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A systemic approach for evaluating Surface Roughness parameters during drilling of Medium Density Fiberboard using Taguchi method

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Abstract

Medium Density Fiberboard (MDF) is a type of hardboard which is made from wood fibers glued under heat and pressure. MDF are appropriate for the many exterior or interior industrial applications. Drilling is one of the most common and fundamental machining processes. It is most frequently performed in material removal and is used as a preliminary step for many operations, such as reaming, tapping and boring. Because of their importance in nearly all production operations, twist drills have been the subject of numerous investigations. This article aims to study the effects of the drilling parameters such as spindle speed, feed rate, and drill diameter (input parameters) used on the prediction of surface roughness (output response) on drilling MDF composite. The experiment was carried out by varying the drilling parameters and the output response surface roughness is modelled mathematically. The adequacy of the mathematical model is analyzed statistically using Analysis Of Variance (ANOVA) which gives a high degree of correlation between the input parameters and output response. It is evident that feed rate during drilling is the most influencing factor to surface roughness.

Keywords: Analysis Of Variance (ANOVA), Drilling, Feed Rate, Surface Roughness

1. Introduction

Medium Density Fiberboard (MDF) is a specially engineered wood product made by breaking down hardwood and softwood residuals into wood fibers, and then combined with wax and resin binder, which forms panels when high pressure and temperature are applied. MDF is generally denser than plywood as well as particle board. Even though it is made up of separated fibers, it can be used as a building material similar in application to plywood.

The physical properties of MDF are entirely different from plywood or particle board. The density of a typical MDF ranges from 500kg/m^3 to 1000kg/m^3 whereas the density of a particle board is between 160kg/m^3 to 450kg/m^3.

In contrast to natural wood, MDF does not contain knots or rings, making it more uniform than natural

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woods during cutting and in service. Typical MDF has hard, flat, smooth surface that makes it ideal for veneering, as there exists no underlying grain to telegraph through the thin veneers as is the case with plywood [1]. Because of the above advantage and its easy machinability, MDF is primarily used in making display cabinets, wall panels and storage units. MDF has been widely used throughout the world for furniture manufacturing and house construction, including flooring [2]. Recently the demand for the particleboard has continued to increase for house construction and furniture industries [4].

Since it is easily machinable, it is one of the most machined materials in today's world, with drilling being the most common machining operation [5-10]. Drilling being the most generally used machining, it affects the surface quality, aesthetic appearance and the performance of the final product by causing drilling damages like surface roughness [3,11] which also effects the surface finish of the product. Surface finish is an important parameter in manufacturing engineering. It is a characteristic that can influence the performance of mechanical parts and production costs.

Surface roughness is a component of surface texture. It can be quantified by the vertical deviations of a real surface from its ideal form. Drilling of holes causes the surface of the MDF to deviate from its original texture, hence it results in surface roughness. The more is the deviation, the more is the surface roughness and vice versa. Surface roughness not only affects the surface finish of the product, it also acts as a catalyst in decreasing the strength of the product.

The surface roughness mainly depends on the feed rate, spindle speed, drill diameter and panel thickness, with feed rate being the most dominant of all [12]. For this purpose, Taguchi's design of experiments was carried out in order to collect surface roughness values by providing various combination of input parameters. Analysis of Variance (ANOVA) is employed to analyse the interaction between input parameters and to check the dependability of the experiment conducted. The objective is to establish a correlation between spindle speed, feed rate and drill diameter with surface roughness in a MDF panel.

2. Experimental Details

2.1 Planning of Experimental Design

In order to develop the mathematical model based on experimental data, a proper planning of experiments is necessary. Hence, to start with, we use Taguchi's design of experiments and response surface methodology (RSM), which is an empirical modeling approach for determining the relationship between various processing parameters and responses. RSM is a collection of mathematical and statistical techniques that are useful for the modeling and analysis of problems in which the desired response is influenced by several parameters and the objective is to optimize this response.

The conventional method of experimentation, i.e. varying one parameter at a time and studying its effect is considered costly and time consuming. Hence, we adopted the design of experiments (DOE) technique that requires minimum number of experiments to be conducted. In this study, cutting speed, feed rate and drill diameter are considered as controllable variables with feed rate and spindle speed being the most significant [13,14]. Feed rate plays the major role in drilling of composites. Previous researches highlight that the increase of feed rate increases the surface roughness. Further the decrease in feed rate reduces the material removal rate and hence reasonable feed rate is preferred for drilling of composites.

2.2 Experimental Conditions

In order to achieve the objective of this experimental work, mainly the establishing of correlations between the cutting parameters with the surface roughness, machining issues were effected with different cutting parameters. The different cutting parameters that are selected are feed rate, spindle speed, drill diameter and panel thickness.

Experiments were carried out at three different levels of feed rates, spindle speeds, drill diameter and panel thickness (Table 1).

Carbide drills give better surface finish and less number of holes to failure. The drill bit used for this experiment is forstner carbide drill bit shown in Figure 1. It is used to form holes with a flat bottom, such as for

Table 1. Factors and Levels of machining parameters

Cutting Parameters	Unit	Level 1	Level 2	Level 3
Feed rate (f)	mm/min	100	300	500
Spindle Speed (N)	rev/min	1000	3000	5000
Drill diameter (d)	mm	4	8	12
Panel Thickness (t)	mm	6	12	18

kitchen cupboard hinges. It is mainly used in a power drill held in a drill stand as there's little in the way of a central point.

2.3 Experimental Setup

In this experiment, a MDF board wood composite of varying thickness (Table I) is drilled using a forstner carbide drill bit. The feed rate, spindle speed & drill diameter are varied as Table I to see what effects does it have on the surface roughness. The surface roughness is denoted by R_a, which is the arithmetic average of the values got across the measuring distance.

The surface roughness is measured using Taylor Hobson surface roughness tester. The surface roughness across the measuring distance is given as a graph which gives a detailed view of how the surface roughness varies. Figure 2 shows the surface roughness graph.

The experimented values for the surface roughness can be seen in Table 2.

3. Response Surface Methodology (RSM)

Experimentation plays a crucial role in science, engineering and industry. Response Surface Methodology (RSM) is a collection of mathematical and statistical techniques useful for the modeling and analysis of problems[15]. In this technique, the main objective is to develop models and to optimize the response surface that is influenced by various drilling parameters. In addition to the above mentioned objective RSM also establishes a relation between the controllable input parameters and obtained response surfaces [16,17]. The design procedure of the RSM system are [18,19]:

1. Design a series of experiments for adequate and reliable measurements of the response of interest.
2. Developing a mathematical model of the response surface with the best fittings.
3. Design the appropriate factorial experiment in localized region of the response surface.
4. Representing the interaction effects of the parameters through two dimensional plots and three dimensional plots.
5. Compute the estimates of the effects and thereby calculate the coefficients of the respective model.
6. Using above model, representing the direct and interactive effects of the process parameters through two and three dimensional plots.

Figure 1. Forstner drill bit used for experimentation.

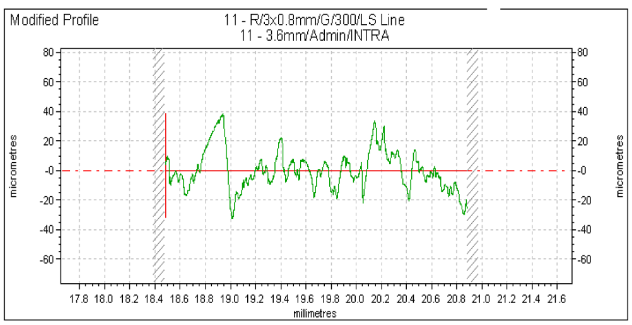

Figure 2. Surface Roughness plot.

4. Mathematical Modelling

The results obtained through the response surface methodology (RSM) are further verified by the following methods:

- Coefficient of Correlation (R^2)
- Regression equation

4.1 Coefficient of Correlation (R^2)

Coefficient of Correlation (R^2) is a statistic used in the context of statistical models whose main purpose is either the prediction of future outcomes or the testing of hypotheses, on the basis of other related information. It provides a measure of how well observed outcomes are replicated by the model, as the proportion of total variation of outcomes explained by the model.

4.2 Regression Equation

The mathematical expression of relationship of the surface roughness parameter with the three variables (feed rate, spindle speed, drill diameter) is shown below as in terms of actual factors. This equation makes it possible to predict the surface roughness. The results got from the experiments are analyzed using MINITAB statistical

Table 2. Experimental L_{27} array of input parameters and output responses

S.No.	Feed rate (f) mm/min.	Spindle speed (N) Rpm	Drill diameter (d) mm	Panel thickness (t) mm	Surface roughness (R_a), µm*
1.	100	1000	4	6	5.48
2.	100	1000	8	12	6.25
3.	100	1000	12	18	7.54
4.	100	3000	4	18	5.45
5.	100	3000	8	6	6.81
6.	100	3000	12	12	7.98
7.	100	5000	4	12	4.41
8.	100	5000	8	18	5.48
9.	100	5000	12	6	6.63
10.	300	1000	4	12	7.85
11.	300	1000	8	18	8.53
12.	300	1000	12	6	9.29
13.	300	3000	4	6	6.62
14.	300	3000	8	12	7.64
15.	300	3000	12	18	8.34
16.	300	5000	4	18	5.65
17.	300	5000	8	6	6.35
18.	300	5000	12	12	7.49
19.	500	1000	4	18	9.47
20.	500	1000	8	6	10.29
21.	500	1000	12	12	11.53
22.	500	3000	4	12	8.57
23.	500	3000	8	18	9.13
24.	500	3000	12	6	9.93
25.	500	5000	4	6	7.74
26.	500	5000	8	12	8.45
27.	500	5000	12	18	8.96

* Average of 3 values

software. Quadratic equation was found to be the best curve of fit.

Surface roughness (R_a), µm = $3.41847 + (0.00766 * f) + (0.00012*N) + (0.25153*d) + (0.08977*t) + (0.00001* f^2) + (0.00372 * d^2) - (0.00409* t^2) - (0.00022 * f * d) + (0.00002* f * t) - (0.00021*d*t)$ R^2 97.70%

Where N= spindle speed in rpm
f= feed rate in mm/min
d= drill diameter in mm
t= panel thickness in mm

5. Validation of Modeling

The adequacy of the mathematical model is analyzed statistically using Analysis Of Variance (ANOVA). It is a statistical method for making simultaneous comparisons between two or more means; a statistical method that yields values that can be tested to determine whether a significant relation exists between variables. The ANOVA table consists of sum of squares and degrees of freedom.

The ANOVA table for the verification of the experimented results is as follows:

Table 3. ANOVA table for surface roughness

Source	Degrees of Freedom	Seq Sum of Squares	Adj Sum of Squares	Adj Mean Square	F- value
Regression	14	73.4838	73.4838	5.2488	36.46
Linear	4	71.3498	1.25841	0.3146	2.19
Square	4	0.7731	0.77308	0.1932	1.34
Interaction	6	1.3609	1.36092	0.2268	1.58
Residual Error	12	1.7275	1.72750	0.1439	
Total	26	75.2113			
R-Sq = 97.70%					

6. Results and Discussions

Table 3 shows the ANOVA results for the surface roughness for a predicted quadratic model. The F value of the model implies that the proposed quadratic model is significant. The goodness of fit of the model was checked by the coefficient of correlation (R^2). In this case, the value of coefficient of correlation (R^2 = 0.97) indicated that only 3% of the total variations were not explained by the regression model.

As it can be inferred from the 3D response graph given below, surface roughness increases with increase in feed rate and decrease in speed (Figure 3). This is due to the fact that the large amount of material removal in a short duration results in poor surface finish. It can also be seen that drill diameter has the least impact on surface roughness when compared with feed rate and spindle speed. Thus, feed rate can be concluded to be the major influencing factor to surface roughness followed by spindle speed and drill diameter.

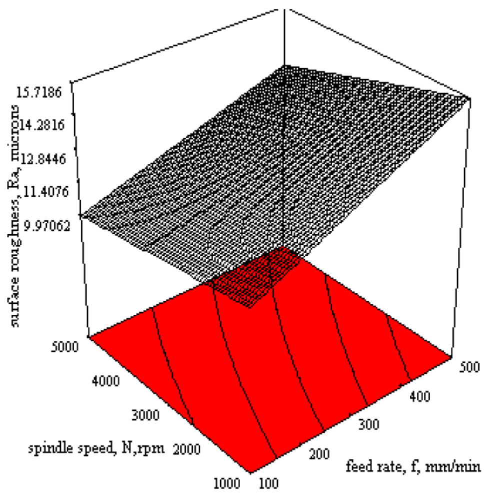

Figure 3. Effect of spindle speed and feed rate on surface roughness.

7. Conclusion

The following conclusions can be made from the experimental values of drilling on medium density fiberboard by a forstner carbide drill bit. An ANOVA table has been developed for predicting the surface roughness on the drilling of MDF by a forstner drill.

The established equation and the surface plots clearly show that the surface roughness increase with increase in the feed rate and decrease in spindle speed.

Figure 4 clearly shows that as drill diameter increases, surface roughness increases. Hence a drill bit of lesser diameter is best suited to get a hole of minimum surface roughness. From Figure 5, it can be observed that feed rate

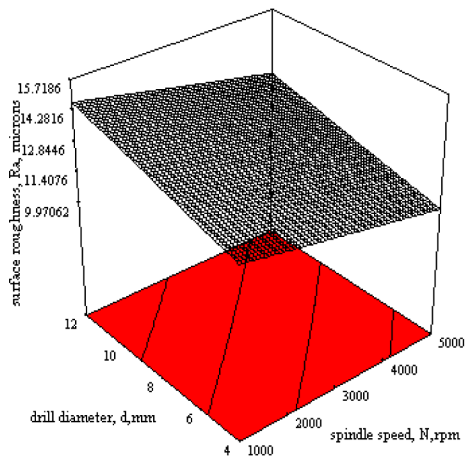

Figure 4. Effect of drill diameter and spindle speed on surface roughness.

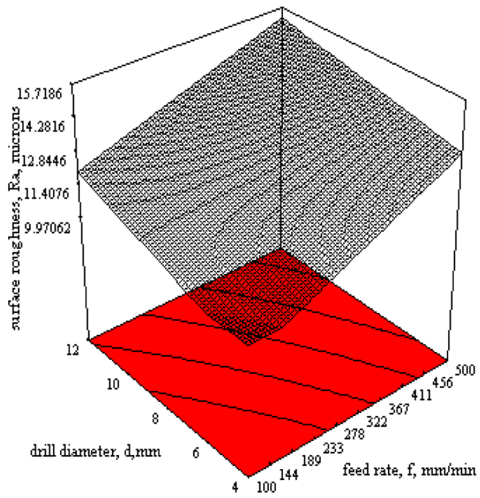

Figure 5. Effect of drill diameter and feed rate on surface roughness.

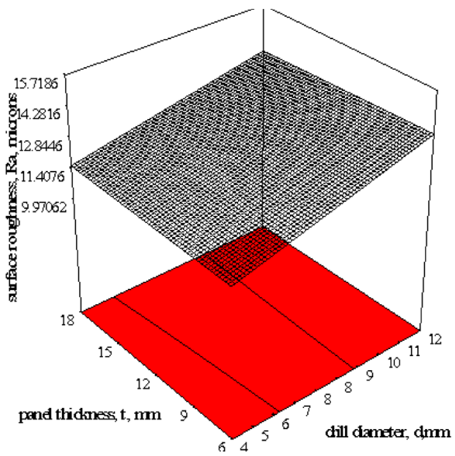

Figure 6. Effect of Panel thickness and drill diameter on surface roughness.

has the maximum influence on surface roughness. Both drill diameter and feed rate are directly proportional to the measured response surface roughness. From Figure 6, we can conclude that MDF panel thickness does not have much impact on the surface roughness of the hole.

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