Evaluation of Wood Surface Quality after 3D Molding of Wood by Pressing

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The goal of this study was to develop and test an appropriate method for the evaluation of surface quality and to identify and quantify the quality of a surface modified by 3D molding. New software was developed to evaluate the surface quality based on the identification of macroscopic defects such as cracks within a scanned area. The influence of specific factors that affect the development of cracks during the uneven pressing process was assessed. Based on the measured and evaluated results, a process combination of factors was designed which yielded an embossed surface that was formed with the lowest proportion of cracks and with sufficient shape stability. In this work, 432 groups of test pieces were monitored, with each piece exposed to different combination of factors. Based on the measured and evaluated results, we found a combination that provided the lowest crack ratio. This innovative method will contribute to the knowledge of embossed surface quality and to the improvement of the uneven pressing process for wood surfaces.

Keywords: Pressing; Embossing; Surface quality identification

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INTRODUCTION

In three-dimensional (3D) molding, the shape of wood is modified by either the surface modification or by that of the surface of wood-based materials (*e.g.*, plywood, MDF boards, and chipboards) for the purpose of decorative changes. In essence, 3D molding of the wood surface is analogous to the direct uneven pressing of a sheet in which the applied force acts in a single direction. Pressing is a discontinuous method of surface molding and performed in a heated hydraulic press. Alternatively, continuous wood surface molding is accomplished with engraved rollers. The final product of this process is a wood component with formed surfaces which has use as decorative elements in furniture manufacturing (Gaff and Gáborík 2009).

Some deficiencies of this process are shape instability and poor quality of the 3D molded surface. On surfaces treated with uneven pressing, two types of roughness are found (Blomberg 2006). The first type is micro-raggedness or surface roughness, as defined by ISO standards (ISO 4287 1975; ISO 468 1975). The second type is macro-raggedness or cracks, which are formed due to the uneven distribution of stresses during the 3D molding. Cracks are defects visible to the unaided eye, which detracts from the desired decorative effect. It is necessary to prevent the formation of these cracks during the uneven pressing process, since their removal after 3D molding is difficult. While a surface modified in this manner can be evaluated using various methods, the evaluation of the surface quality is typically based on a fast and accurate roughness assessment

(Ando and Onda 1999). Despite frequent use of the method, the surface quality cannot always be evaluated comprehensively, particularly when the complex and expensive equipment is not readily available. Both a limited measurement range and the human factor affect surface quality assessment using the roughness test (Zemiar and Gaff 2005; Zemiar *et al.* 2004).

The formation of cracks on a decorative wood surface is problematic, and typical for such processes as wood drying, slicing, peeling, and embossing as well as decorative 3D pressing (Barcík *et al.* 2013). This study assessed the surface quality after uneven decorative pressing or embossing using the discontinuous method. Since no analytical method is available for the objective assessment of 3D molded wood surfaces (Bergander and Salmen 2002), our group developed software (*i.e.*, SURFACE) to measure and evaluate the size of cracks on a molded surface.

The objective of this study was to design appropriate methodology for the use of novel software (*i.e*., SURFACE) to identify cracks on an embossed surface and determine the impact of selected factors on surface quality. The goal was to identify major macroscopic defects that cannot be identified by the mean of the roughness test due to its low measurement range (in order of micrometers) while the cracks generated during the embossing are typically greater (in the order of millimeters). Parameters that were monitored include shape of tool face, direction of wood fibers, surface compression, penetration depth of tool, surface treatment by moistening, and pressure temperature of tool.

EXPERIMENTAL

Materials

The samples used in the tests consisted of aspen wood originating from the Poľana area in Slovakia, with dimensions of 35 mm x 35 mm x 15 mm (Fig. 1). The samples were conditioned for a moisture content between 8% and 16%.

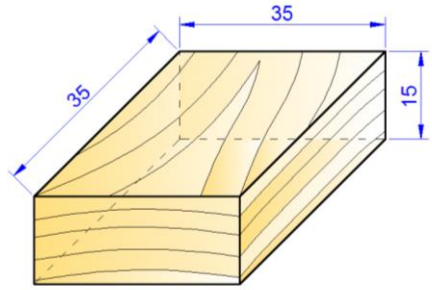

Fig. 1. Schematic illustrating the dimensions of the aspen wood

Methods

The evaluation of wood surface quality after surface 3D molding was based on the use of novel software to calculate the ratio of surface cracks relative to the surface area. The goal was to identify major macroscopic defects that cannot be identified by the mean of the roughness test due to its low measurement range. The measurement range of conventional roughness meter is in order of micrometers, while the cracks generated during the embossing were typically greater, with dimensions measured in millimeters.

Shape of tool face

Three typical tool wedges (*i.e.*, a 45° tip, a convex tip, and a concave tip) manufactured in our mechanical lab to specification (Fig. 2) were fixed in a tensile-testing apparatus (Fig. 3a) and pressed into the test piece surface within the defined compression depth (*e.g.*, 2, 4, and 6 mm) (Figs. 3b, 3c, and 3d). The tool face shape, along with orientation, compression depth, moisture of the wood, and temperature of the wood are critical factors that affect the final surface quality.

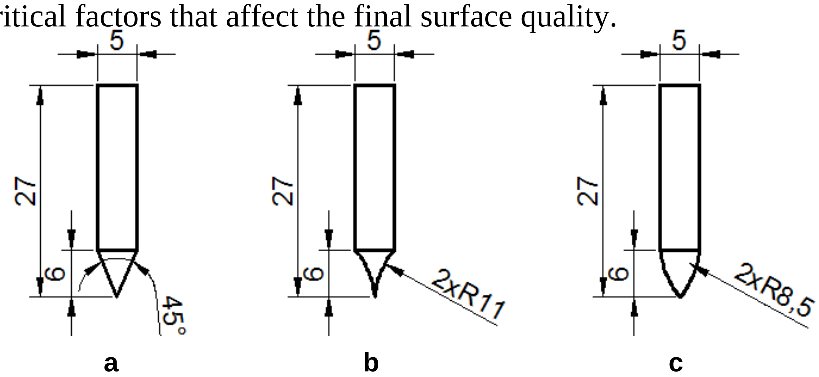

Fig. 2. Tool wedge shapes. (a) 45°tip; (b) convex tip; and (c) concave tip

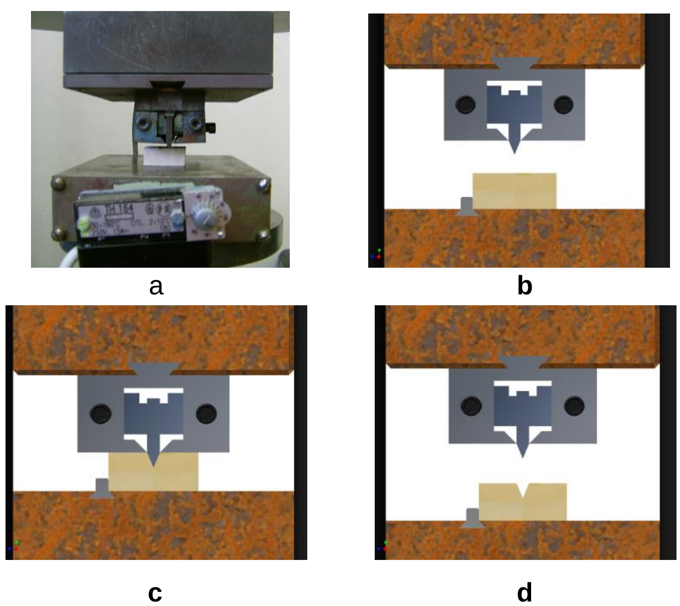

Fig. 3. (a) Testing tool with fixed tool wedge. Embossing of wood by tool wedges (b) before compression, (c) during compression, and (d) after compression

Direction of wood fibers

Each edge shown in Figs. 2a, 2b, and 2c were pressed perpendicularly to the tangential surface, and oriented parallel to the wood fibers (Fig. 4a), perpendicular to the fibers (Fig. 4b), or 45° to the fibers (Fig. 4c) as shown in the compression scheme (Fig. 3).

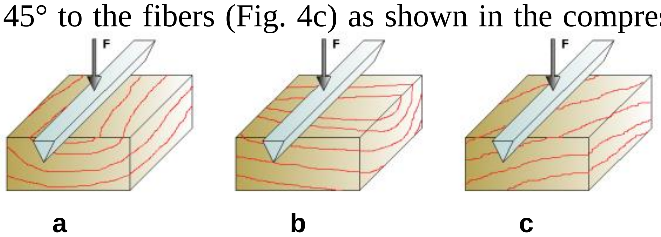

Fig. 4. Position of tool wedges. (a) parallel to fibers; (b) perpendicular to fibers; and (c) 45° angle

The wedges were compressed to three different depths (2, 4, and 6 mm) at a compression speed of 10 mm/min; once depth was achieved, the wedge was immediately retracted without further compacting.

Surface compression

The surface quality was determined on the compressed (2 mm relative to total thickness) (Fig. 5a) and non-compressed samples (Fig. 5b). The wedge overlap was set according to the required compression depth, and once the wedge was compressed the zone around the embossed area became thicker. Once the wedge achieved, the defined depth (*e.g.*, 2 mm, 4 mm, or 6mm), the entire surface of the test piece was compacted to decrease the original thickness by 2 mm (Figs. 5a and 5b). The extent of the thickened zone was monitored by the tensile-testing machine scale. The results on the test pieces with wedge compression and subsequent surface compacting (Figs. 5a and 5b) were compared with the results on the pieces with wedge compression to a defined depth without the surface compacting (Figs. 3b, 3c, and 3d). The test piece thickness did not change, and was constant for all test piece groups.

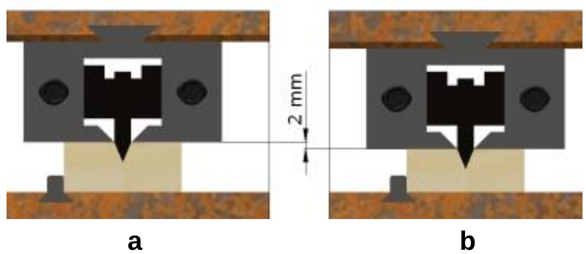

Fig. 5. Schematic representation of (a) compressed and (b) non-compressed samples

Penetration depth of tool

The tool wedges were pressed into the wood samples at 2 mm (Fig. 6a), 4 mm (Fig. 6b), and 6 mm (Fig. 6c), and released without further compacting.

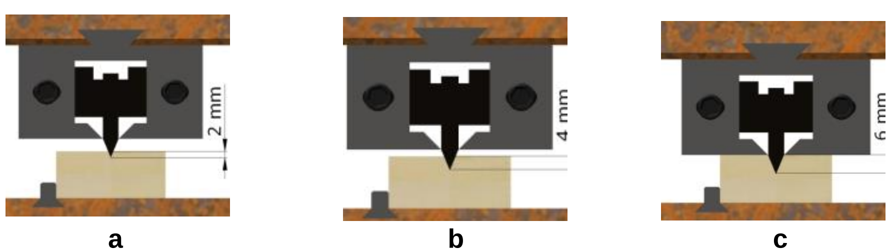

Fig. 6. Pressing wedges into samples. (a) 2 mm; (b) 4 mm; and (c) 6 mm

Surface treatment by moistening

The wood samples were moistened by immersion into water for 1 min, then examined and compared with dry control samples to determine the impact of the wood surface wetting on the wood forming capability. The area with the cracks following embossment was checked on the samples subject to moistening and compared with the results measured on samples not subject to moistening. The average moisture after soaking, as measured by a GHH 91 digital moisture meter (Greisinger Electronic, Germany), was 52%.

Pressure temperature of tool

Both unheated (room temperature; 20 °C) and heated (160 °C) tool wedges were pressed into the sample surfaces according to the method of Gaff and Zemiar (2008) in order to determine the influence of heat as a plasticizing agent. The wedges were heated by resistance heating in the pressing apparatus (Fig. 3a), which was equipped with a thermal switch to maintain the required temperature of the wedges. The wedges were extracted immediately after being compressed into the wood.

Calibration, surface scan, surface quality evaluation, and export of results

A photograph of a calibration image (Fig. 7a) serves as the correct scale conversion for the SURFACE software. Therefore, the digital photograph must be taken from the same lens distance as the test sample. The digital image of the calibration photo was imported into the SURFACE software and the actual distance between the vertical lines (L) shown in Fig. 7 is input, which allows the software to compute correctly the dimensions of the cracks in the wood.

In order to determine the area of the cracks, a digital image of the wood surface (Fig. 7b) is analyzed by the software, taking into account the evaluated area versus the crack area ratio (Fig. 7c).

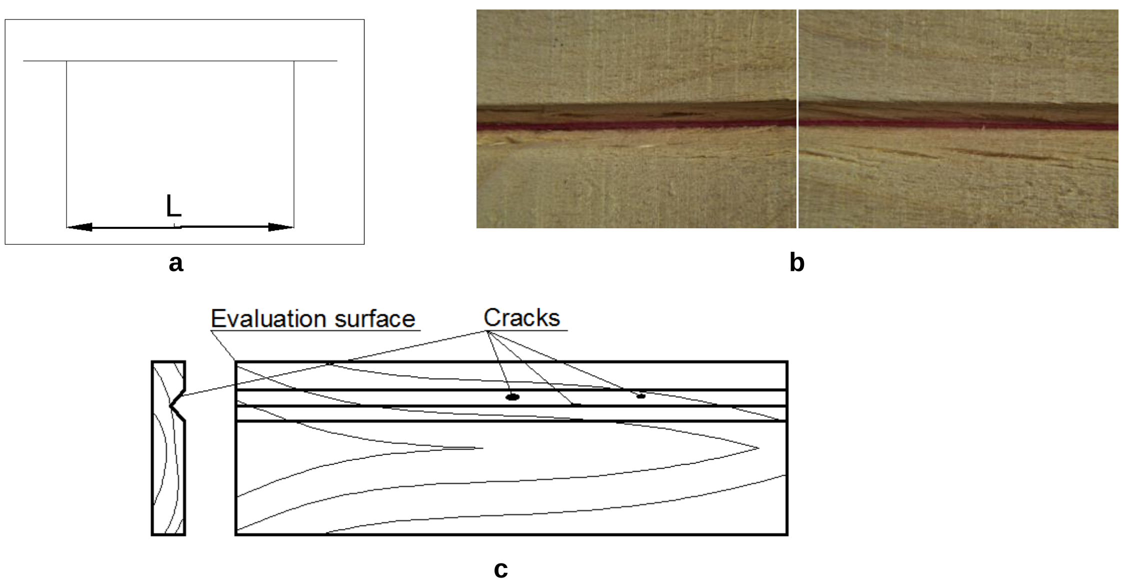

Fig. 7. Use of SURFACE software. (a) Schematic illustration of calibration image, (b) digital images used to calculate the area of the crack, and (c) measurement and evaluation principle of SURFACE software

Based upon the color contrast, the software identifies the size of cracks: surface cracks are visualized as significantly darker spots (Fig. 7b). Therefore, a first-class soft light is required so that the wood surface will be illuminated without shadows on this surface. In order to achieve sufficient depth of focus, the basic lens of a digital camera needs to be set to a higher blind number, often from 8 to 11. The software has the feature of optional correction of an identified area. The purpose of this correction is to prevent the application to include into the group of cracks also such spots, which are not cracks. For example, these could include burnt surface, more colored parts of the wood structure, *etc.* The correction is based on the change of colors contrast sensitivity. After the evaluation, the software will generate the digital image of the evaluated area (Fig. 8), where the identified cracks are accentuated with green color. A visual check can be made on the resulting digital image, and the obtained digital image (Fig. 8) can be compared with the original digital image of the surface (Fig. 6b). If the software has been included into the group of surface cracks and also the burnt area or another color deviation, then the undesirable area can be removed from the selection within the next step.

The designed SURFACE software was used to evaluate the images. A greater or lesser amount of cracks of various sizes characterize the surface of the embossed wood. The cracks differ by color from the undamaged surface.

The software determines the crack area on the scanned wood surface and subsequently the percentage related to the overall evaluated area, as computed in Eq. 1,

$$\mathrm{Stp} = \frac{\mathrm{St}}{Sc} \tag{1}$$

where Stp is the ratio of related cracks to the overall evaluated area, St is the area of the cracks (mm^2), and S*c* is the overall evaluated area (mm^2).

The SURFACE software exports the data into Microsoft® Excel, so that the results subsequently can be presented in diagrams and statistics.

This method has proven to be valid, and thereby it is possible to exactly measure and subsequently evaluate the cracks on the molded surfaces. Figure 8 shows the software output for the evaluation of the cracks. The evaluated surface of the test sample is shown in red color and the cracks identified by the software in yellow. Subsequently, the software calculates the overall area of the sample and the area of the cracks.

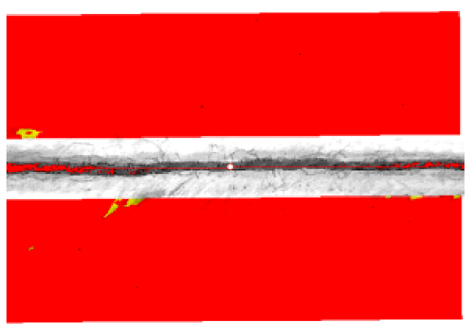

Fig. 8. Graphic evaluation and calculation of the cracks on the wood surface

RESULTS AND DISCUSSION

Table 1 shows the combinations of influencing factors and the basic statistical characteristics. The data (as calculated by SURFACE software) are listed in ascending order by the average value of the crack area on the embossed surface. As the results are very extensive, only a portion of the final table of statistical characteristics is shown. Microsoft® Excel was used for the evaluation, sorting the measured data in ascending order of the crack ratios.

While evaluating the effect of the 7 factors on the monitored feature, even a change of 1 of the factors may change totally the final result: the surface quality.

Therefore we conclude by recommending a set of parameters whose observance gave us the best quality.

The test wood group with the lowest crack ratio on the embossed surface is listed first in the table and the group with the highest crack ratio is listed last. Based on the results processed in this manner, the most suitable combination of factors was determined.

As shown in the Table 1, the lowest crack area was found at the test samples 16 and 17 and the highest crack area in test sample 198.

Table 1. Basic Characteristics Evaluating the Effect of Different Combinations of Factors on Cracks Area of Embossed Wood

Sample No.	W (%)	Direction of tip	Heat treatment	Moistening treatment	Wedge penetration depth	Surface compression	Wedge shape	Average value of crack area	Number of measurements	Standard deviation	Variation coefficient
16	8	parallel	20	Without moistening	6	With compression	45° tip	0	10	0.00	
17	8	parallel	20	Without moistening	6	With compression	convex tip	0	10	0.00	
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432	16	slantwise	160	With moistening	6	With compression	concave tip	0.25	10	0.12	47.94
198	8	slantwise	160	Without moistening	6	With compression	concave tip	0.34	10	0.07	20.65

W, percent of initial moisture
Note: The dots in rows 3 through 5 means the data is truncated, since 432 test groups were compared under various combinations of factors

While evaluating the effect of the 7 factors on the monitored feature, even a change of 1 of the factors may completely change the final result: the surface quality. Therefore we conclude by recommending a set of parameters whose observance gave us the best quality.

The results have shown that for the mentioned molding method, the surface embossing is unambiguously better at lower moisture of 8%. As shown in the table, the moisture increase will cause the cracks portion on the surface.

The wedge orientation related to the wood fibers orientation is a factor that cannot be prevented during the wood surface embossing. We may only mention that the best results were obtained by the mean of wedge use in the direction of the fibers.

Generally, we found better results on the pieces when non-heated wedges were used. The results prove that the wedge heating is not appropriate as far as the obtained quality concerns.

We monitored the depth effect from 2 to 6 mm herein. It was found out that while observing the recommended parameters, even at 6 mm an embossment shape with convenient surface quality can be achieved.

According to the results, the embossment-affected zone compaction has a positive impact on the surface quality.

As far as the wedge shape concerns, the best results were found for a wedge with 45° shape of the tip and for a tip of convex shape. However, the practice requires one to deal also with other tip types. It is therefore recommendable to use a more detailed analysis with this issue also in the future.

Each test sample group represents different combination of stored factors, *i.e.,* a different surface 3D molding process. Based on the obtained results, it is possible to identify which of the monitored combinations are deemed better relative to the formation of surface cracks. As shown in Table 1, the optimal combination was found in the test No. 16 group. For this combination of monitored factors, no cracks were generated on the embossed surface. Therefore, this combination of factors can be deemed as optimal.

Potential uses of this software include determination of burned area while finding out the ignitability of upholstery fabrics and determination of contact angle while evaluating the wood surface soaking rate of painting materials.

CONCLUSIONS

1. This work introduces the testing of an innovative method of surface quality evaluation. Data is provided on the combined action of various monitored factors and summarizes the theoretical contributions on the monitored factors.
2. Based on the results, the following combination of monitored factors of the optimal embossed surface quality are recommended: initial moisture content 8%; orientation of the wedge tip parallel to wood fibers; wedge heating to 20 °C; no moistening of wood; wedge penetration depth 6 mm; surface compression; and either hollow wedge or wedge with an angle of 45°. For wood surface embossing, it is very important to take into account the influence of all factors entering the process.

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