | 0.534 | 0.25 | 0.75 | 100 | 1.05 | 0.42 | 7.14 | -17.07 |
| 20 | 0.534 | 0.875 | 1 | 124 | 1.14 | 1.14 | 6.605 | -16.40 |
| 21 | 0.534 | 1.5 | 0.5 | 147 | 0.75 | -2.50 | 10.48 | -20.41 |
| 22 | 0.534 | 0.25 | 0.75 | 124 | 0.75 | -2.50 | 15.11 | -23.59 |
| 23 | 0.534 | 0.875 | 1 | 147 | 0.91 | -0.82 | 9.72 | -19.75 |
| 24 | 0.534 | 1.5 | 0.5 | 100 | 0.91 | -0.82 | 10.14 | -20.12 |
| 25 | 0.534 | 0.25 | 1 | 124 | 0.99 | -0.09 | 8.51 | -18.60 |
| 26 | 0.534 | 0.875 | 0.5 | 147 | 0.99 | -0.09 | 11.17 | -20.96 |
| 27 | 0.534 | 1.5 | 0.75 | 100 | 0.79 | -2.05 | 15.33 | -23.71 |
| 28 | 0.534 | 0.25 | 1 | 124 | 0.79 | -2.05 | 12.09 | -21.65 |
| 29 | 0.534 | 0.875 | 0.5 | 147 | 0.97 | -0.26 | 10.55 | -20.47 |
| 30 | 0.534 | 1.5 | 0.75 | 100 | 0.97 | -0.26 | 9.11 | -19.19 |
| 31 | 0.534 | 0.25 | 1 | 147 | 1.07 | 0.59 | 8.79 | -18.88 |
| 32 | 0.534 | 0.875 | 0.5 | 100 | 1.07 | 0.59 | 8.23 | -18.31 |
| 33 | 0.534 | 1.5 | 0.75 | 124 | 0.93 | -0.63 | 10.37 | -20.32 |
| 34 | 0.534 | 0.25 | 1 | 100 | 0.93 | -0.63 | 13.20 | -22.41 |

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| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 35 | 0.534 | 0.875 | 0.5 | 124 | 0.98 | -0.18 | 10.93 | -20.77 |
| 36 | 0.534 | 1.5 | 0.75 | 147 | 0.98 | -0.18 | 10.10 | -20.09 |

"Orthogonal Arrays" (OA) provide a set of well balanced (minimum) experiments and Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results.[9]

For larger is better

$$\frac{S}{N}\ Ratio = -10log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}\left\{\frac{1}{Y\ i^2}\right\}\right]$$

For Smaller is better

$$\frac{S}{N}\ Ratio = -10log_{10}(Y\ i^2)$$

### *3.8 Selection of Orthogonal Array*

Taguchi orthogonal design uses a special set of predefined arrays called orthogonal arrays (OAs) to design the plan of experiment. These standard arrays stipulate the way of full information of all the factors that affects the process performance (process responses) the orthogonal array is selected from standard chart for array selection based on number of levels and factors in Mini-Tab software Taguchi Array is L36 ($2^1$ ,$3^3$) with Factors 4 and runs 36 times [9]

### *E. Material Removal Rate (MRR)*

Material Removal Rate (MRR) is the amount of material cut in a particular period of time. MRR can be calculated as;

$$MRR = \frac{W_b - W_a}{T}$$

Where,

$W_b$= Weight before Machining (gm).

$W_a$= Weight after Machining (gm).

T= Time Required to Cut-Down the Material (sec).

For Material Removal Rate (MRR)

**Table 5-Response table of S/N Ratios for MRR**

| Level | Focusing Tube | Abrasive Material Flow Rate | Stand-off Distance | Feed Rate |
|---|---|---|---|---|
| 1 | -20.24 | -19.90 | -19.90 | -19.85 |
| 2 | -20.15 | -20.04 | -20.04 | -20.23 |
| 3 | - | -20.64 | -19.07 | -20.50 |
| Delta | 0.09 | 0.74 | 0.97 | 0.65 |
| Rank | 4 | 2 | 1 | 3 |

For each input find the maximum value of average S/N in column and take respective level recommended level for optimization. -0.57, -0.32, -0.29, -0.46 are highest in respective column so FT level-1 as 1.016 mm, AMFR level-1 as 0.25 lbs. /min, SOD level-1 as 0.5 mm, and FR level-1 as 100 mm/min is optimum set of solution for maximum MRR.

### *F. Surface Roughness*

Surface Roughness (Ra) can be calculated by the surface roughness tester which can be formulated as;

For Surface Roughness

**Table 6-Response table of S/N Ratios for Surface Roughness**

| Level | Focusing Tube | Abrasive Material Flow Rate | Stand-off Distance | Feed Rate |
|---|---|---|---|---|
| 1 | -0.57 | -0.32 | -0.29 | -0.46 |
| 2 | -0.57 | -0.50 | -0.87 | -0.61 |
| 3 | - | -0.89 | -0.56 | -0.65 |
| Delta | 0 | 0.57 | 0.58 | 0.18 |
| Rank | 4 | 2 | 1 | 3 |

For each input find the maximum value of average S/N in column and take respective level as recommended level for optimization -20.15, -19.90, -19.07, -1985 are highest in respective column so FT level-2 should be selected as 0.534 mm, AMFR level-1 as 0.25 lbs. /min, SOD level-3 as 1 mm, and FR level-1 as 100 mm/min is optimum set of solution for minimizing surface roughness

## IV. DEVELOPMENT OF ANFIS MODEL

An ANN model was constructed that can predict MRR and surface roughness (Ra), for every possible combination of values for the four studied input parameters, namely the Focusing Tube, Abrasive material flow rate, the stand-off distance, Feed rate. However, the prediction capability of the model is more efficient while the values of the parameters are inside the valid ranges Prediction of AWJM process by ANFIS consists of two main stages, training and testing. Hence, in the present study, we had carried out 36 experiment and then first 26 sample (72%) have been selected as training data to train a primary ANFIS network. In the second stage 10 sample (28%) have been selected as testing data This subset is used to compare output (simulated data) and target (experimental data) [6]

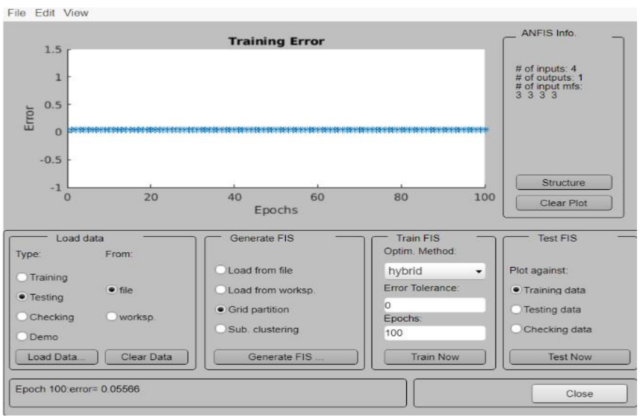


**Fig 3. Validation procedure of MRR Training sample and MRR Testing Sample**

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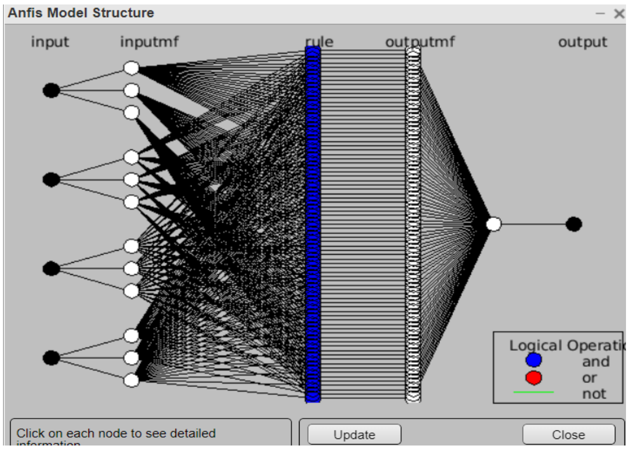


**Fig 4. Structure of developed ANFIS model for MRR**

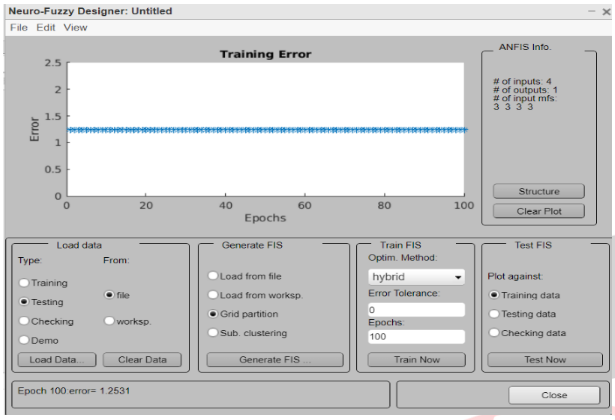


**Fig 5. Validation procedure of Surface Roughness Training sample and Surface Roughness Testing Sample**

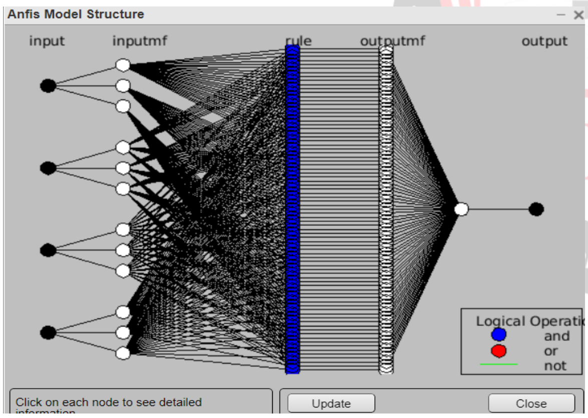


**Fig 6. Structure of developed ANFIS model for surface Roughness**

## V MODELLING RESULT

**Table 7 Experimental Vs Simulated data of MRR and Surface Roughness**

| No of EXPT | EXPT MRR (g/sec) | Simulated of MRR (g/sec) | EXPT Ra (µm) | Simulated Ra (µm) |
|---|---|---|---|---|
| 1 | 1.14 | 1.02 | 6.605 | 8.16 |
| 2 | 0.75 | 0.83 | 10.48 | 10.3 |
| 3 | 0.75 | 0.87 | 15.11 | 11.8 |
| 4 | 0.91 | 1.02 | 9.72 | 8.16 |
| 5 | 0.91 | 0.83 | 10.14 | 10.3 |
| 6 | 0.99 | 0.87 | 8.51 | 11.8 |
| 7 | 0.99 | 0.99 | 11.17 | 11.2 |
| 8 | 0.79 | 0.79 | 15.33 | 15.3 |
| 9 | 0.79 | 0.79 | 12.09 | 12.1 |
| 10 | 0.97 | 0.97 | 10.55 | 10.5 |
| 11 | 0.97 | 0.97 | 9.11 | 9.11 |
| 12 | 1.07 | 1.07 | 8.79 | 8.79 |
| 13 | 1.07 | 1.02 | 8.23 | 9.58 |
| 14 | 0.93 | 0.95 | 10.37 | 10.2 |
| 15 | 0.93 | 0.99 | 13.2 | 10.9 |
| 16 | 0.98 | 1.02 | 10.93 | 9.58 |
| 17 | 0.98 | 0.95 | 10.1 | 12.1 |
| 18 | 1.05 | 0.99 | 8.63 | 10.9 |
| 19 | 1.05 | 1.05 | 7.14 | 7.14 |
| 20 | 1.14 | 1.14 | 6.605 | 6.6 |
| 21 | 0.75 | 0.75 | 10.48 | 10.5 |
| 22 | 0.75 | 0.75 | 15.11 | 15.1 |
| 23 | 0.91 | 0.91 | 9.72 | 9.72 |
| 24 | 0.91 | 0.91 | 10.14 | 10.1 |
| 25 | 0.99 | 0.99 | 8.51 | 8.51 |
| 26 | 0.99 | 0.99 | 11.17 | 11.2 |
| 27 | 0.79 | 0.79 | 15.33 | 1.5 |
| 28 | 0.79 | 0.99 | 12.09 | 2.5 |
| 29 | 0.97 | 0.99 | 10.55 | 1.6 |
| 30 | 0.97 | 0.98 | 9.11 | 3.56 |
| 31 | 1.07 | 1.06 | 8.79 | 2.1 |
| 32 | 1.07 | 1.05 | 8.23 | 2.3 |
| 33 | 0.93 | 0.92 | 10.37 | 3.96 |
| 34 | 0.93 | 0.94 | 13.2 | 3.2 |
| 35 | 0.98 | 0.97 | 10.93 | 4.2 |
| 36 | 0.98 | 0.96 | 10.1 | 3.52 |

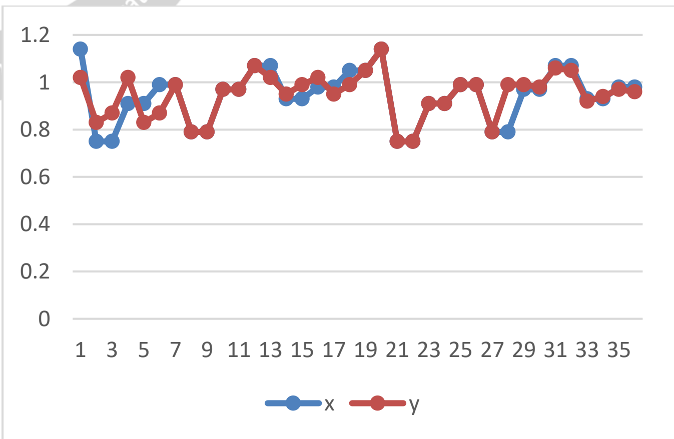


**Fig 7. Comparison between Experimental VS Simulated data of MRR**

Calculation of Coefficient of correlation MRR

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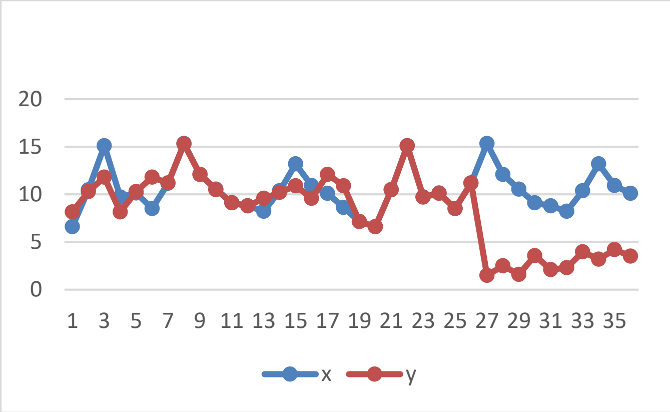
**Table 8 Coefficient of correlation MRR**

**Fig 8. Comparison between Experimental VS Simulated data of Surface Roughness**




| X | Y | X. | Y. | $X.^2$ | $Y.^2$ | X.*Y. |
|---|---|---|---|---|---|---|
| 1.14 | 1.02 | 0.1973 | 0.1038 | 0.038927 | 0.010774 | 0.02048 |
| 0.75 | 0.83 | -0.1927 | -0.0862 | 0.037133 | 0.00743 | 0.016611 |
| 0.75 | 0.87 | -0.1927 | -0.0462 | 0.037133 | 0.002134 | 0.008903 |
| 0.91 | 1.02 | -0.0327 | 0.1038 | 0.001069 | 0.010774 | -0.00339 |
| 0.91 | 0.83 | -0.0327 | -0.0862 | 0.001069 | 0.00743 | 0.002819 |
| 0.99 | 0.87 | 0.0473 | -0.0462 | 0.002237 | 0.002134 | -0.00219 |
| 0.99 | 0.99 | 0.0473 | 0.0738 | 0.002237 | 0.005446 | 0.003491 |
| 0.79 | 0.79 | -0.1527 | -0.1262 | 0.023317 | 0.015926 | 0.019271 |
| 0.79 | 0.79 | -0.1527 | -0.1262 | 0.023317 | 0.015926 | 0.019271 |
| 0.97 | 0.97 | 0.0273 | 0.0538 | 0.000745 | 0.002894 | 0.001469 |
| 0.97 | 0.97 | 0.0273 | 0.0538 | 0.000745 | 0.002894 | 0.001469 |
| 1.07 | 1.07 | 0.1273 | 0.1538 | 0.016205 | 0.023654 | 0.019579 |
| 1.07 | 1.02 | 0.1273 | 0.1038 | 0.016205 | 0.010774 | 0.013214 |
| 0.93 | 0.95 | -0.0127 | 0.0338 | 0.000161 | 0.001142 | -0.00043 |
| 0.93 | 0.99 | -0.0127 | 0.0738 | 0.000161 | 0.005446 | -0.00094 |
| 0.98 | 1.02 | 0.0373 | 0.1038 | 0.001391 | 0.010774 | 0.003872 |
| 0.98 | 0.95 | 0.0373 | 0.0338 | 0.001391 | 0.001142 | 0.001261 |
| 1.05 | 0.99 | 0.1073 | 0.0738 | 0.011513 | 0.005446 | 0.007919 |
| 1.05 | 1.05 | 0.1073 | 0.1338 | 0.011513 | 0.017902 | 0.014357 |
| 1.14 | 1.14 | 0.1973 | 0.2238 | 0.038927 | 0.050086 | 0.044156 |
| 0.75 | 0.75 | -0.1927 | -0.1662 | 0.037133 | 0.027622 | 0.032027 |
| 0.75 | 0.75 | -0.1927 | -0.1662 | 0.037133 | 0.027622 | 0.032027 |
| 0.91 | 0.91 | -0.0327 | -0.0062 | 0.001069 | 3.84E-05 | 0.000203 |
| 0.91 | 0.91 | -0.0327 | -0.0062 | 0.001069 | 3.84E-05 | 0.000203 |
| 0.99 | 0.99 | 0.0473 | 0.0738 | 0.002237 | 0.005446 | 0.003491 |
| 0.99 | 0.99 | 0.0473 | 0.0738 | 0.002237 | 0.005446 | 0.003491 |
| 0.79 | 0.79 | -0.1527 | -0.1262 | 0.023317 | 0.015926 | 0.019271 |
| 0.79 | 0.99 | -0.1527 | 0.0738 | 0.023317 | 0.005446 | -0.01127 |
| 0.97 | 0.99 | 0.0273 | 0.0738 | 0.000745 | 0.005446 | 0.002015 |
| 0.97 | 0.98 | 0.0273 | 0.0638 | 0.000745 | 0.00407 | 0.001742 |
| 1.07 | 1.06 | 0.1273 | 0.1438 | 0.016205 | 0.020678 | 0.018306 |
| 1.07 | 1.05 | 0.1273 | 0.1338 | 0.016205 | 0.017902 | 0.017033 |
| 0.93 | 0.92 | -0.0127 | 0.0038 | 0.000161 | 1.44E-05 | -4.8E-05 |
| 0.93 | 0.94 | -0.0127 | 0.0238 | 0.000161 | 0.000566 | -0.0003 |
| 0.98 | 0.97 | 0.0373 | 0.0538 | 0.001391 | 0.002894 | 0.002007 |
| 0.98 | 0.96 | 0.0373 | 0.0438 | 0.001391 | 0.001918 | 0.001634 |

Coefficient of correlation MRR (r) = 0.8055

Where,

$$x = \text{Experimental data of MRR}$$

$$y = \text{Simulated data of MRR}$$

$$X. = x - \bar{x}$$

$$Y. = y - \bar{y}$$

$$\bar{x} = \sum \frac{x}{n}$$

$$\bar{y} = \sum \frac{y}{n}$$

$$n = \text{Number of Experiments in MRR}$$

$$r = \frac{\sum xy}{\sqrt{(\sum x^2)(\sum y^2)}}$$

r = relation between two quantities in MRR [5]

Calculation of Coefficient of correlation Surface Roughness

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**Table 9 Coefficient of correlation Surface Roughness**

| X | Y | X. | Y. | $X^2$ | $Y^2$ | X.*Y. |
|---|---|---|---|---|---|---|
| 6.605 | 8.16 | -3.855 | 0.13 | 14.86103 | 0.0169 | 0.251151 |
| 10.48 | 10.3 | 0.02 | 2.27 | 0.0004 | 5.1529 | 0.002061 |
| 15.11 | 11.8 | 4.65 | 3.77 | 21.6225 | 14.2129 | 307.3184 |
| 9.72 | 8.16 | -0.74 | 0.13 | 0.5476 | 0.0169 | 0.009254 |
| 10.14 | 10.3 | -0.32 | 2.27 | 0.1024 | 5.1529 | 0.527657 |
| 8.51 | 11.8 | -1.95 | 3.77 | 3.8025 | 14.2129 | 54.04455 |
| 11.17 | 11.2 | 0.71 | 3.17 | 0.5041 | 10.0489 | 5.06565 |
| 15.33 | 15.3 | 4.87 | 7.27 | 23.7169 | 52.8529 | 1253.507 |
| 12.09 | 12.1 | 1.63 | 4.07 | 2.6569 | 16.5649 | 44.01128 |
| 10.55 | 10.5 | 0.09 | 2.47 | 0.0081 | 6.1009 | 0.049417 |
| 9.11 | 9.11 | -1.35 | 1.08 | 1.8225 | 1.1664 | 2.125764 |
| 8.79 | 8.79 | -1.67 | 0.76 | 2.7889 | 0.5776 | 1.610869 |
| 8.23 | 9.58 | -2.23 | 1.55 | 4.9729 | 2.4025 | 11.94739 |
| 10.37 | 10.2 | -0.09 | 2.17 | 0.0081 | 4.7089 | 0.038142 |
| 13.2 | 10.9 | 2.74 | 2.87 | 7.5076 | 8.2369 | 61.83935 |
| 10.93 | 9.58 | 0.47 | 1.55 | 0.2209 | 2.4025 | 0.530712 |
| 10.1 | 12.1 | -0.36 | 4.07 | 0.1296 | 16.5649 | 2.146811 |
| 8.63 | 10.9 | -1.83 | 2.87 | 3.3489 | 8.2369 | 27.58455 |
| 7.14 | 7.14 | -3.32 | -0.89 | 11.0224 | 0.7921 | 8.730843 |
| 6.605 | 6.6 | -3.855 | -1.43 | 14.86103 | 2.0449 | 30.38931 |
| 10.48 | 10.5 | 0.02 | 2.47 | 0.0004 | 6.1009 | 0.00244 |
| 15.11 | 15.1 | 4.65 | 7.07 | 21.6225 | 49.9849 | 1080.799 |
| 9.72 | 9.72 | -0.74 | 1.69 | 0.5476 | 2.8561 | 1.564 |
| 10.14 | 10.1 | -0.32 | 2.07 | 0.1024 | 4.2849 | 0.438774 |
| 8.51 | 8.51 | -1.95 | 0.48 | 3.8025 | 0.2304 | 0.876096 |
| 11.17 | 11.2 | 0.71 | 3.17 | 0.5041 | 10.0489 | 5.06565 |
| 15.33 | 1.5 | 4.87 | -6.53 | 23.7169 | 42.6409 | 1011.31 |
| 12.09 | 2.5 | 1.63 | -5.53 | 2.6569 | 30.5809 | 81.25039 |
| 10.55 | 1.6 | 0.09 | -6.43 | 0.0081 | 41.3449 | 0.334894 |
| 9.11 | 3.56 | -1.35 | -4.47 | 1.8225 | 19.9809 | 36.41519 |
| 8.79 | 2.1 | -1.67 | -5.93 | 2.7889 | 35.1649 | 98.07139 |
| 8.23 | 2.3 | -2.23 | -5.73 | 4.9729 | 32.8329 | 163.2747 |
| 10.37 | 3.96 | -0.09 | -4.07 | 0.0081 | 16.5649 | 0.134176 |
| 13.2 | 3.2 | 2.74 | -4.83 | 7.5076 | 23.3289 | 175.144 |
| 10.93 | 4.2 | 0.47 | -3.83 | 0.2209 | 14.6689 | 3.24036 |
| 10.1 | 3.52 | -0.36 | -4.51 | 0.1296 | 20.3401 | 2.636077 |

Coefficient of correlation Surface Roughness (r)= 0.7208

Where,

$$x = \text{Experimental data of Surface Roughness}$$

$$y = \text{Simulated data of Surface Roughness}$$

$$X. = x - \bar{x}$$

$$Y. = y - \bar{y}$$

$$\bar{x} = \sum \frac{x}{n}$$

$$\bar{y} = \sum \frac{y}{n}$$

$$n = \text{Number of Experiments in Surface Roughness}$$

$$r = \frac{\sum xy}{\sqrt{(\sum x^2)(\sum y^2)}}$$

r = relation between two quantities in Surface Roughness

## VI CONCLUSION

From the above experimentation and results it can be concluded that in case of Material Removal Rate (MRR) the main objective is to maximize the MRR.so, to obtain maximized MRR the optimum set of input parameters required is FT-1.016 mm, AMFR-0.25 lbs./min, SOD-0.5 mm and FR-100 mm/min. In case of surface roughness, the main target is to minimize the surface roughness so, to obtain minimum surface roughness the optimized set of input parameter required is FT-0.534 mm, AMFR-0.25 lbs./min, SOD-1.5 AND FR-100 mm/min. In can also be observed that as the FT increases, The MRR also maximizes. In case of surface roughness FR required will be low so as to obtain high surface finish; Due to low FR the time required for cutting also increases. AMFR and FT also plays an important role in case of minimization of kerf width. It can also be concluded that as the stand of distances increases kerf width decreases, but, also the cutting speed reduces resulting in increase in production time. The proposed hybrid approach based on Artificial Neural Networks and Taguchi methodology was used for AWJM mean kerf width and surface roughness modelling purpose. The Taguchi approach was used in order to optimized the experimental effort without losing the prediction accuracy of the ANN model. The acquired results indicate that the proposed modelling approach could be effectively used to predict the kerf geometry and the surface roughness in AWJM, thus supporting the decision-making during process planning From above calculations and observation our correlation of coefficient of MRR (r)= 0.8055 and surface roughness (r)= 0.7208. And correlation of coefficient is always between 0 to 1. So, our calculations and observations are verified.

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