ADAPTIVE NEURO FUZZY INFERENCE SYSTEM (ANFIS) MODELING OF THRUST FORCE IN DRILLING PARTICLE BOARD (PB) COMPOSITES

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ABSTRACT

Delamination is a significant problem, associated in drilling particle board, which reduces the structural integrity of the material, results in poor assembly tolerance and long term performance deterioration. The key in solving this problem lies in reducing thrust force during drilling. A fuzzy rule based model is developed with and without sub clustering by varying the input parameters- spindle speed, feed rate and drill diameter to predict thrust force in drilling particle board. The experiments were planned as per L_{27} Taguchi orthogonal array, for these three parameters in three levels. Fuzzy rules were written based on the experimental values and were defuzzified by the Adaptive Neuro Fuzzy Inference System (ANFIS) in MATLAB. The effect of spindle speed, feed rate and drill diameter on thrust force and their interaction effects are studied.

Keywords: Particle board, Drilling, Composites, ANFIS, Thrust force, Modeling, Taguchi design of experiments.

I. INTRODUCTION

Machining of composite materials have gained emphasis for product development and manufacturing. Since drilling is the primary operation in most of the secondary machining for wood composites, delamination is the major concern of the quality of the product. Investigators have studied experimentally that delamination is drilling is dependant on thrust force during the exit of the drill (3, 4). There exists a critical thrust force below which no delamination occurs (5). Hocheng and Dharan (6) have used linear elastic fracture mechanics to find the critical thrust force that relates the delamination of composite materials to drilling parameters and material properties.

Fuzzy logic theory is one of the most active and innovative area of research in engineering application, especially in the field of industrial processes (1). Fuzzy set theory is used to analyze complex systems with great ease which gives a considerable approximation of the parameters (2). MATLAB environment is used for modeling, identification and validation of system under consideration. Jagdev et al (9) have described fuzzy modeling and mathematical analysis for the intelligent control of the compressor in order to regulate refrigerant mass flow in vapour compression refrigeration system. Jang (10) has presented the architecture and learning procedure underlying ANFIS.

II. THE DRILLING PROCESS

Particle fiber board of 9 mm thickness manufactured by ASIS India Ltd., is taken for the study. The drill bits used are spade carbide drills of diameters 6, 9 and 12 mm. The spade drill bit is a very commonly used tool for rough drilling in wood and wood based products. They tend to cause splintering when they emerge from the work piece. They are flat, with a centering point and two cutters. The cutters often are equipped with spurs in an attempt to ensure a cleaner hole. With their small shank diameters relative to their boring diameters, spade bit shanks often have flats forged or ground into them to prevent slipping in drill chucks. The spade bits yield lower thrust and torque over the whole range of pragmatic operating conditions. Fig 1 shows the spade drill bits.

Fig. (a) 12 Diameter Spade drill bit

Fig. (b) 9 Diameter Spade drill bit

Fig. (c) 6 Diameter Spade drill bit

Fig. 1. Spade Carbide drill bits,

Fig 2. Drilling set up

Experiments were conducted on ARIX Vertical Machining Centre and the thrust force for various cutting conditions was measured using Kistler dynamometer. The drilling set up of particle board on the machining centre is shown in Fig 2. The parameters considered for the study are spindle speed, feed rate and drill diameter. Three levels of each parameter is chosen for the study as shown in Table 1.

Table 1. Drilling parameters and levels

Parameters	**Levels**		
	1	**2**	**3**
SPINDLE SPEED (*N*) rpm	1000	3000	5000
FEED RATE (*f*) mm/min	100	300	500
DRILL DIAMETER (*d*) mm	6	9	12

III. Taguchi Design of experiments

Taguchi's orthogonal arrays are highly fractional designs, used to estimate main effects with a few experimental runs. The steps involved in this study using this method can be summarized as follows.

- Identify the quality characteristics and process parameters to be evaluated.
- Determine the number of levels for the process parameters and possible interactions between the process parameters.
- Select the appropriate orthogonal array and assign the process parameters to the orthogonal array.
- Conduct the experiments based on the arrangement of the orthogonal array.
- Create a mathematical model and validate the same.
- Compute the appropriate summary statistics and analyze the experimental results
- Select the optimal levels of process parameters.

Taguchi L_{27} Orthogonal array is chosen for three parameters and three levels. Table 2 gives the experimental thrust force for different combination of levels of the parameters.

IV. Fuzzy logic in drilling

Fuzzy logic reflects the qualitative and the inexact nature of human reasoning, makes it possible to cope with uncertain and complex systems, which are difficult to model mathematically. In fuzzy modeling, practical situations can be transformed into a form, where decision making rules can be applied. Further it takes many factors into account without incurring undue complexity.

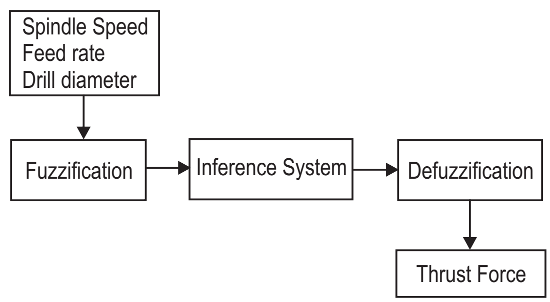

Fig. 3. Block diagram of the fuzzy control system for drilling particle board.

Fig 3 shows the schematic representation of the fuzzy control system with the input parameters and the output response. The force exerted on the work piece is measured by varying the input parameters- spindle speed, feed rate and drill diameter. Fuzzification is resolving all the fuzzy statements into a degree of membership. Inference system analyses the input membership functions based on the Boolean operators specified in the rules and the weights given to each rule. Defuzzification transforms the output of the inference system as a single output model.

A. Sugeno Fuzzy Inference System

There are two types of fuzzy inference system that can be applied in a fuzzy logic toolbox of MATLAB-Mamdani and Sugeno. Mamdani greatly simplifies the

Table 2. Taguchi L_{27} Orthogonal array with experimental and predicted Thrust force

Exp No	Speed (rpm)	Feed (mm/min)	Drill Diameter (mm)	Experimental Force(Fz) in N	Predicted Force (Fz) without suclustering in N	Predicted Force (Fz) with suclustering in N
1	1000	100	6	66.16	66.2	66.1
2	1000	100	9	63.01	63.0	63.0
3	1000	100	12	88.27	88.3	88.2
4	1000	300	6	84.33	84.3	84.4
5	1000	300	9	80.99	81.0	81.0
6	1000	300	12	106.26	106.0	106.3
7	1000	500	6	99.07	99.1	99.1
8	1000	500	9	83.02	83.0	83.0
9	1000	500	12	114.02	114.0	114.0
10	3000	100	6	56.0	56.0	56.00
11	3000	100	9	54.81	54.8	55.10
12	3000	100	12	81.45	81.4	81.5
13	3000	300	6	79.52	79.5	79.5
14	3000	300	9	59.43	59.4	59.3
15	3000	300	12	79.1	79.1	78.8
16	3000	500	6	73.08	73.1	73.2
17	3000	500	9	63.07	63.1	62.7
18	3000	500	12	91.5	91.5	91.5
19	5000	100	6	43.82	43.8	43.4
20	5000	100	9	42.37	42.4	42.2
21	5000	100	12	68.73	68.7	68.6
22	5000	300	6	54.77	54.8	54.4
23	5000	300	9	51.53	51.5	51.5
24	5000	300	12	67.77	67.8	67.7
25	5000	500	6	53.16	53.2	53.6
26	5000	500	9	55.32	55.3	55.1
27	5000	500	12	75.36	75.4	74.9

computation required by finding the centroid of a two dimensional function. Rather than integrating across the two-dimensional function to find the centroid, weighted average of a few data points are found using Sugeno-type systems. In general, Sugeno-type systems can be used to model any inference system in which the output membership functions are either linear or constant. ANFIS editor is used to create, train and test the sugeno fuzzy system. ANFIS learns information about the data set and computes the membership function parameters using the given input/output data. This learning method is similar to that of neural networks which maps inputs through input membership functions and associated parameters, and then through output membership functions and associated parameters to outputs, can be used to interpret the input/output map.

The parameters associated with the membership functions will change through the learning process. The computation of these parameters is facilitated by a gradient vector, which provides a measure of how well the fuzzy inference system is modeling the input/output data for a given set of parameters. Once the gradient vector is obtained, any of several optimization routines could be applied in order to adjust the parameters so as to reduce some error measure. For membership function parameter estimation, hybrid system is used which uses least square estimation and back propagation.

B. Design of Fuzzy Inference System

Generally ANFIS produces a Fuzzy Inference System (FIS) structure based on a fixed number of membership functions. This causes an explosion of a number of rules when the number of inputs is more than four or five. FIS can also be generated using subtractive clustering. This subtractive clustering method partitions the data into groups called clusters, and generates an FIS with the minimum number rules required to distinguish the fuzzy qualities associated with each of the clusters. Modeling is done using sub clustering and without sub clustering. The subtractive clustering method assumes each data point is a potential cluster center and calculates a measure of the likelihood that each data point would define the cluster center, based on the density of surrounding data points.

Number of nodes: 222

Number of linear parameters: 108

Number of nonlinear parameters: 162

Total number of parameters: 270

Number of training data pairs: 27

Number of checking data pairs: 0

Number of fuzzy rules: 27

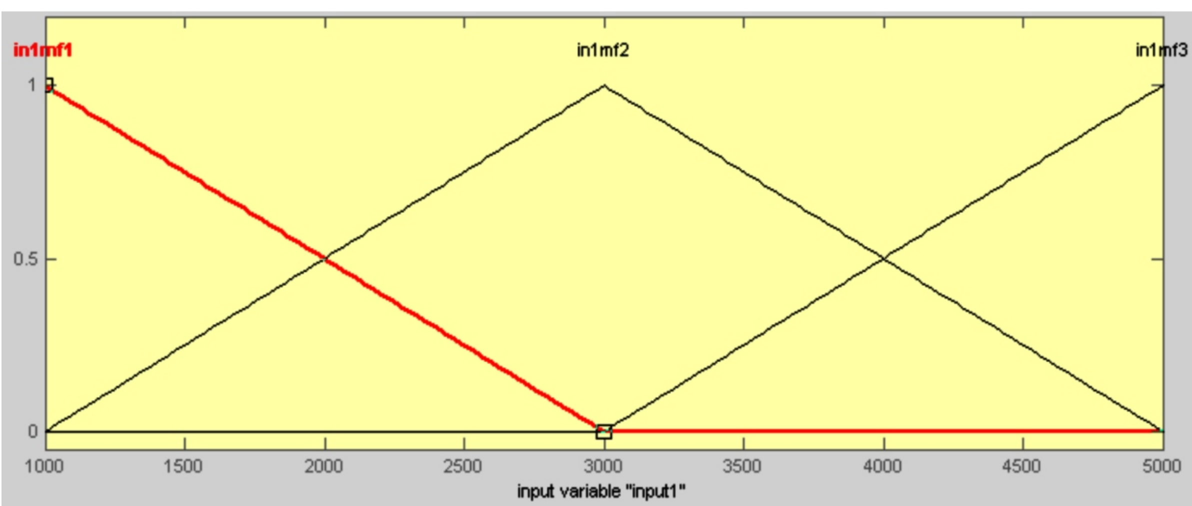

Fig. 4. Input membership functions(speed) without sub clustering

Fig 4. Shows the input membership function for speed without subclustering and Fig 8 shows with subclustering. The membership function chosen is triangular membership function. Then the 27 experimental values of thrust force (shown in Table 2) are given as input values and ANFIS is trained as shown in Fig. 5 and Fig 9. Fuzzy rules serve to describe the qualitative relationship between variables in linguistic terms. Our rules have 3 inputs and a single output, and then the general format of the rules generated is

$$\text{If } X_1 \text{ is } A_{1j},\ X_2 \text{ is } A_{2j},\ X_3 \text{ is } A_{3j} \text{ then } Y \text{ is } B_j$$

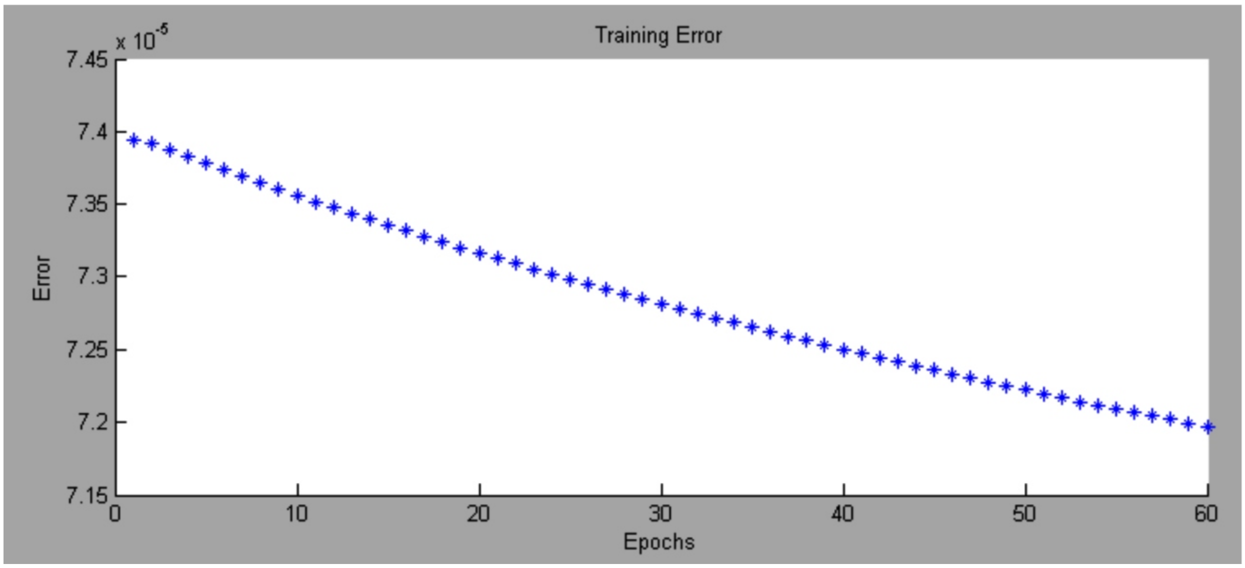

Fig 5. ANFIS editor trained with the experimental values

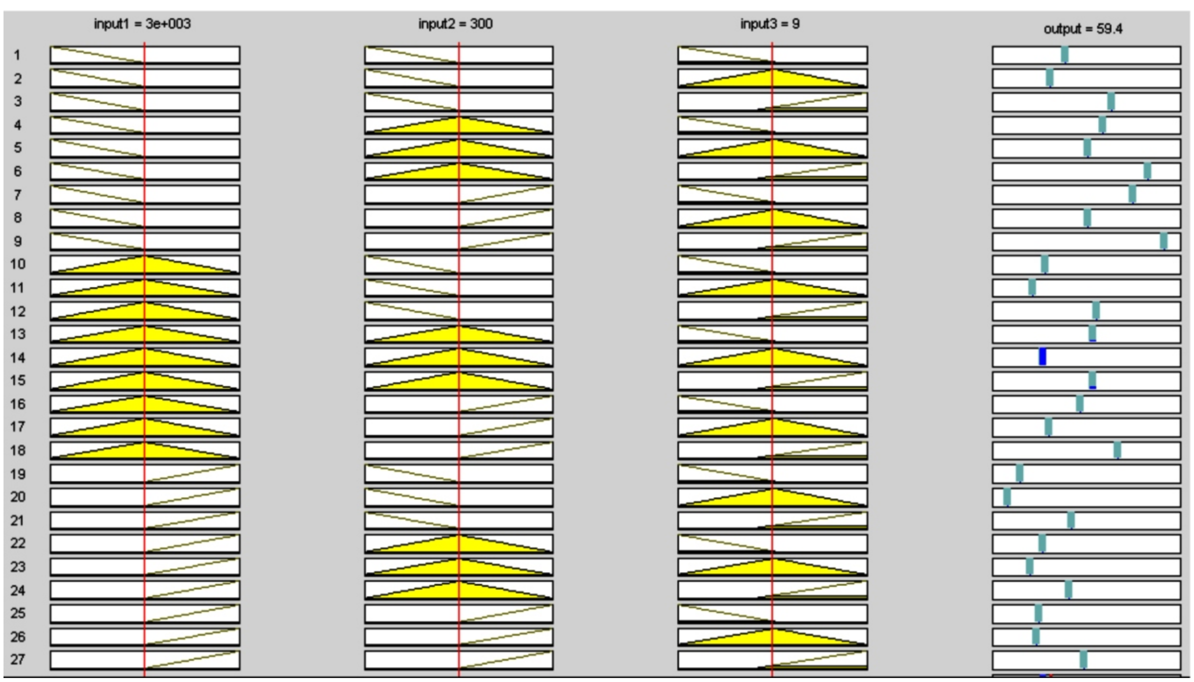

Fig. 6. Twenty seven rule base with membership functions without subclustering

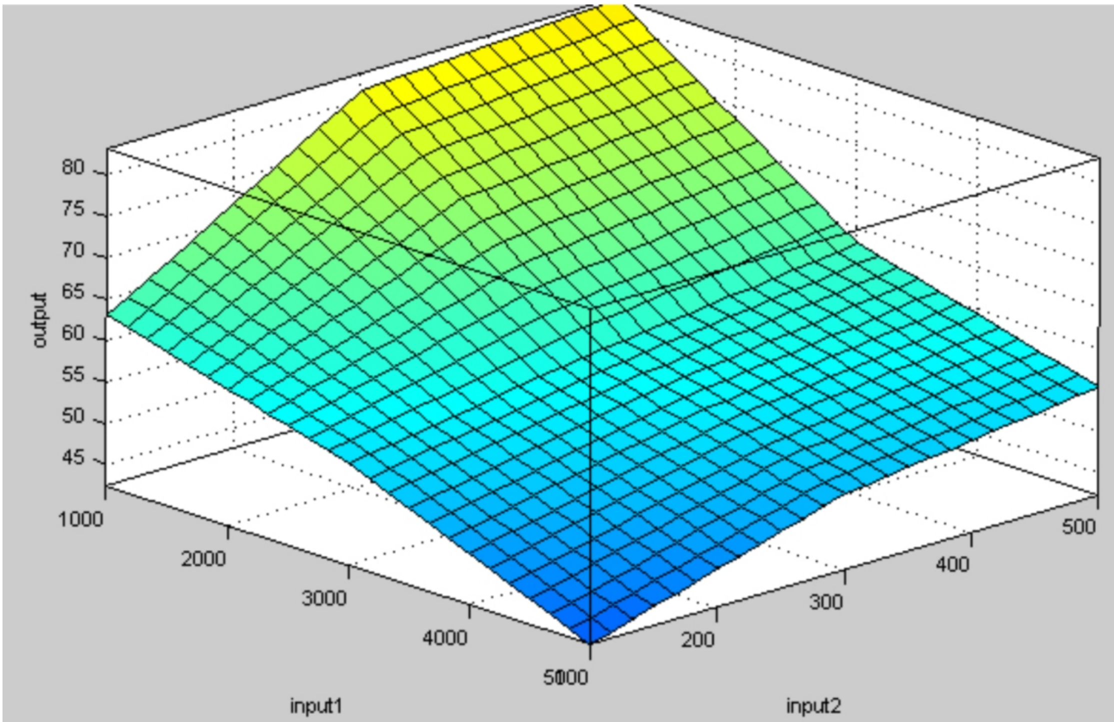

Fig. 7. Control surface without subclustering

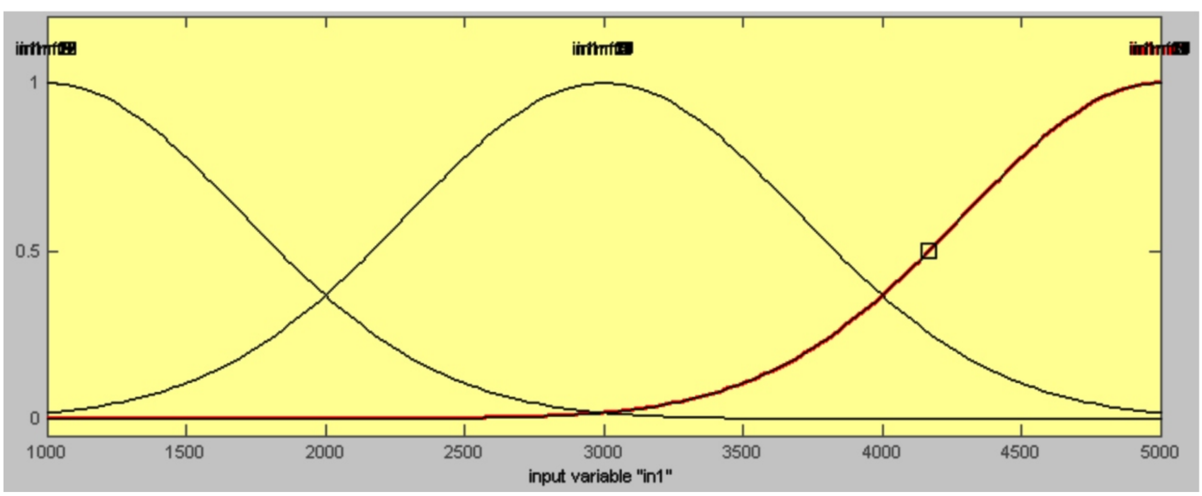

Fig. 8. Input membership functions(speed) with subclustering

Where A_{1j} ,A_{2j} , A_{3j} are the fuzzy sets of the linguistic variables X_1, X_2, X_3 respectively and Bj is called the set of output linguistic variable Y. As 27 inputs are given 27 rules are created which is shown in Fig 6 and Fig 10. The 3D surface plot shown in Fig

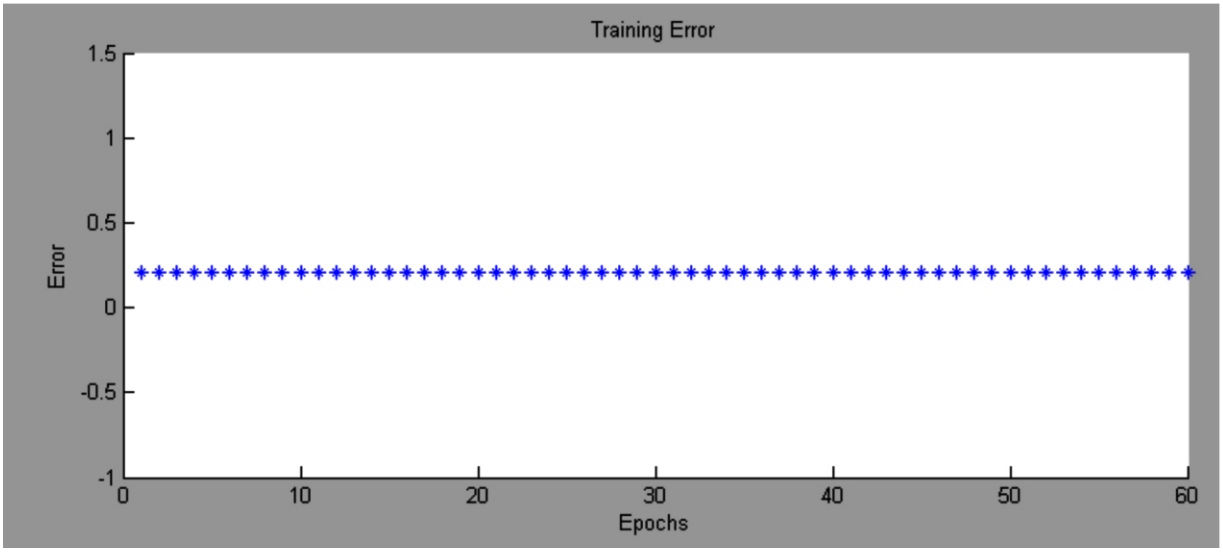

Fig 9. ANFIS editor trained with experimental values

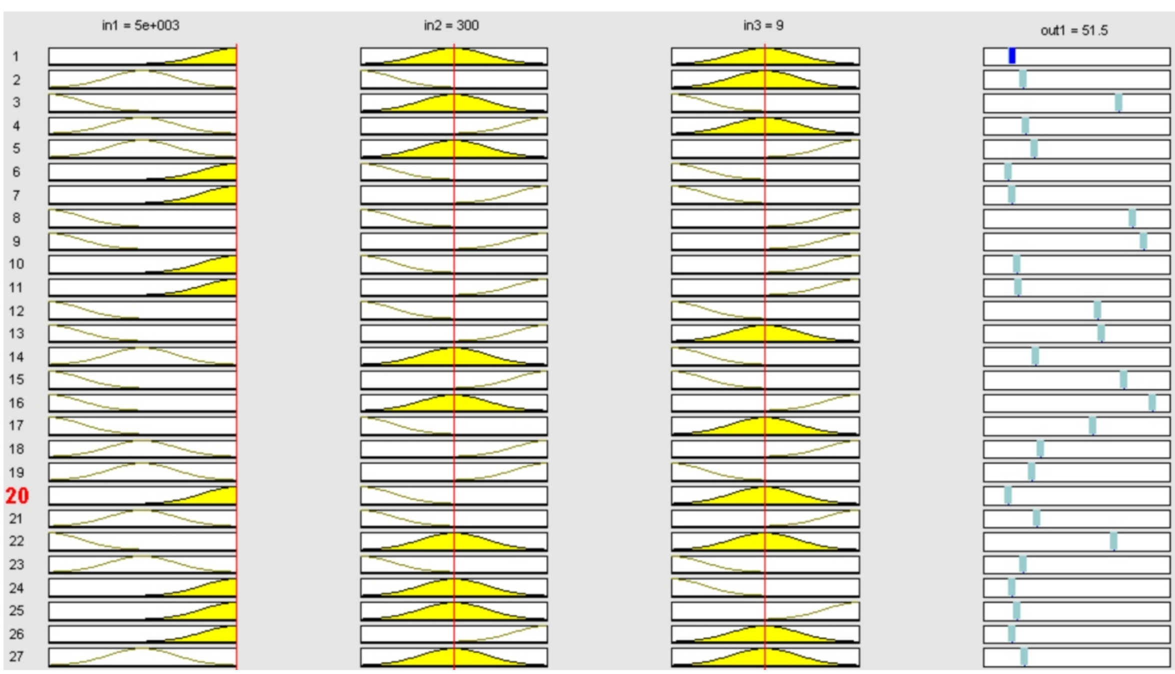

Fig. 10. Twenty seven rule base with membership functions with subclustering

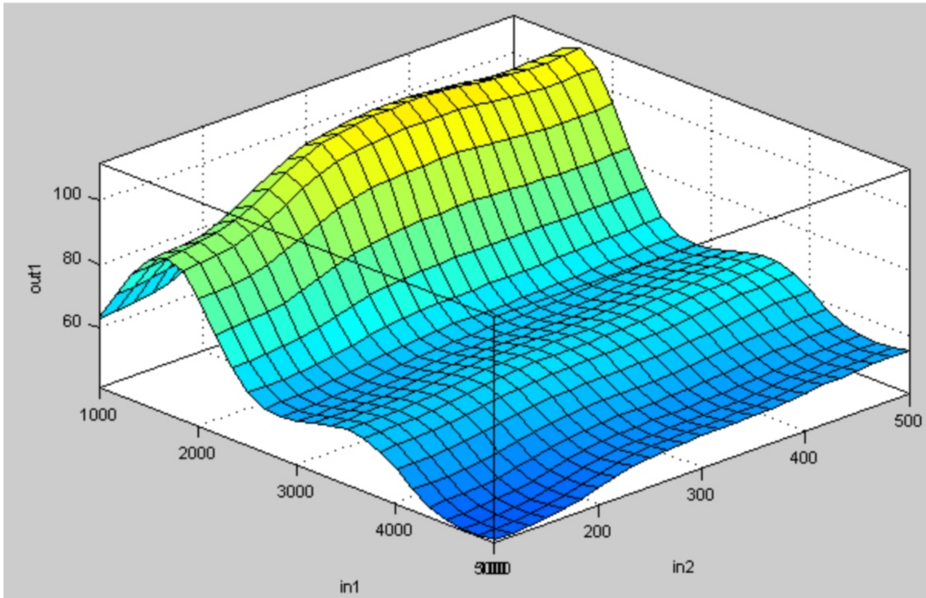

Fig. 11. Control surface with subclustering

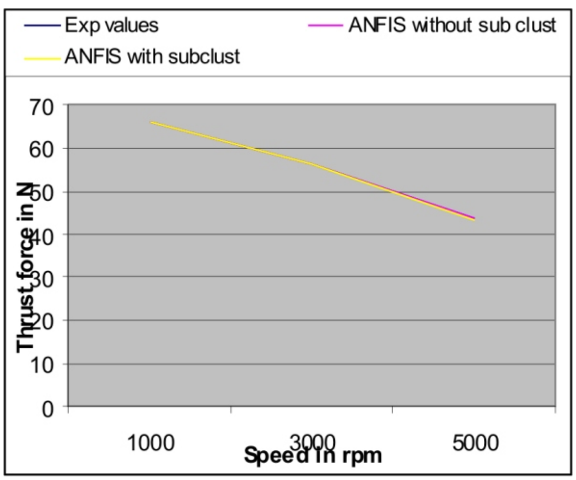

Fig. 12. Thrust force at different speeds when f=100 mm/min, d=6 mm

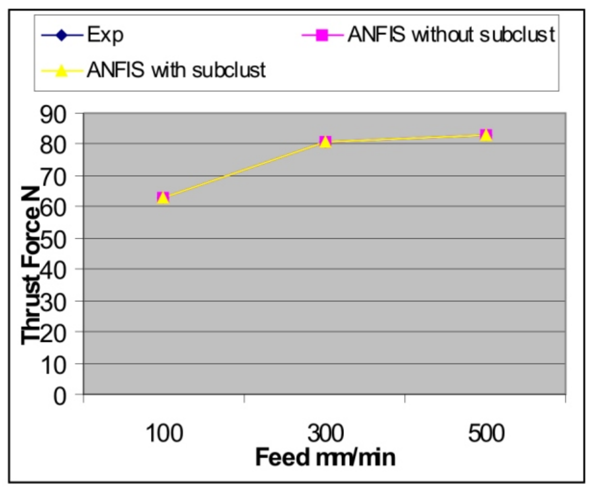

Fig 13. Thrust force at different feed rates when speed=1000 rpm and d=9 mm.

7 and Fig 11 shows the output response for a combination of any two inputs.

V. VALIDATION OF ANFIS MODELING

The 27 input combinations of speed, feed and drill diameter are fed in fuzzy as a query to validate the model. The values got through ANFIS with and without subclustering are shown in Table 2. With subclustering model seems to deviate a little away from the experimental values in the order of +/- 0.02%, shown in Fig 9. Without subclustering seem to well merge with the experimental values with almost nil error percent. The comparison in the values of thrust force obtained through experimental and ANFIS at different cutting conditions are shown in Fig.12 and Fig.13.

VI. CONCLUSION

An ANFIS model with and without subclustering to predict thrust force in drilling particle board was developed. It can be inferred that both subclustering and without subclustering model holds good for the prediction of thrust force with minimum error.

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