Optimization of Process Parameters in Oriented Strand Board Manufacturing by Taguchi Method

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Optimization of process parameters in oriented strand board (OSB) manufacturing is a vital issue for improving product quality. In this study, the Taguchi method (TM) was applied to determine the effects of production factors such as adhesive ratio, press pressure, and pressing time on the thermal conductivity of OSB. Obtained results showed that adhesive ratio is the main factor affecting thermal conductivity. Press pressure and pressing time are the second and third most important factors influencing thermal conductivity, respectively. The study also identified the optimal values of factors that minimize thermal conductivity.

Keywords: Oriented strand board; Process parameters; Taguchi method

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INTRODUCTION

Determination of the optimum values of process parameters plays a significant role in product quality. This task is important but usually challenging. Generally, a human process planner selects the proper machining process parameters using his own experience or from handbooks. However, these parameters do not give optimal results (Pawar and Rao 2013). Process parameter optimization is also important in oriented strand board (OSB) manufacturing. OSB is made from strands of wood and has favorable physical and mechanical properties that make it desirable for construction and industrial packaging. OSB is very commonly used in light wood frame construction, such as a sheathing material for shear walls and ceiling coverings (Salari *et al*. 2013). Because of its importance, properties of the OSB manufacturing process have been extensively studied (Hermawan 2007; Ayrilmis *et al.* 2009; Gminski *et al*. 2010; Gunduz *et al*. 2011; Ozsahin 2012; Evans *et al*. 2013; Chen *et al*. 2015). OSBs are multi-layer panels bonded with a binder under pressure and heat. There are many factors affecting OSB properties such as press pressure, pressing time, and adhesive ratio; a significant factor is thermal conductivity (TC). Thus, the determination of the effects of manufacturing factors (process parameters) on the TC of OSBs is vital (Yapıcı 2008; Yapıcı *et al*. 2010; Gunduz *et al*. 2011; Ozsahin 2013).

The Taguchi method (TM) developed by Genichi Taguchi is an effective and robust experimental design technique used to determine the most important factors and their impact degree in process parameter optimization. TM aims to obtain the best values of controllable factors with a smaller number of experiments compared with traditional experimental design methods (Taguchi *et al*. 2005). The main advantages of TM are cost minimization, effort minimization, robust design, and easy explication of method outputs. TM uses a special design of orthogonal arrays, which have been frequently used in analyzing engineering problems. The orthogonal arrays reduce the number of experiments and minimize the effects of the uncontrollable parameters (Hamzacebi and Kutay 2004;

Tiryaki *et al*. 2015). For process parameter optimization, TM uses a signal-to-noise (S/N) ratio. S/N ratio is used to detect control factors that reduce variability in a process by minimizing the effects of uncontrollable factors. TM has been widely used in different fields, as represented in the following recently published studies: Gunay and Yucel (2013); Rajasekaran *et al*. (2013), Sutcu (2013), Dasgupta *et al*. (2014), Gu *et al*. (2014), Qasim *et al*. (2015), and Esen and Turgut (2015).

The aim of this study was to use TM to optimize process parameters such as press pressure, adhesive ratio, and pressing time and to obtain the optimum TC of OSB.

EXPERIMENTAL

Data

The data used in this study was taken from Yapıcı (2008) and Yapıcı *et al*. (2010). The effects of adhesive ratio, pressing time, and press pressure on the TC of OSB were investigated by full factorial experimental design in Yapıcı *et al*. (2010). The authors used Scots pine wood (*Pinus sylvestris* L.) for the OSB production experiment. The detailed experimental conditions can be found in Yapıcı *et al*. (2010).

Implementation of Taguchi Method

To optimize process parameters by TM, a systematic method was followed. The adhesive ratio, pressing time, and press pressure were considered controllable factors. Table 1 indicates the process parameters and their levels. As deduced from Table 1, there were 3 factors, which had 3 levels. After the factor definitions, a proper orthogonal array should be selected (Taguchi *et al*. 2005). The suitable Taguchi orthogonal array was selected as L_9. The L_9 design sheet and output of each experiment is given in Table 2.

Table 1. The Process Parameters and their Levels

Factors	Level 1	Level 2	Level 3
Adhesive Ratio (%)	3%	4.5%	6%
Pressing Time (minute)	3	5	7
Press Pressure (kg/cm^2)	35	40	45

Table 2. The Design Sheet and Output of Each Experiment

Experiment	Factors			TC of OSB	
	Adhesive Ratio	Pressing Time	Press Pressure	$\bar{y}$	s
1	1	1	1	0.129	0.010
2	1	2	2	0.153	0.028
3	1	3	3	0.152	0.025
4	2	1	2	0.142	0.023
5	2	2	3	0.143	0.026
6	2	3	1	0.146	0.025
7	3	1	3	0.163	0.027
8	3	2	1	0.154	0.018
9	3	3	2	0.170	0.019

In Table 2, $\bar{y}$ and s present the mean and standard deviation of the TC values, respectively. MINITAB 17 statistical software (State College, PA, USA) was used to analyze experiments in the Taguchi design. The TC of OSB was evaluated using the S/N ratio and Pareto ANOVA analysis (Venkateswarlu *et al*. 2010). It was easier to analyze the results using both S/N ratio and Pareto ANOVA; hence, the optimum settings of the parameters were detected. Higher S/N ratio values indicate robust control factor settings that minimize the effects of the noise factors. The three types of S/N ratio calculations (Taguchi *et al*. 2005) are given in Fig. 1, where $\bar{y}$ is the mean of observed data, s^2 is the variance of y, n is the number of observed data, and y_i is the i^th^ observed data.

Smaller value of response is better:	Nominal value of response is the best:	Larger value of response is better:
$S/N = -10\log\left(\frac{\sum_{i=1}^{n} y_i^2}{n}\right)$	$S/N = -10\log(s^2)$	$S/N = -10\log\left(\frac{\sum_{i=1}^{n} \frac{1}{y_i^2}}{n}\right)$

Fig. 1. Types of S/N ratio

Pareto ANOVA is a simplified ANOVA technique based on the Pareto principle. Here, Pareto ANOVA was used to determine the contribution of each process parameter to the TC of OSB. Pareto ANOVA does not use an F-test, but it identifies the important parameters and determines the percent contribution of each parameter (Venkateswarlu *et al*. 2010; Tiryaki *et al*. 2014). To obtain the Pareto ANOVA of S/N ratio values, the overall mean of S/N ratios and the sum of squares due to variation about overall mean were calculated by Eqs. 1 and 2, respectively,

$$\overline{S/N} = \frac{1}{m}\sum_{i=1}^{m}(S/N)_i \tag{1}$$

where $\overline{S/N}$ is the overall mean of S/N ratio, $(S/N)_i$ is the S/N ratio for ith parameter, and m is the number of S/N ratios.

$$SS_{Total} = \sum_{i=1}^{m}\left((S/N)_i - (\overline{S/N})\right)^2 \tag{2}$$

In Eq. 2, SS_{Total} is the total sum of squares. Secondly, for the ith process parameter, the sum of squares due to variation about overall mean was calculated by Eq. 3,

$$SS_i = \sum_{j=1}^{k_i}\left((S/N)_{ij} - (\overline{S/N})\right)^2 \tag{3}$$

where SS_i is the sum of the square for ith parameter, $(S/N)_{ij}$ is the S/N ratio of ith parameter of jth level, and k_i is the number of levels of ith parameter. Finally, the contribution of ith parameter was calculated by Eq. (4).

$$Contribution_i = \frac{SS_i}{SS_{Total}} x100 \tag{4}$$

RESULTS AND DISCUSSION

In this study, TM was implemented to optimize the process parameters such as press pressure, adhesive ratio, and pressing time to obtain the optimal TC value for OSB. S/N ratio and Pareto ANOVA analysis were used to evaluate the results of Taguchi experiments. The biggest S/N ratio indicated the optimal combination of parameter values. S/N ratios also showed the importance of the order of process parameters (Table 3). The main effect graph of S/N ratios states the optimal level of the factors (Fig. 2).

Table 3. S/N Ratio Values of TC

Level	Adhesive Ratio	Pressing Time	Press Pressure
1	16.74	16.77	16.86
2	16.74	16.39	16.14
3	15.74	16.07	16.23
Delta	1.00	0.70	0.72
Rank	1	3	2

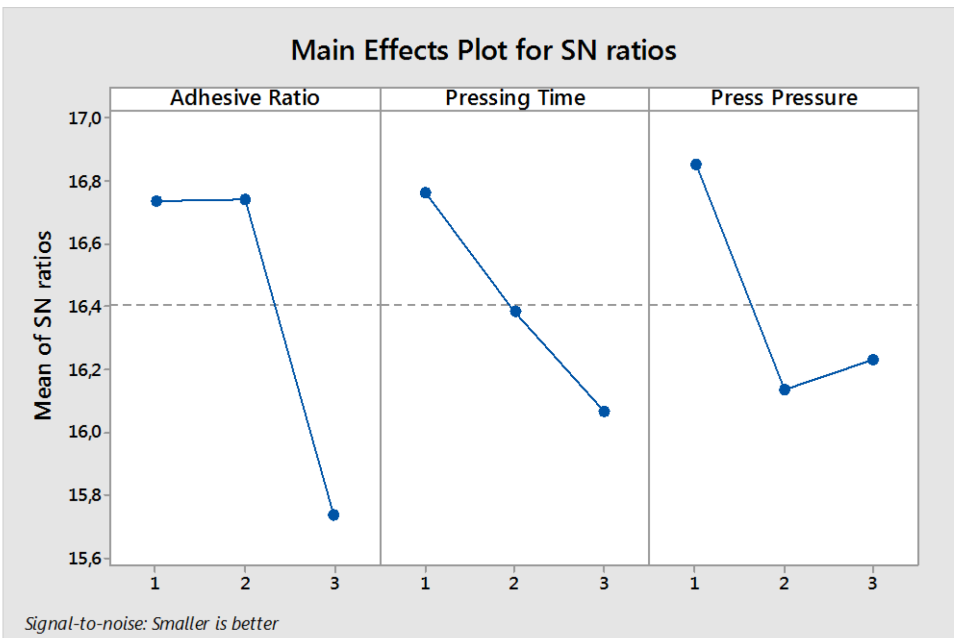

Fig. 2. Main effect plots for S/N ratios of process parameters

The ranking of the process parameters was obtained from S/N ratio table. This order was determined by comparison of delta values. The delta value is equal to the difference between maximum and minimum values for levels of each factor. Table 3 shows that the order of importance in minimizing the TC of OSB is adhesive ratio, press pressure, and pressing time. Figure 2 shows the optimal level of the process parameters. The level that produced a bigger S/N value was preferred. As deduced from Fig. 2, the second level of adhesive ratio (3%), the first level of pressing time (3 min), and the first level of press pressure (35 kg/cm^2) were the optimal values for the minimization of the TC of OSB.

After determining the ranking of the parameters and best level searching, Pareto ANOVA was applied to determine the percent contribution of each parameter on the TC

(Table 4). Adhesive ratio most significantly affected the TC of OSB. The contribution of the adhesive ratio was 54.64%. The second parameter was pressing time, with a 25.23% contribution, followed by press pressure, with an influence of 20.13%.

Table 4. Contribution of Process Parameters based on Pareto ANOVA

Process Parameter	Sum of Squares (SS_i)	% Contribution	Rank
Adhesive Ratio	0.6667	54.64	1
Press Pressure	0.2456	20.13	3
Pressing Time	0.3078	25.23	2
Total	1.2201	100	

Although this study was based on data from Yapıcı *et al*. (2010), further findings have been achieved. For example, Yapıcı *et al*. (2010) reported the factors that affect the TC of OSB, but the ranking of the factors and the best level of the factors that optimize the response were not reported. These shortcomings were eliminated by TM in this study.

CONCLUSIONS

1. TM is a powerful technique to analyze the effects of the process parameters.
2. Time and cost of experiments can be reduced by using TM. As a result of a selected orthogonal array, 9 experiments were performed instead of 27 experiments, which should be done for full factorial design implementation.
3. The same results were obtained by both S/N ratio analysis and Pareto ANOVA. Thus, the most significant variable on TC of OSB was determined to be the adhesive ratio.

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