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Experimental Studies on Surface Roughness in Drilling MDF Composite Panels using Taguchi and Regression Analysis Method

[1]S. Prakash, [1]J. Lilly Mercy, [2]K. Palanikumar, [3]S. Ramesh, [1]M.I. Rizwan Jamal and [4]A. James Michael
[1]Department of Mechanical and Production, Engineering Sathyabama University, Chennai, 600119, India
[2]Sri Sai Ram Institute of Technology, Chennai, India
[3]Sona College of Technology, Salem-5, India
[4]SAP Labs India, Banglore, India

Abstract: Medium Density Fiber board (MDF) panels are appropriate for many exterior and interior industrial applications. The degree of surface roughness of MDF plays an important role since, any surface irregularities will affect the final quality of the product. In the present study, regression model were developed to predict surface roughness in drilling MDF panels with carbide step drills. In the development of predictive models, drilling parameters of spindle speed, feed rate and drill diameter were considered as model variables. For this purpose, Taguchi's design of experiments was carried out in order to collect surface roughness value. The Orthogonal Array (OA) and Analysis of Variance (ANOVA) are employed to study the surface roughness characteristics in drilling operation of MDF panels. The objective is to establish a correlation between spindle speed, feed rate and drill diameter with surface roughness in a MDF panel. The experiments are conducted as per Taguchi L_{27} orthogonal array with different cutting conditions. ANOVA and F-test were used to check the validity of regression model and to determine the significant parameter affecting the surface roughness. The statistical analysis showed that the feed rate was an utmost parameter on surface roughness. The microstructure of drilled surfaces were also studied by scanning electron microscopy (SEM).The SEM investigations reveled that drilling MDF panels with step drill produce surface striations and waviness which were increased significantly with feed rate.

Key words: Analysis of variance, contour plots, drilling, design of experiments, MDF panel, regression model, Taguchi technique, SEM

INTRODUCTION

Wood composites find wide applications in construction and furniture industries. The demand for wood based Medium Density fiber boards have increased greatly due to population growth while the timber resources are alarmingly depleted. These composites are subjected to various machining operations while in assembly of parts. Among the machining operations, drilling is most critical due to characteristics of composites. The poor hole drilling had been reported to account for 75% of all part rejections (Irle and Loxton, 1996). Because drilling is preferred on nearly completed parts, such defects are very costly. Also the quality of holes has been linked to the strength of the joint being assembled and life of the part (Aguilera *et al*., 2000; Neese *et al*., 2004). Surface finish is an important parameter in manufacturing engineering, which can influence the performance of final parts and production.

In Metal drilling and turning had been studied extensively in the literature but MDF drilling has not received much attention. However, many works of various authors (Hiziroglu *et al*., 2004; Hiziroglu and Suzuki, 2007; Engin *et al*., 2000) have presented about the machining of MDF. They strongly recommended that the machinability is dependent on the mechanism of cutting tool and work piece material.

From the literature, it has been asserted that machining MDF is strongly dependent on the machining parameters. Philip and Gordon (2006) studied the application of PCD tool in machining MDF. According to his study the friction on the rake is small and the pressure exerted by uncut chip on the rake face mainly dominates the force on the rake face. Lin *et al*. (2006) reports about the machinabilty of MDF. This author confirms that the board densities were found to have major influence on the machinability characteristics of the panel. Davim *et al*. (2008) presents the study of surface roughness aspect in

Corresponding Author: S. Prakash, Department of Mechanical and Production, Engineering, Sathyabama University, Chennai, 600119, India Tel: 044-22431527, 9940390301

milling MDF. In his study the surface roughness in milling decreases with an increase of spindle speed and increase with feed rate. Prakash and Palanikumar (2010) formulated a mathematical model for the prediction of surface roughness in drilling MDF panel with Tin coated carbide drill. The result shows that the feed rate is the major factor which influences surface roughness followed by drill diameter associated with spindle speed. Recently, Prakash *et al*. (2011) evaluated modeling for surface roughness parameters (R_a, Rz) in drilling of MDF panel using Box-Behnken Experimental Design (BBD) with Brad and spur drills. In his study, the surface roughness, both R_a and R_z increases with increasing feed but decreases with increasing spindle speed.

SURFACE ROUGHNESS

Surface roughness is a measure of the technological quality of a product and a factor that greatly influences the manufacturing cost. There are several methods to describe surface roughness, such as roughness average (R_a), root-mean-square (RMS) Roughness (R_q) and maximum peak-to-valley roughness (R_{max}) etc. The surface roughness used in this study is the arithmetic mean average surface roughness (R_a), which is mostly used in the industry. It can be expressed by the following mathematical relationship (Prakash *et al*., 2011):

$$R_a = \frac{1}{L}\int_0^L \left[Y(x)\right] dx \qquad (1)$$

where, Ra is arithmetic average deviation from the mean line and Y is ordinate of the profile curve and L is the sampling length.

EXPERIMENTAL STUDIES

Materials choice: In this study, MDF panel has been used for experimentation with a tensile strength of 0.8 N mm^{-2}, density of 700 kg mm^{-3} and modulus of rupture of 28 N mm^{-2} was selected. The panels are supplied by ASIS, India, which is manufactured by them. These panels are commercial available and used for furniture industry. The important properties of the board as per ISO 12406 are given in Table 1.

Drilling procedure and design of experiments: For conducting, the experiments an VMC 100 machining centre with following specifications: Table size: 1270×230 mm; spindle speed 60-5000 rpm; maximum feed rate: 4000 mm min^{-1} was employed. The drill bit used in the investigation is 'Step drill' carbide type, having drill diameter of 4, 8 and 12 mm was used. The experimental setup and the drill bit used are presented in Fig. 1. In the experimental plan, the most dominant process parameters such as Feed rate (f), spindle speed (N) and Drill diameter (d) were varied at three levels. The three process parameters and their factor levels are summarized in Table 2.

In order to measure the average surface roughness (Ra) of MDF panels, Taylor Hobson surface roughness

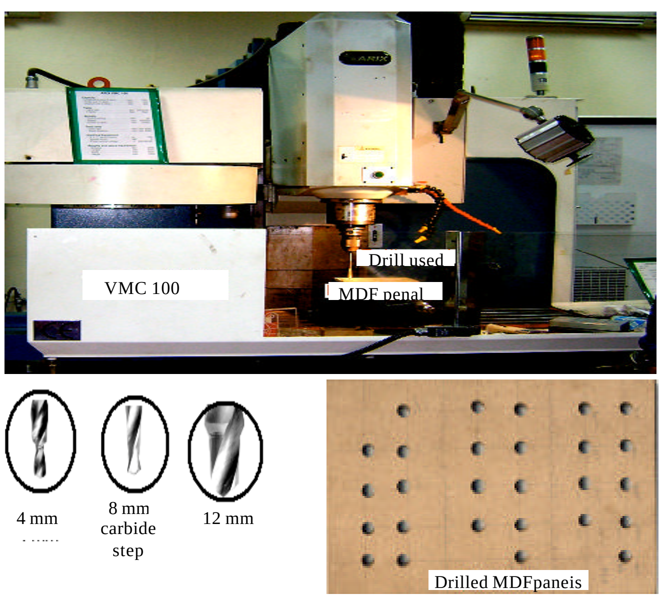

Fig. 1: Experimental setup and drill bit used

measuring device was used. A Scanning Electron Microscope (SEM) was used to investigate the machined surface.

Normally one need to conduct many number of experiments, when three factors, each varied at three levels are considered, using experimental design. In order to save on experimental cost and time, Taguchi's orthogonal array was applied to obtain the surface roughness of MDF panel drilling process. A L_{27} orthogonal array was found to be appropriate and it was chosen. The layout of the L_{27} orthogonal array and the measured surface roughness values are shown in Table 3.

Determination of regression analysis model for surface roughness: Regression analysis method includes the experimental investigations, mathematical methods and statistical analysis. In the present investigation, a whole analysis was done using the experimental data in Table 3. A response surface regression analysis was performed to predict the surface roughness using Minitab 16 software. Specially, with a sample on n observations of the dependent variable Y (Ra), the regression model can be expressed as:

$$R_a = \beta_0 + \sum_{i=1}^{k} \beta_i Xi + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i<j}\sum \beta_{ij} X_i X_j + \varepsilon_i \qquad (2)$$

where, k is the number of factors (3) β_0 is the free term, β_1 is the linear effect, β_{ii} is the squared effect and β_{ij} is the interaction effect (Montgomery, 1997). The second order polynomial regression equation representing the surface roughness (Ra) can be expressed as function drilling parameters such as spindle speed, feed rate and drill diameter. Eq. 4 can be rewritten to build relationship between the drilling process parameters and surface roughness as follows:

$$Ra = b_0+b_1f+b_2N+b_3d+b_{11}f^2+b_{22}N^2+b_{33}d^2+b_{12}fN +b_{13}fd+b_{23}Nd \qquad (3)$$

Table 1: Mechanical and physical properties of MDF panel

Modulus of elasticity ($N\ mm^{-2}$)	Elasticity modulus ($N\ mm^{-2}$)	Humidity (%)	Moisture content (%)
2800	2800	5-8	5-10

Table 2: Machine settings used in the experiments

			Factor levels		
Symbol	Drilling parameter	Unit	1	2	3
N	Spindle speed	rpm	1000	3000	5000
f	Feed rate	$mm\ min^{-1}$	100	300	500
d	Drill dia	mm	4	8	12

RESULTS AND DISCUSSION

Results of regression analysis, used to establish input-output relationship in drill MDF panels are shown and discussed below.

Table 3: Experimental design using L_{27} orthogonal array and experimental results

				Experimental results (Ra)				
Run	f	N	d	1	2	3	Average (Ra)	S/N ratio (dB)
1	100	1000	4	6.85	7.22	6.87	6.98	-16.88
2	100	1000	8	7.52	8.12	7.92	7.85	-17.90
3	100	1000	12	9.12	9.62	9.22	9.32	-19.39
4	100	3000	4	6.79	7.12	6.91	6.94	-16.83
5	100	3000	8	8.24	8.75	8.50	8.50	-18.58
6	100	3000	12	9.52	10.02	9.92	9.82	-19.84
7	100	5000	4	5.60	6.01	5.69	5.77	-15.22
8	100	5000	8	6.75	7.22	6.98	6.98	-16.88
9	100	5000	12	7.98	8.54	8.34	8.29	-18.37
10	300	1000	4	9.38	10.12	9.52	9.67	-19.71
11	300	1000	8	10.68	10.20	10.45	10.44	-20.38
12	300	1000	12	11.55	11.00	11.35	11.30	-21.06
13	300	3000	4	8.58	8.11	8.13	8.27	-18.35
14	300	3000	8	9.32	9.58	9.40	9.43	-19.49
15	300	3000	12	10.18	10.50	10.02	10.23	-20.20
16	300	5000	4	6.80	7.37	7.34	7.17	-17.11
17	300	5000	8	8.01	7.85	8.05	7.97	-18.03
18	300	5000	12	9.42	9.35	9.02	9.26	-19.34
19	500	1000	4	11.75	11.55	11.25	11.52	-21.23
20	500	1000	8	12.55	12.65	12.12	12.44	-21.90
21	500	1000	12	13.95	14.05	13.55	13.85	-22.83
22	500	3000	4	10.69	10.58	10.20	10.49	-20.42
23	500	3000	8	11.65	11.02	10.73	11.13	-20.93
24	500	3000	12	12.29	12.12	11.68	12.03	-21.61
25	500	5000	4	9.66	9.65	9.35	9.55	-19.60
26	500	5000	8	10.69	10.35	10.02	10.36	-20.30
27	500	5000	12	11.03	11.11	10.67	10.94	-20.78

Table 4: ANOVA test results for surface roughness

Source	DF	SS	MS	F	p-value
Regression	9	94.5882	10.5098	73.49	0.000
Linear	3	92.0021	0.6046	4.23	0.021
f	1	56.3957	1.5458	10.81	0.040
N	1	16.2241	0.0310	0.22	0.647
d	1	19.3822	0.4064	2.84	0.110
Square	3	0.8350	0.2783	1.95	0.160
f^2	1	0.5074	0.5074	3.55	0.077
N^2	1	0.3016	0.3016	2.11	0.165
d^2	1	0.0261	0.0261	0.18	0.675
Interaction	3	1.7511	0.5837	4.08	0.024
fN	1	1.2303	1.2303	8.60	0.009
fd	1	0.5132	0.5132	3.59	0.075
Nd	1	0.0076	0.0076	0.05	0.821
Residual error	17	2.4312	0.1430		
Total	26	97.0194			

R^2: 0.97, DF: Degree of freedom, SS: Sum of squares, MS: Mean square

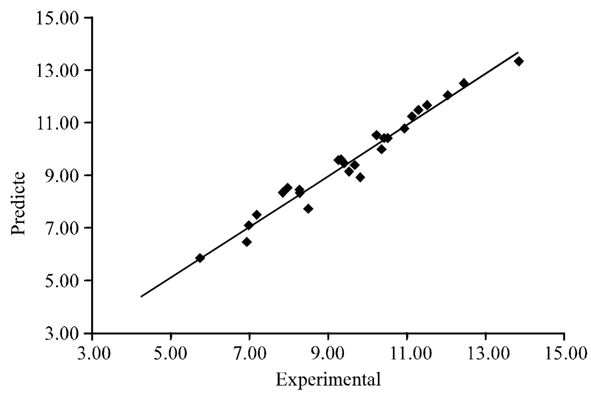

Fig. 2: Comparison of regression model results with experimental measurements

Estimation of surface roughness by regression analysis: From the results (Table 3), the final regression model for surface roughness obtained is as follows:

$$Ra = 4.54+4.72713E\text{-}05\ f+6.72747E\text{-}08\ N+0.0661022\ d +1.81748E\text{-}10\ f^2-1.40127E\text{-}14\ N^2+0.000257451\ d^2-2.00122E\text{-}12\ f\ N -3.23134E\text{-}07\ d\ f -3.92795E\text{-}10\ N\ d \quad (4)$$

Note that some interaction terms are removed from full model because of their no significant effect. Regression statistics R^2 and R^2_{Adj} are obtained equal to 97.49 and 96.17%, respectively. The R^2 value indicates that the drilling parameter explain 97.49% of variance in surface roughness. This value indicates that the presented model fits the data very well. The Analysis of Variance (ANOVA) for regression analysis is shown in Table 4.

The p-value shows that the model terms are significant influence on surface roughness. The results predicated by regression model are compared with experimental measurements results in Fig. 2. It can be seen from Fig. 2 that model prediction presents a good agreement with the experimental data.

Table 5: Response table for the surface roughness

Level	Feed	Speed	Diameter
1	-17.77	-20.14	-18.37
2	-19.30	-19.58	-19.38
3	-21.07	-18.40	-20.38
Delta	3.30	1.74	2.01
Rank	1	3	2

Analysis of the S/N ratio: In the Taguchi method, the term ‘signal’ represents the desirable value (mean) for the output characteristics and the term ‘noise’ represents the undesirable value (standard deviation) for the output characteristics. Therefore, the S/N ratio is the ratio of the mean to the standard deviation. There are several S/N ratios available, depending on the type of characteristics: Lower Is Better (LB), Nominal Is Best (NB), or Higher Is Better (HB) (Montgomery, 1997).

The lower the better quality characteristics can be formulated as (Engin *et al*., 2000):

$$S/N(\eta) = -10 \times \log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \quad (5)$$

where, n is the number of measurements in a trail/row, in this case, n = 3 and y_i is the ith measured value in a row/run. The S/N ratio values are calculated by taking into consideration Eq. 5. The surface roughness values measured from the experiments and their corresponding S/N ratio values are listed in Table 3.

The response table for each level of process parameters was created in the integrated manner and the results are given in Table 5.

Based on the S/N analysis ratio and the ranking position in the response (Table 5), the most influencing parameter is feed rate (rank 1), followed by drill diameter (rank 2) and spindle speed (rank 3). Figure 3-5 show the effect of drilling parameters on the surface roughness.

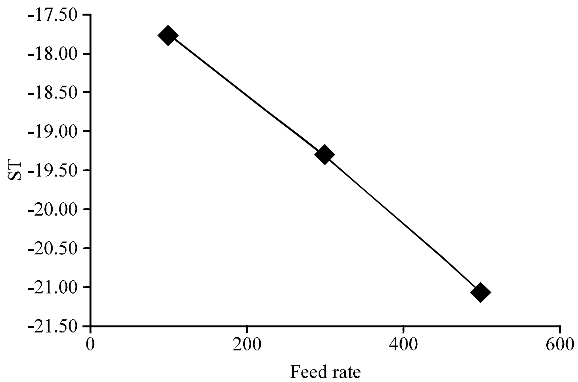

Fig. 3: Feed rate vs. S/N ratio

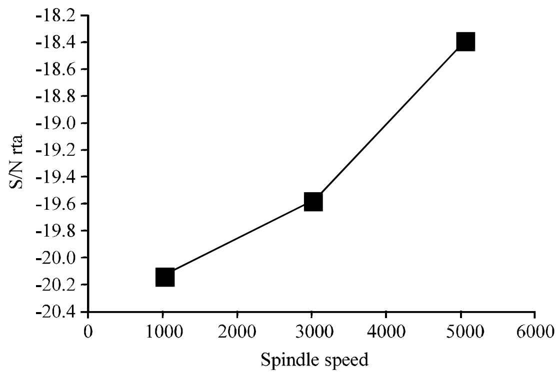

Fig. 4: Spindle speed vs. S/N ratio

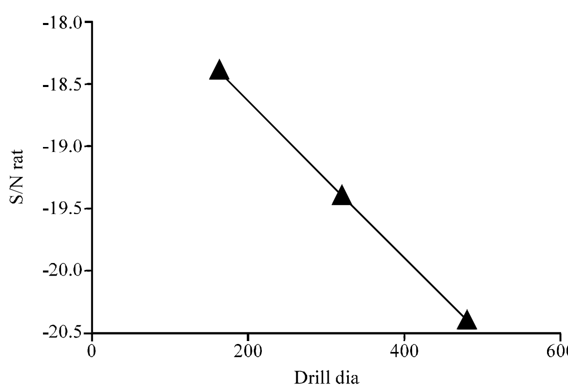

Fig. 5: Drill dia vs. S/N ratio

THE CHARACTERISTICS OF DRILLED SURFACE OF MDF PANELS

The drilled MDF panels were observed under Scanning Electron Microscope (SEM) for analyzing the quality of surfaces. Figure 6 and 7 show, SEM image of

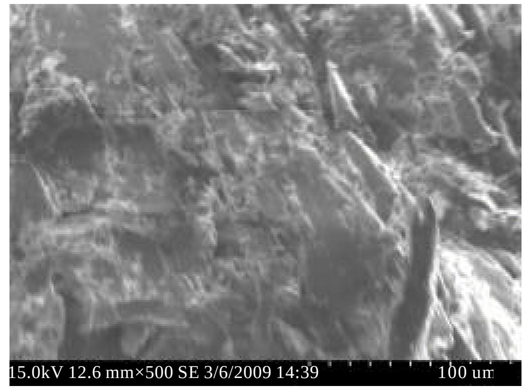

Fig. 6: Scanning electron micrograph of a broken fiber

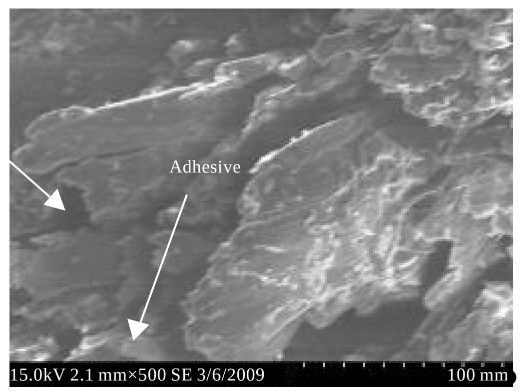

Fig. 7: SEM micrograph of dust form at higher magnification

the wood dust observed in drilling of MDF composites. Figure 6 shows how the wood fiber fracture takes place while drilling of wood composite materials which consists of lingocellulosic fibers. The fracture is takes place in the middle of the weaving used in drilling of composites. It does not show the combination of fibers and matrix materials, it may be due to the weak bond between the lingocellulosic fiber and the matrix materials, since the composite is manufactured through dry processing technology. The separation of adhesive and lingocellulosic fibers is observed in the Fig. 7, which is taken at high magnification (100X). In drilling of composite materials, the chips formed are in a loose form with completely discontinued powder chips. The chips study indicates that the chip production process in MDF composites is completely different from the drilling of metals. Figure 8 shows, the microstructure of the specimen which has been taken at low feed rate of 100 mm min^{-1} for drill diameter 4 mm. The surface of the microstructure indicated that smooth surface is observed

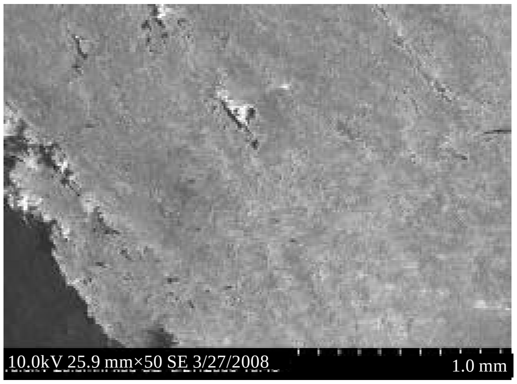

Fig. 8: SEM micrograph at a low feed rate of 100 mm min^{-1} for 4 mm drill diameter

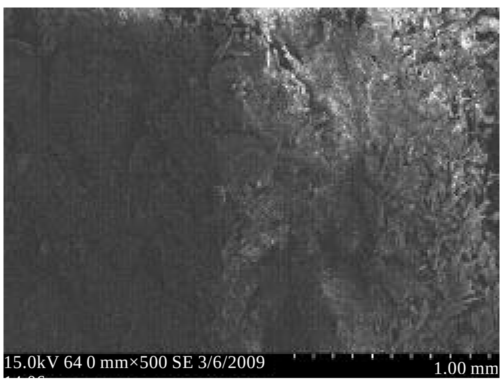

Fig. 9: SEM micrograph at a medium feed rate of 300 mm min^{-1} for 4 mm drill diameter

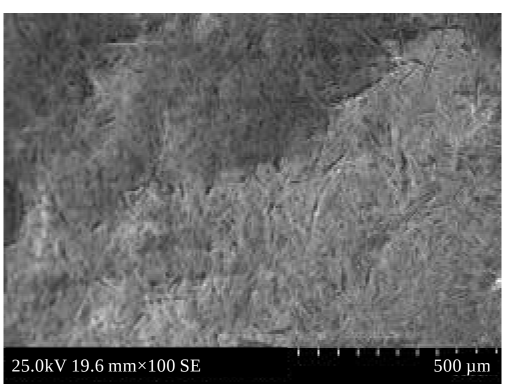

Fig. 10: SEM micrograph at a high feed rate of 500 mm min^{-1} for 4 mm drill diameter

in drilling of MDF composites. In some portion of the work piece, there is a small fracture and tiny tots are observed. It is the common phenomenon in drilling of MDF composites.

Figure 9 shows, the microstructure of the work piece observed in drilling of MDF composites at a medium feed rate of 300 mm min^{-1} for 4 mm drill diameter which indicates that the surface is not smooth. Fussy surface is observed at 300 mm min^{-1} of feed rate. Figure 10 shows, the microstructure of the specimen taken at high feed rate (500 mm min^{-1}) which shows the fiber pull out and protruding fibers. Generally the surface is not smooth.

From these microstructures, it can be predicted that, low feed rate is preferred for drilling of MDF composite panels. It has been noticed that almost smooth surface is observed inside the holes. In some places tiny pits and small damages are observed in the cut section; it is due to the incomplete distribution of adhesives and removal of some fibers in the composite materials when drilling is carried out.

CONCLUSION

To determine the relationship between drilling parameters and surface roughness in MDF panels, regression analysis was carried out based on Taguchi's orthogonal array. The drilled surfaces were also examined using Scanning Electron Microscopy (SEM). Summarizing the main features of the results regression analysis is seen to be sufficient for estimating surface roughness in drilling the MDF panels. The predicted process parameters are found to be close correlation with the actual performance results.

From this, the predictive models can be used for predicting surface roughness in drilling MDF panels with a higher reliability. The performance can further be enhanced with large experimental data from full factorial experimentation and considering the additional performance characteristics. Based on the ANOVA and Taguchi method, the most dominant parameter on surface roughness was found to be feed, while the second ranking factor was drill diameter. Spindle speed is less effective on surface roughness.

Further study could consider more factors different drill properties, point angle, board thickness in the research to see how these factors would affect the surface roughness.

REFERENCES

Aguilera, A., P.J. Meausoone and P. Martin, 2000. Wood material influence in routing operations: The MDF case. Holz als Roh Werkstoff, 58: 278-283.

Davim, J.P., V.N. Gaitonde and S.R. Karnik, 2008. An investigate study drilling of medium density fiberboard (MDF) using response surface models. Int. J. Adv. Manuf. Tech., 37: 49-57.

Engin, S., Y. Altintas and F.B. Amara, 2000. Mechanics of routing medium density fiberboard. Forest Prod. J., 50: 65-69.

Hiziroglu, S. and S. Suzuki, 2007. Evaluation of surface roughness of commercially manufactured particle board and medium density fiber board in Japan. J. Mater. Process. Technol., 184: 436-440.

Hiziroglu, S., S. Jarusombuti and V. Fueangvivat, 2004. Surface characteristics of wood composites manufactured in Thailand. J. Building Environ., 39: 1359-1364.

Lin, R.J.T., J. van Houts and D. Bhattacharyya, 2006. Machinability investigations of medium density fiberboard. Holzforschung, 60: 71-77.

Irle, M. and C. Loxton, 1996. Manufacture and use of panel products in the UK. J. Institute Wood Sci., 14: 21-26.

Montgomery, D.C., 1997. Design and Analysis of Experiments. 4th Edn., John Wiley and Sons, New York.

Neese, J.L., J.E. Reeb and J.W. Funck, 2004. Relating traditional surface roughness measures to glue-bond quality in plywood. Forest Products J., 54: 67-73.

Philip, P. and S. Gordon, 2006. Recent research on the machining of wood based composite materials. Int. J. Mach. Mach. Mater., 1: 186-201.

Prakash, S. and K. Palanikumar, 2010. Modeling for prediction of surface roughness in drilling MDF panels using response surface methodology. J. Composite Mater., 45: 1639-1646.

Prakash, S., K. Palanikumar, J.L. Mercy and S. Nithyalakshmi, 2011. Evaluation of surface roughness parameters (Ra, Rz) in drilling of MDF composite panel using Box-Behnken Experimental design (BBD). Int. J. Design Manuf. Technol., 5: 52-62.