ANFIS and RSM Modelling Analysis on Surface Roughness of PB Composites in Drilling with HSS Drills

T. N. Valarmathi, K. Palanikumar, S. Sekar, and B. Latha

1 Introduction

Nowadays Particleboard (PB) is used in interior decorative applications. Particleboard panels have been fabricated using wood waste particles. As it is a low cost material it replaces wooden boards or plywood in less strength requirement applications. Wood is a natural composite also known as engineered wood are fiber-reinforced polymers. These are made by adding a little amount of adhesives and additives with wood elements such as fibers, particles, flakes, veneers and laminates. Wood composite panels are available as plain, pre-laminated, interior and exterior grades. High strength, light weight, low cost, usage of waste wood and smaller diameter trees and their flexibility in making different shaped products, free from defects and aesthetic appearance are some of the features of wood composites. Wood composite panels are widely replacing the traditional wood or steel and

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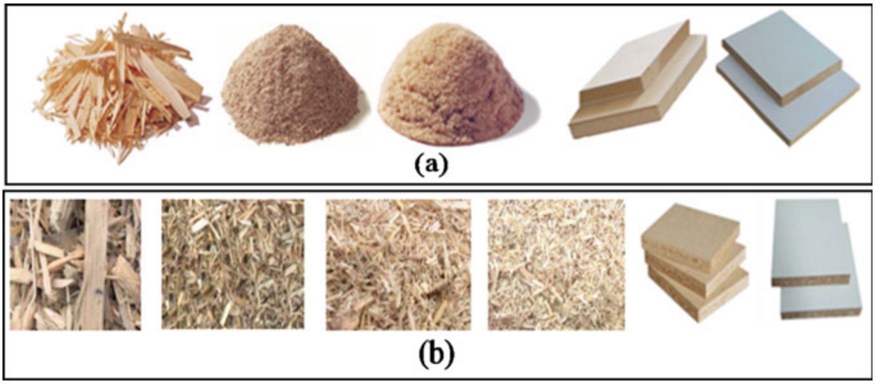

Fig. 1 Sample of wood fibers and particles used for **a** MDF and **b** PB panels

greatly reducing the demand for plywood. They are used in furniture industries, interior and exterior construction and structural applications and domestic appliances. Wood based composites products are light weight but have similar levels of strength, free from defects, uniform and aesthetic. Figure 1 is the sample of wood fibers and particles used for MDF and PB panels.

Wood composite panels are available as plain and pre-laminated MDF, plain and pre-laminated Particleboard, plain and pre-laminated Hardboard. Pre-laminated boards are available as one side or both side laminated, interior and exterior grades. MDFs are used in industries for manufacturing furniture, fixtures, modular kitchens, partitions, cabinetry, flooring, architectural millwork and moldings, doors, interiors, wood carvings, domestic appliances, toys, architectural components, etc., because of their smooth surfaces, rigid edges and superior machinability properties.

Particleboard has been a staple building material and used in the manufacturing of wall partitions, computer tables, interiors, false ceiling, wall lining, etc. Particle board is popularly used as a building material as it is cheaper, eco-friendly and available in varieties. Particle board is used as a flooring material, flooring underlayment, wall partitions, wall panels, false ceilings, ceiling tiles, core material in doors, and furniture industry (Fig. 2).

Machining is the most important process in product manufacturing industries for the removal of extra unwanted material using sawing, turning, milling, drilling, etc. Machining is carried out using traditional, computer controlled machine tools and different forms of energy to machine complex profiles, to obtain high dimensional accuracy and good surface finish, etc. Initially the composites were machined as metals and alloys leads to poor surface quality and tool wear. Hence further development is introduced in composite machining with special working conditions to obtain the optimum results.

Drilling is an extensively used machining operation in the final product assembly. Drilling produces better surface finish but milling is found to be good for economic and environmental sustainability considerations [1]. Modelling and optimization

Fig. 2 Typical applications of Particleboard

techniques are used for optimizing the machining parameters on surface roughness [2]. The parameters were optimized using regression model and Genetic algorithm in machining of hybrid composites [3]. Research works reported the consequence of machining parameters and geometry of tool on surface characteristics of wood composite panels [4–7, 15, 21] during various machining processes. ANFIS model has been successfully applied and revealed that the developed model is effective for predicting the surface roughness [5].

The impact of turning parameters and HSS drill with and without TiN coating on the characteristics of wood plastic composite has been analyzed and revealed that the sticking of particles is less in HSS than coated HSS [8, 9]. ANFIS can be effectively used for analysing the responses [10]. Process Parameters have been optimized in drilling of Delrin using Neural Network [11]. Influence of parameters are analyzed [12]. The influence of parameters on delamination in drilling is analyzed [13]. The drilling parameters have been optimized in drilling of self- healing GFRP [14]. The machining processes on the surface qualities of lumber and red pine has been reported [16, 17]. A multi-objective based optimization is applied to achieve the optimum solution in machining of Polytetrafluoroethylene [18, 19]. Feed and point angle have contribution in drilling of MDF [20].

Modelling and optimization techniques like RSM, Taguchi are used [21]. Surface roughness in drilling of MDF is analyzed using Taguchi [22]. Effect of drilling of coated composites has been analyzed [23]. Multiple-response optimization and ANOVA has been used to achieve good surface quality and metal removal rate at the same time [24]. The input parameters are optimized using Taguchi and ANOVA techniques [25]. The magnitude of torque can be determined by the drill diameter and the cutting force [26]. Taguchi and RSM methods were useful tools in predicting the effect of parameters [27–30]. The surface roughness has been analyzed in electric discharge machining of H12 tool steel and in drilling of PB [31, 32].

From literature it is asserted that the quality depends upon the surface characteristics. But the surface quality is depending on the input parameters, tool geometry, and type of tool material. Hence the evaluation of impact of parameters during drilling is essential to improve the quality. In this work the HSS twist drills have been used to analyze the surface roughness (Ra) in drilling of PB.

2 Materials and Measurements

2.1 Plan of Experiments

The experiments are carried out on 12 mm thick particle board panels using HSS twist drills in a CNC vertical machining center (Fig. 3). Table 1 shows the parameters

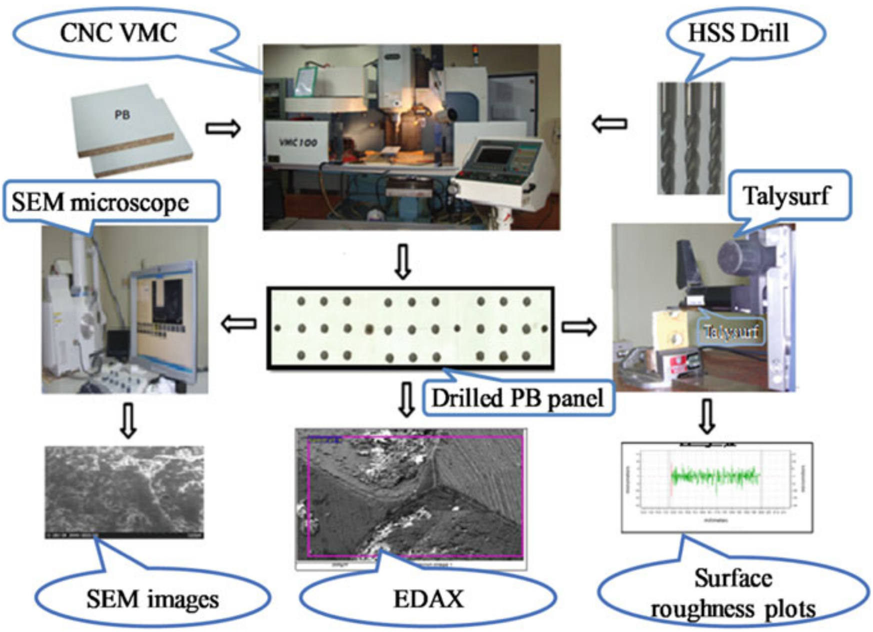

Fig. 3 Experimental arrangement

Table 1 Machining parameters used

Levels	Parameters		
	Speed (N) (rpm)	Feed (f) (mm/min)	Point angle (φ) (degrees)
1	1000	75	100
2	3000	150	118
3	5000	225	135

and levels.

2.2 Measurement of Surface Roughness

The surface roughness values (Table 2) were evaluated using Taylor Hobson meter for the analysis.

Table 2 Results and S/N ratio

Trial no.	N	f	φ	Ra	S/N Ratio
1.	1000	75	100	13.54	−22.6324
2.	1000	75	118	21.11	−26.4898
3.	1000	75	135	22.49	−27.0398
4.	1000	150	100	19.56	−25.8274
5.	1000	150	118	24.32	−27.7193
6.	1000	150	135	25.56	−28.1512
7.	1000	225	100	25.04	−27.9727
8.	1000	225	118	27.92	−28.9183
9.	1000	225	135	28.34	−29.048
10.	3000	75	100	11.14	−20.9377
11.	3000	75	118	16.52	−24.3602
12.	3000	75	135	17.76	−24.9889
13.	3000	150	100	12.56	−21.9798
14.	3000	150	118	21.94	−26.8247
15.	3000	150	135	24.33	−27.7228
16.	3000	225	100	25.63	−28.175
17.	3000	225	118	25.94	−28.2794
18.	3000	225	135	28.02	−28.9494
19.	5000	75	100	9.36	−19.4255
20.	5000	75	118	11.62	−21.3041
21.	5000	75	135	14.68	−23.3345
22.	5000	150	100	12.31	−21.8052
23.	5000	150	118	18.04	−25.1247
24.	5000	150	135	24.86	−27.91
25.	5000	225	100	23.11	−27.276
26.	5000	225	118	26.04	−28.3128
27.	5000	225	135	26.97	−28.6176

3 Method of Analysis

3.1 Response Surface Methodology (RSM)

RSM is a statistical method process used for developing mathematical model equation to predict the response values using experimental data. The Eq. (1) used is as

$$Y = f(X1, X2, \ldots, XK) \quad (1)$$

The general polynomial response equation in matrix form is given in Eq. (2) as

$$Y = X\beta + \varepsilon \quad (2)$$

3.2 Adaptive Neuro Fuzzy Inference System (ANFIS)

ANFIS combines ANN and a fuzzy logic of artificial intelligence concept to get the advantages and to eliminate the disadvantages of both techniques. In Fig. 4 ANFIS Architecture (Fig. 4) for three inputs and one output with 3 different membership functions used are presented. Training in ANFIS is performed for number of iterations containing 10, 40, 70 and 100 epochs. Three membership functions are chosen for each input to reduce the error. Generated rules are 27.

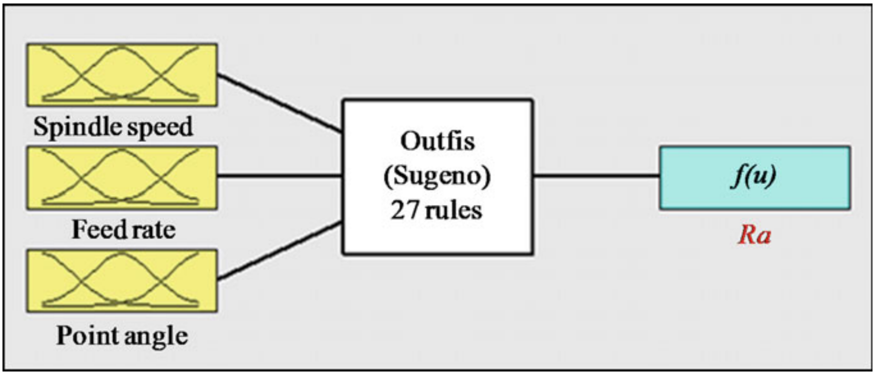

Fig. 4 Sugeno-type FIS model

4 Results and Discussion

Drilling is normally used operation in furniture industries. Drilling defects like surface roughness can be optimized by understanding the influence of input parameters. In this work, the empirical relationship between input and output variables are developed using RSM and ANFIS.

4.1 RSM Analysis

The Table 3 presents the summary of models and the (R2 = 0.94) for quadratic. The quadratic model equation is given in Table 4. Results obtained presented in Table 5 for some of the experiment runs, reveals that the model has good predictive ability.

The normal probability plot and the correlation graph for predicted and actual surface roughness are presented in Figs. 5, 6 and 7. The plots indicate that the deviation is very less.

The surface plots illustrate how the response parameter relates to two input factors on the basis of mathematical model equation. Figure 7a indicates the interaction effects between point angle and spindle speed on surface roughness. It explains that low point angle and high speed is the preferred combination. The low feed and high speed combination reduces the roughness as shown in Fig. 7b. The effect of point angle and feed on the roughness is shown in Fig. 7c. For minimum surface roughness, a smaller point angle, low feed and smaller point angle combination gives better performance.

Table 3 Model summary

Source	Standard Deviation	R-Squared	Adjusted R-Squared	Predicted R-Squared	Press
Linear	2.09	0.8938	0.8799	0.8533	138.00
2FI	1.82	0.9298	0.9088	0.8741	118.50
Quadratic	1.82	0.9400	0.9082	0.8487	142.44

Table 4 RSM model equation

Response	Model Expression	R^2
Ra	$-62.4367-0.00403585{*}N + 0.106691{*}f + 1.12666{*}\varphi + 9.98611E\text{-}08{*}N^2 + 8.1679E\text{-}05{*}f^2 - 0.00361365{*}\varphi^2 + 9.05556E\text{-}06{*}N{*}f + 8.01007E\text{-}06{*}N{*}\varphi - 7.23939E\text{-}04{*}f{*}\varphi$	94.0%

Table 5 Results of experimental, predicted values and residual error

Std order	Actual Ra	Predicted Ra	Residual	Leverage	Run order
1	25.04	24.85	0.19	0.512	7
2	11.14	10.36	0.78	0.344	10
3	24.33	23.10	1.23	0.259	15
4	27.92	28.16	−0.24	0.343	8
5	25.63	23.25	2.38	0.344	16
6	25.94	26.85	−0.91	0.259	17
7	19.56	19.30	0.26	0.344	4
8	28.02	28.10	−0.082	0.341	18
9	21.11	19.94	1.17	0.343	2
10	9.36	6.84	2.52	0.512	19

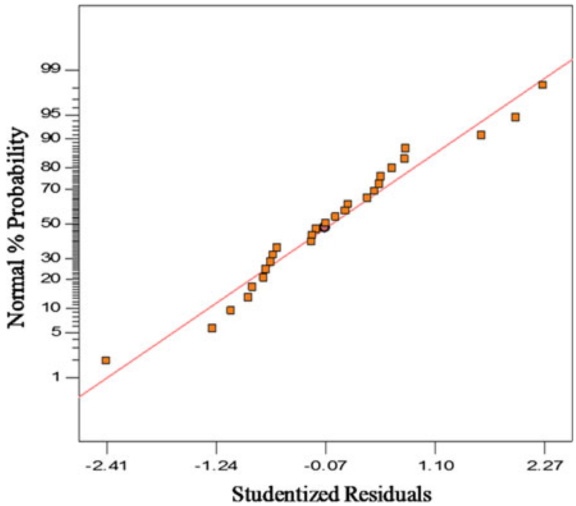

Fig. 5 Normal probability plots for residuals

4.2 *Adaptive-Neuro Fuzzy Inference System (ANFIS) Analysis*

The ANFIS models are developed for the output response considered. To evaluate the ability of the surface roughness model, performance factors such as coefficient of multiple determination, average training error and checking error in percentage, root mean square error (RMSE) for training data and checking data, mean absolute error (MAE) for training data, the co-efficient of determination (R2) values are determined. The error variation (variation in the errors in a set of data) can be diagnosed using MAE and RSME together. The average error in percentage is the average of the differences between actual and predicted values is also considered. The RMSE &

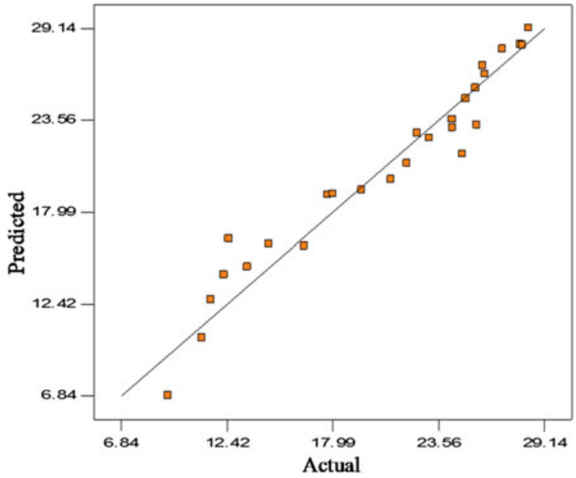

Fig. 6 Correlation graph

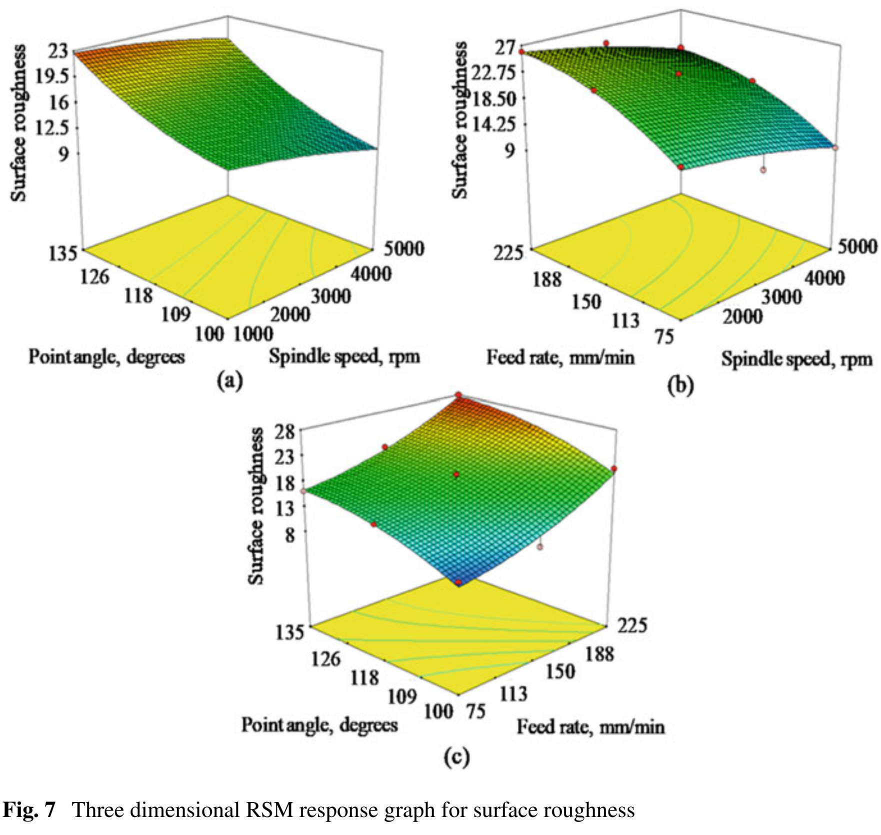

Fig. 7 Three dimensional RSM response graph for surface roughness

MAE and R2 values can be calculated by Eqs. (3), (4) and (5) as:

$$\text{RMSE} = \sqrt{\frac{\sum (x-y)^2}{n}} \tag{3}$$

$$MAE = \frac{\sum |x-y|}{n} \tag{4}$$

$$\text{R}^2 = 1 - \frac{\sum (\text{x}-\text{y})^2}{\sum (\text{x}-\bar{\text{y}})^2} \tag{5}$$

where n-no. of patterns, x, y & $\bar{y}$- actual, predicted and mean of outputs.

Three types of membership functions for modelling the surface roughness of PB panels using the HSS drills are reported. The gaussmf (100 epochs) model shows smallest amount (0.067874%) of average checking error than gbellmf (0.067874%) and Gauss2mf (0.200930). ANFIS surface plots (Fig. 8) of surface roughness show the interaction effects. The required combination in getting minimum roughness is high speed, low feed and smaller point angle.

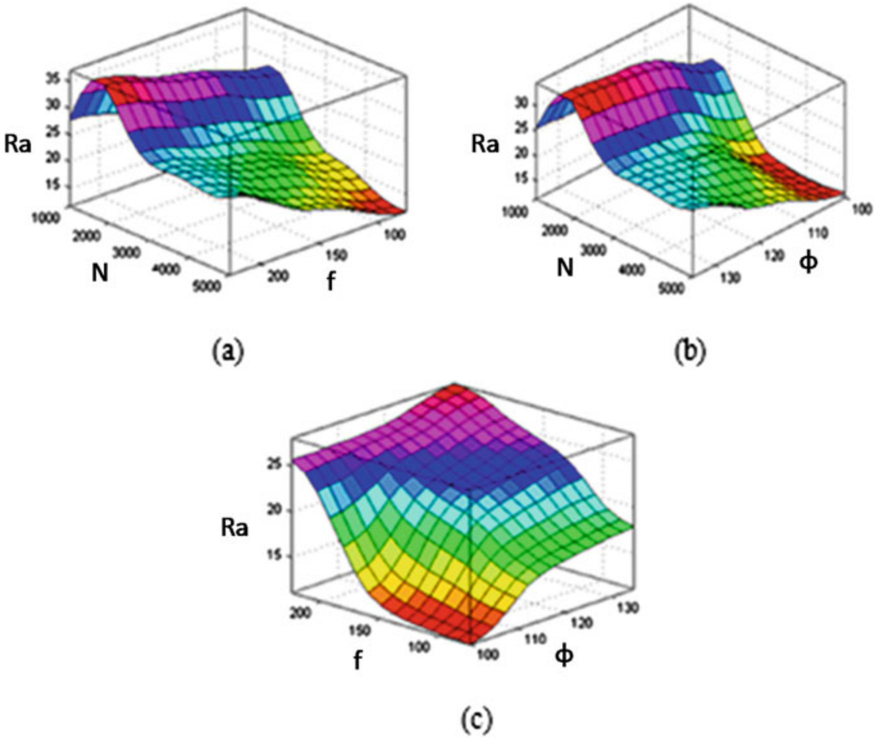

Fig. 8 ANFIS plots

Table 6 ANOVA for surface roughness with HSS drills

Source	DF	Seq SS	Adj SS	Adj MS	F	Percentage contribution
Regression Model	9	884.997	884.997	98.3330	29.580	93.9971
Spindle speed (N)	1	92.8880	93.0940	93.0940	28.000	9.86580
Feed rate (f)	1	542.192	543.908	543.908	163.60	57.5872
Point angle (φ)	1	206.436	205.099	205.099	61.690	21.9259
N * N	1	0.95700	0.95700	0.95700	0.2900	0.10164
f * f	1	1.26700	1.26700	1.26700	0.3800	0.13457
φ * φ	1	7.33400	7.33400	7.33400	2.2100	0.77896
N * f	1	22.1410	22.1410	22.1410	6.6600	2.35164
N * φ	1	0.94300	0.94300	0.94300	0.2800	0.10016
f * φ	1	10.8370	10.8370	10.8370	3.2600	1.15102
Residual Error	17	56.5180	56.5180	3.32500		6.00288
Total	26	941.515				100

4.3 ANOVA Analysis

The F-value 29.58 in ANOVA (Table 6) inferred, the model is being more effect with R2 value of 93.99 with the probability of < 0.0001. The model expressions are satisfactory when the values of "Prob F" is less than 0.0500.

4.4 Control Factors and Their Interaction Effects

PB panels have numerous industrial applications. During the fabrication of PB panel products, the joining using drilled holes are necessary. The drilling of composite panel results in defects like poor surface characteristics, delamination, etc. In this study, for analysing the effect of factors and their interaction RSM and ANFIS modelling have been performed.

The interaction plots (Fig. 9) reveals the Ra (Fig. 9a) is small with smaller point angle and high spindle speed combinations. The increase of feed increases the Ra (Fig. 9b) and it is less for low feed and high speed combinations. The smaller point angle shows reduced surface roughness (Fig. 9c) with low feed combinations in PB panels with HSS drills. The surface roughness established in drilling being abridged with proper combination of factors.

The SEM images of PB (Fig. 10a, b) are taken with higher speed with lower feed and high feed and at low speed and HSS drill (Fig. 11) after drilling.

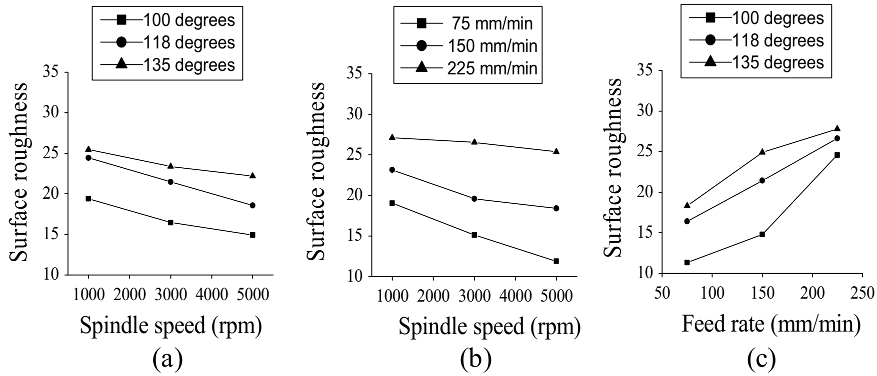

Fig. 9 Interaction effect between the parameters

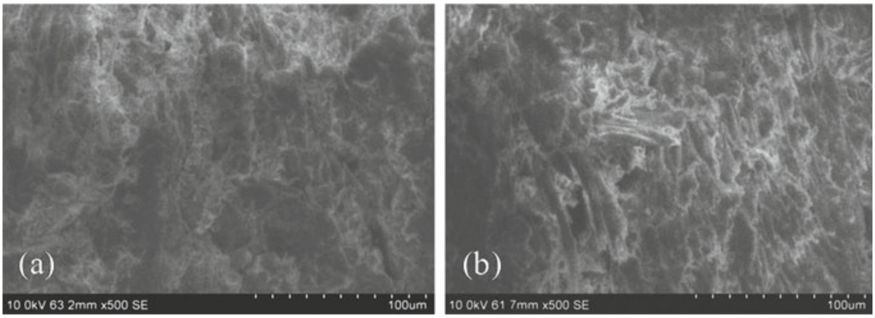

Fig. 10 SEM images at **a** low feed **b** high feed

4.5 Comparison of RSM and ANFIS Models

In the present investigation, for modelling and analysing the performances in the drilling of PB panels, two kinds of modelling technique such as RSM and ANFIS are used and compared (Table 7). The values of R2 for both models are more than 90% and hence these modelling techniques are effectively used for the different performance indicators in the drilling.

From the comparison chart (Fig. 12) shows the relationship of experimental and predicted values of used modelling techniques.

4.6 Confirmation Experiments

The results obtained for the verification tests are presented in Table 8. The test plots for confirming the predicting capability is presented in Fig. 13. The confirmation

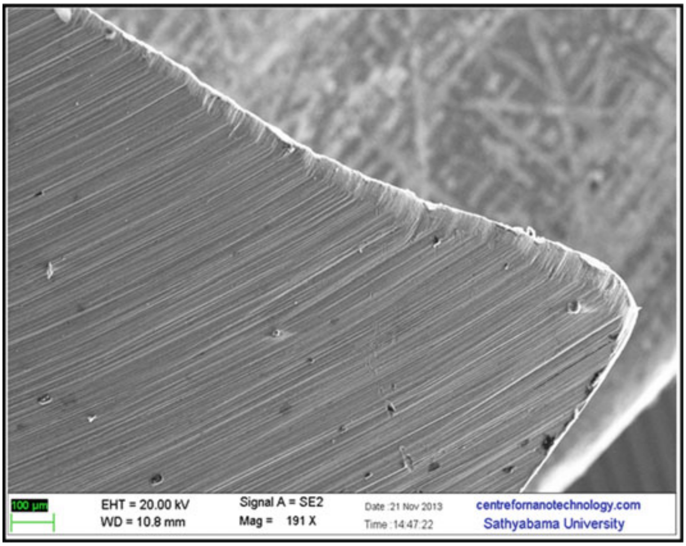

Fig. 11 SEM image HSS twist drill after drilling

Table 7 The predicted R2 values of the models

Response	R2 Value	
	RSM	ANFIS
Surface roughness	0.94	0.999

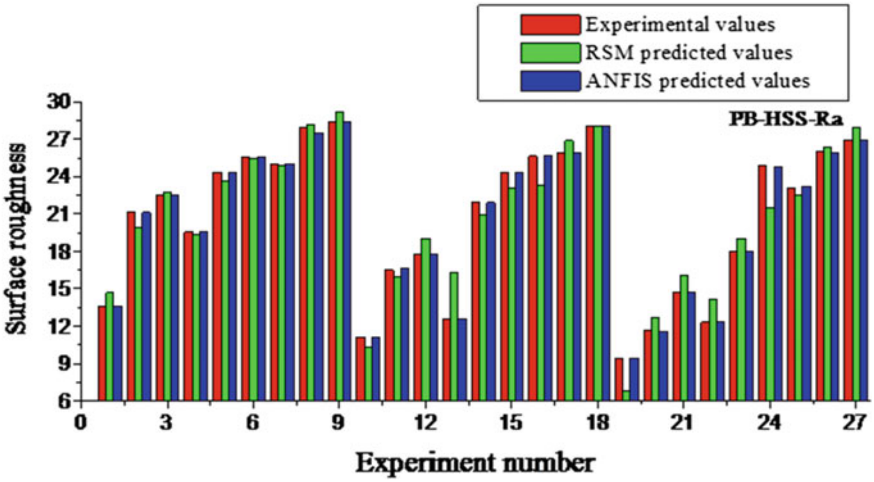

Fig. 12 Comparison plots in drilling PB using HSS Drills

Table 8 Confirmation experiments

Expt. no.	Speed	Feed rate	Point angle	Ra		
				Expt.	RSM	ANFIS
1	2000	75	100	9.46	9.55	9.47
2	4000	75	100	6.82	6.92	6.81

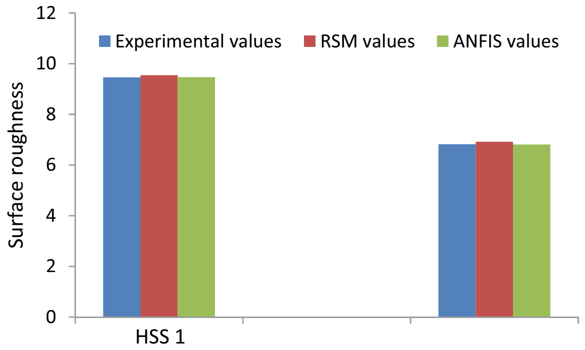

Fig. 13 Validation test plots

experiment test results are in close agreement and hence, the used RSM and ANFIS methods are efficient for predicting the response values in the drilling.

5 Conclusions

Drilling experiments performed on PB using twist drills made of HSS. RSM and ANFIS models are developed. The findings of the research work are

- The developed models are effective in predicting the surface roughness.
- The influence of feed and point angle interaction is more.
- The smaller point angle with low feed rate and high spindle speed combination minimizes the surface roughness in drilling of PB with HSS twist drills.

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