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Effects of feed speed ratio and laser power on engraved depth and color difference of Moso bamboo lamina

Cheng-Jung Lin[a], *Yi-Chung Wang*[b], *Lang-Dong Lin*[c], *Chyi-Rong Chiou*[d], *Ya-Nan Wang*[d], *Ming-Jer Tsai*[d,*]

[a] *Division of Forest Utilization, Taiwan Forestry Research Institute, 53 Nan-Hai Road, Taipei 100, Taiwan*
[b] *Department of Forestry, Chinese Culture University, 55 Hwa-Kang Road, Yang-Ming-Shan, Taipei 11114, Taiwan*
[c] *Department of Forest Products Science, National Chiayi University, Chiayi, Taiwan*
[d] *School of Forestry and Resource Conservation, College of Bio-Resource and Agriculture, National Taiwan University, No.1, Sec. 4, Roosevelt Road, Taipei 10608, Taiwan*

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ABSTRACT

In this study, Moso bamboo (*Phyllosachys edulis*) lamina was engraved using various laser output power levels in conjunction with various feed speed ratios in order to understand the effects of feed speed ratio and laser output power on engraved depth and color difference. The bamboo culm was sliced into strips and then the strips were planed for obtaining smooth surfaces. Two kinds of Moso bamboo laminae, including without and with steam treatment were investigated. The results showed that the engraved depth became deeper for either higher laser power or a lower feed speed ratio. Moreover, the color difference values increased under a lower feed speed ratio and higher power, and resulted in a brownish color in the engraved zone. The average engraved depth and color difference values were 0.69–0.86 mm and 46.9–51.9 pixels by different engraving parameters, respectively. The engraved depth and color difference values could be predicted and estimated by regression analyses. Because of various desired engraving depths and color differences of product, we suggested that the fitting both laser's speed and power is important for valuable engraving and cost effective.

1. Introduction

In addition to plantation wood, bamboo is also an important material due to its fast growth and a shortage of wood supplies in Taiwan. Moso bamboo (*Phyllostachys edulis*) is a multipurpose species grown in Taiwan for fuel wood, food (bamboo shoot), construction materials, handicrafts, mat boards, pressboards, and several other uses. In order to develop an innovative processing system which significantly increase the value of the utilization of bamboo, manufacturers have engaged in sequential studies on Moso bamboo, in an attempt to utilize it as stock for quality products or valuable handcrafts. For example, laser engraving has gained increasing interest in the bamboo handcraft industry and is well suited for high-volume automated manufacturing owing to the high processing speed, low waste, precision of operation, and high quality of engraved products.

Barnekov et al. (1986, 1989) and Yilbas (2001) indicated that in the laser cutting process, the process parameters can be adjusted and tuned to achieve the quality of cut desired. However, if a different workpiece material is used for cutting, all of these parameters may require re-adjustment, which

* *Corresponding author*. Tel.: +886 2 33664641; fax: +886 2 23686335.
E-mail addresses: d88625002@yahoo.com.tw (C.-J. Lin), tmj@ntu.edu.tw (M.-J. Tsai).
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consumes a considerable amount of time and effort. These parameters include the laser power, energy coupling factor, and cutting speed. Black (1998) reported that the laser machining of any material is a complex process involving many different parameters, all of which need to work is concerned to produce a quality machining operation. Straight-line testing was used to evaluate the laser parameters for acceptable full-through cutting. This test combines the examination of two separate parameters in one test. Laser beam power (W) and cutting speed (mm/min) are the most important laser parameters, as they dictate the amount of energy input per unit length of cut. Therefore, they were paired for the test runs.

However, the applicability of laser engraving for creating valuable and quality wood materials has been investigated (Su et al., 2005; Wang et al., 2005). No report has been published that details the effects of feed speed ratio (%) and laser power (W) on the engraving depth and color difference of Moso bamboo engraved by laser machining. Therefore, it is important to develop such information to understand the effect of the two parameters on the engraved results of bamboo when estimating engraving performance using lasers.

In the light of the above reasons, the present study was carried out to investigate the effect of engraving speed ratio and laser power (two important parameters) on the engraved depth and color difference. Furthermore, mathematical models based on the two parameters were employed to formulate relationships between the engraved depth and color difference. Thus, the process parameters (feed speed ratio and laser power) can be adjusted and tuned to achieve the quality (engraved depth and color difference) of engraving desired. The results can provide information for estimating utilization of Moso bamboo in laser engraving.

2. Materials and methods

2.1. *Preparation of test samples*

Moso bamboo culm was sliced into strips and then the strips were planed for obtaining smooth surfaces. Two different bamboo laminae, including internode material without steam treatment (laminae N) and internode material with steam treatment (laminae S) were selected. The bamboo laminae were boiled in a solution (H_2O_2, 100 °C, 6–8 h) to reduce the starch and sugar contents that would otherwise attract termites or beetles, and then half the laminae (laminae S) were steamed (carbonized) under heat and pressure (3.5 kg/cm^2, 145 °C, 90 min) to darken the color. Twenty laminae were prepared from each type of material for each set of experiments.

2.2. *Experimental materials*

Two kinds of bamboo laminae, including laminae N and laminae S were investigated. The size of each specimen of bamboo lamina was 200 (longitudinal) × 25 (tangential) × 7.5 mm (radial). Specimens were conditioned in a controlled-environment room at 20 °C and 65% relative humidity (moisture content of 12%).

The density value of lamina was calculated from the following formula:

$$\rho = \frac{W}{V} \quad (1)$$

where ρ (g/cm^3) is the density, V (cm^3) the volume, and W (g) is the weight of lamina at moisture content of 12%.

2.3. *Laser engraving method*

A nominal 100-W EPILOG, a commercially designed carbon-dioxide laser coupled to a precision computer-controlled X–Y table, was used in the study. The laser engraving tests were conducted for two kinds of bamboo specimens, using a laser machine (Epilog Radius Model 4000, Denver, CO, USA). The standard of the laser focusing lens was 2 in. (5.1 cm). The scanning model factor was used to set the laser engraving (in the raster mode). The scanning resolution of the operation software was 600 dpi (dots per inch).

Image to engraving in following processes: (1) start by connecting laser system to computer, (2) import the engraving image into CorelDRAW software, (3) convert the image to grayscale, (4) configure the laser's speed and power, and then (5) send the print job to the laser system for engraving. Two factors (speed and power) were considered in this practical experiment: (1) nominal engraving speed ratios (S) (set 10% [780 mm/min], 20% [1560 mm/min], 30% [2340 mm/min], 40% [3120 mm/min], 50% [3900 mm/min], 60% [4680 mm/min], 70% [5460 mm/min], 80% [6240 mm/min], 90% [7020 mm/min], and 100 %, with the fastest feed speed at 7800 mm/min); (2) laser output power (P) (set 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 W). Other laser-engraving factors were held constant at the default settings.

The X–Y table was computer-programmed to engrave an 8-mm^2 area on the surface of the specimens. The engraving positions and sequences on the surface of the specimens are shown in Fig. 1. The engraving feed speed ratio and laser power ($S \times P$) were paired for the test runs. The same $S \times P$ treatments were repeated 20 times. Therefore, the data set consisted of 20 replicates × 10 feed speed ratios × 10 laser power levels × 2 kinds of bamboo specimens. In total, 4000 engraved areas were investigated for engraved depth and color difference.

After engraving, the average engraved depth of the different treatments ($S \times P$) was measured in specimens with a caliper (with an accuracy of 0.001 mm). The engraved color difference (grayscale intensity differences) was calculated using Eq. (2):

$$\text{Color difference} = (\text{pixels before engraving}) - (\text{pixels after engraving}) \quad (2)$$

Specimens were scanned (using a MICROTEK scanner, China), and the average number of pixels (ranging from 0 [black] to 255 [white]) was measured using Adobe Photoshop software (version 7.0.1).