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DETERMINATION OF THE MINIMUM INTACT DIMENSIONS AVAILABLE IN PRACTICAL APPLICATIONS OF LASER CUTTING

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Abstract:
The reuse of wastes is one of the main requirements of sustainable wood processing. Technologies available for waste management however are currently suited to the reuse of large quantities. This study investigates the utilisation of individual pieces of sawn wood and veneer wastes by laser cutting, with special emphasis on the search for the practical minimum intact dimension that can be produced by laser cutting.

Key words*: laser; laser cutting; optimisation; reuse; wood material.*

INTRODUCTION

In wood-processing, just as in any branches of industry, wastes of raw material are produced that should be managed in some ways. There exist a number of possibilities to do this, such as

- reuse,
- recycling,
- energy generation,
- final disposal (Németh 2009).

However, these solutions can only be economical above a certain volume of wastes to be treated. What can be done when wastes of more valuable raw material are produced in small quantities? This paper seeks to answer this question.

OBJECTIVE

In the manufacture of wood-based products, wastes of sizing or reject parts are produced in a number of different processing technologies (Németh and Varga 2004). These wastes are typical while processing solid wood, veneer or hardboard. When these types of waste are in relatively small quantities, their utilisation should allow for added value that substantially raises their market potential.

That is, the usual pulping or combustion cannot be a solution because it will not result in sufficient added value. There exists, however, branches of industry, where these kinds of raw material do have value. It is true that their current market is limited, but may grow to a real potential in the future (Deák 2011). Such branches may include jewellery, inlay-type decoration and model making. All three areas work typically with high added value. Wastes of veneers of uncommon, or even some common wood species may serve for quality raw material, where realisation of added value is based, beyond sophisticated elaboration, on the aesthetics of the final product (Figures 1 and 2).

Fig. 1.
Pendant ear rings made of wood by laser made cut (Kámán 2013).

Fig. 2.
Furniture face elements decorated by laser made cut (Egedi and Antal 2014).

In order to get good results in practice, proper processing parameters are needed. First of all the smallest dimension that it is possible to shape must be known. It must be borne in mind that in the case of raw materials of different origin even small failures in processing may result in destruction of aesthetics. Good quality can only be attained through well-adjusted working parameters.

The quality of a laser made cut can be defined in many different ways. Some such criteria are:

- kerf width,
- cut edge squareness,
- inner side slope of the kerf,
- heat affected zone extent,
- dross appearance,
- surface roughness (striations), the wavelength, the depth (Di Pietro and Yao 1992).

MATERIALS AND METHOD

Materials

Laser made cut tests were performed on solid wood and veneer samples as well as on wood composites. Both types of materials can be optimally processed according to industrial criteria by laser made cutting with properly chosen working parameters (Gerencsér 2003). Properties of the raw material to be cut have to be taken into account, since these factors largely influence the results (Belic 1989). The species of wood used were beech (Fagus sylvatica) in the form of 4mm thick solid samples and 1.2mm thick sliced veneer. Among wood composites samples of HDF (High Density Hardboard) of 2.5mm, 3mm, 4mm and 5mm thickness respectively were tested. Before starting cutting tests, the samples were stored in the testing laboratory at a temperature of 21°C and relative humidity of 48-49%. Moisture content (U) of the samples and their corresponding density (ϱ) is shown in Table 1.

Table 1

Density and moisture content of the test samples

Material (thickness)	beech solid (4 mm)	beech veneer (1.2 mm)	HDF (2,5 mm)	HDF (3 mm)	HDF (4 mm)	HDF (5 mm)
U (%)	8.7	8.6	9.1	8.9	8.8	8.9
ρ (kg/m^3)	709	715	887	856	845	840

Parameters of the testing equipment

Laser cut tests were performed on a Universal ILS 9.75D (Fig. 3) type laser cut equipment, using 2-inch lens with focus adjusted to the surface of the material to be cut. The maximum laser power in the middle of the work space with this equipment is 160 W ($P_{head-top}$=83 W, $P_{head-bottom}$=77 W, P_{max}=$P_{head-top}$+$P_{head-bottom}$). Maximum laser power was applied.

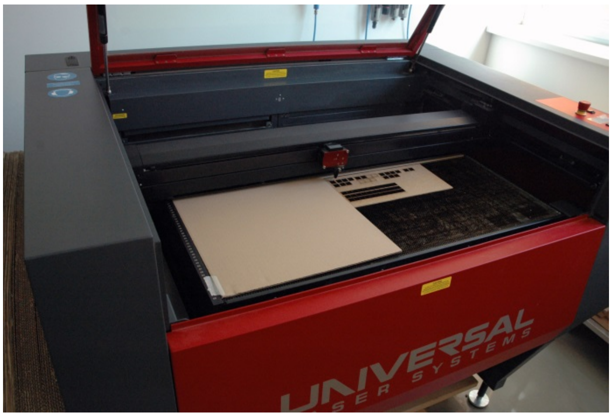

Fig. 3.
Laser cut equipment, test material in the center of the working area.

Study of speed of through cut

In the course of the tests the maximal through-cut speed of the different samples was first determined. This parameter means the feed speed of the head when the laser beam just cuts through the material at the maximum laser power. A thickness can be regarded through cut if the pattern made by cut (15mm by 15mm square, Fig. 4) falls out by itself (Fig. 5).

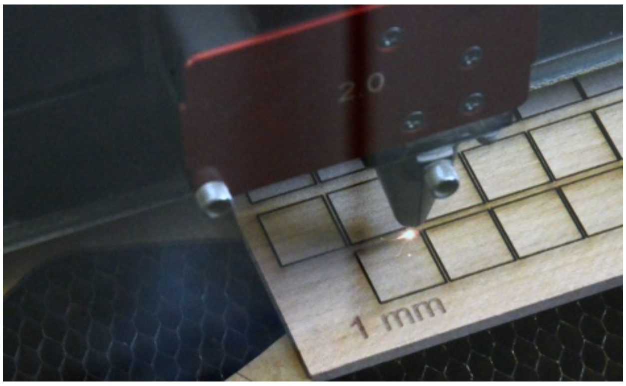

Fig. 4.
Cutting squares 15 by 15mm for determining the maximal speed of cut.

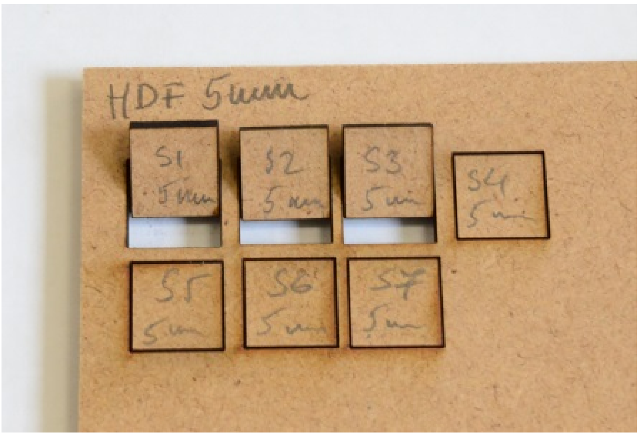

Fig. 5.
5mm thick HDF not cut through at a speed rate of S4 (20mm/s).

Using the controller of the equipment, the feed speed can be defined as a percentage value (S) where 100% means the maximum head speed available; equipment manufacturer's specification of the latter is v_{head}, max= 500mm/s. Cutting tests of all samples were started at a speed level of 1%, that is 5mm/s. After each cut, the next cut was performed at a speed of 1% higher. The process was repeated until the pattern did not fall out. Then again, the speed of the last complete through-cut was increased in 0.1% steps until complete through-cut was attained.

Table 2

Complete through cut speeds established at different samples

Sample	beech solid	beech veneer	HDF (2,5 mm)	HDF	HDF (4 mm)	HDF (5 mm)
S (%)	6.5	38.2	8.7	6.6	3.8	3.6
Speed (mm/s)	32.5	191	43.5	33	19	18

Through-cut speeds established for the different sample materials are shown in Table 2. It can be seen how the type of material and thickness influences the applicable cutting speed. In the case of HDF, as could be expected, speed of through cut decreases with increasing thickness of the material for example the time needed for through cut increases with thickness.

Determination of the intact width obtained by cut

Using the established cutting speeds one can determine the minimum width of the cut patterns that is still possible in different practical applications (Fig. 6). Width is defined in this case as the distance (t) between the two adjacent surfaces on the same continuous piece of material obtained by laser cut.

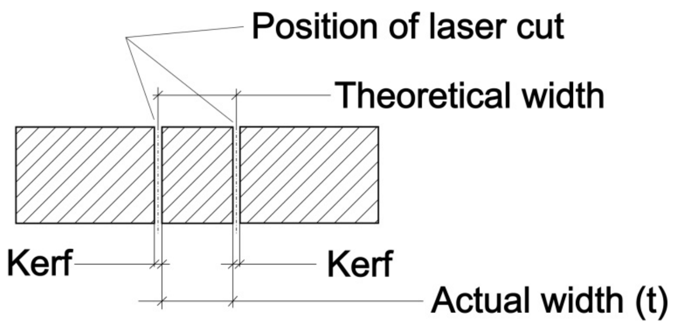

Fig. 6.
Definition of width obtained by cut.

In the course of the tests cut patterns were prepared by drawing 15mm by 15mm squares side by side on the faces of the samples. The distance between the squares (theoretical width) was started at 1mm and decreased in 0.1mm steps until 0.1mm (Fig. 7). In preparing the cutting pattern, the line thickness used in drawing has no relevance, since the laser cut equipment interprets the use of a given type of line in the graphic software (in our case hairline, Coreldraw X5) as a one-time head travel along the line. Therefore, the resulting kerf and actual width is dependent on the adjusted parameters of the equipment as well as on the properties of the material to be cut.

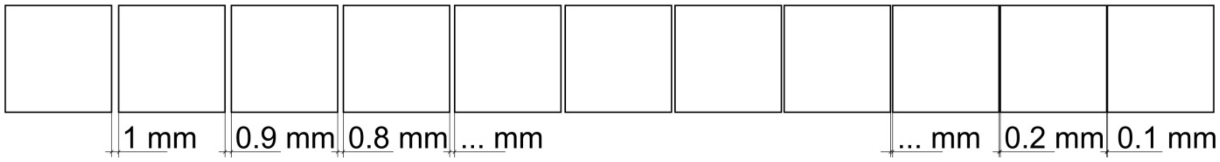

Fig. 7.
Cut pattern, decreasing distance between squares.

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After performing the laser cuts the individual parts of the pattern were allowed to drop out of their places; care was exercised not to harm the remaining thin material. Since the cutting speeds to be applied were established beforehand, the squares cut fell out by themselves (Fig. 8).

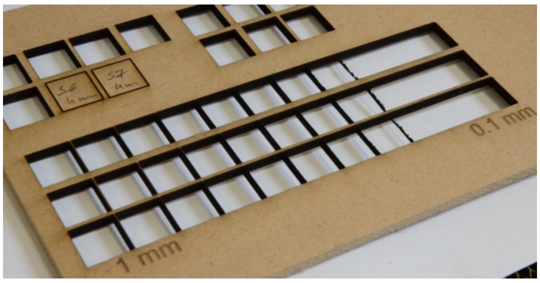

Fig. 8.
Cut pattern of 4mm HDF for the determination of the minimum width obtainable by laser cut with planned widths of 1.0 through 0.1mm.

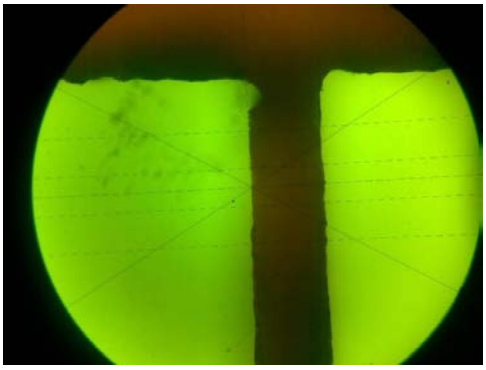

Fig. 9.
Microscopic view and measurement of cut width (t); measuring line fitted to the left side of the detail to be measured.

RESULTS & DISCUSSION

Completing the cuts according to the patterns described above it was found that the remaining material between cut lines with some planned (theoretical) widths became so thin (because of burning) that it could not be measured. The cut of each pattern was performed in three replications for all materials tested (Fig. 9). Results of measurements are summarised in tables 3 to 8 below. The first column in these tables shows the theoretical, planned dimensions from 1.0mm through 0.1mm given in the cut patterns. The second column contains the actual widths remaining after cut, as an average of the three replicates, with standard deviation in the fourth column. The last column in these tables contains remarks of practical importance.

Table 3

Obtained cut dimensions of 4mm thick beech (Fagus Sylvatica) samples

Sample: beech, solid wood (Fagus Sylvatica)		4mm thick	
Theoretical width of remaining part	Average actual width ($\bar{t}$)	Standard Deviation	Remark
1.0 mm	0.79	0.02	-
0.9 mm	0.68	0.07	-
0.8 mm	0.62	0.02	-
0.7 mm	0.56	0.01	-
0.6 mm	0.43	0.03	-
0.5 mm	0.35	0.01	-
0.4 mm	0.23	0.01	-
0.3 mm	-	-	No measurable data
0.2 mm	-	-	No measurable data
0.1 mm	-	-	No measurable data

Table 4

Obtained cut dimensions of 1.2mm thick beech (Fagus Sylvatica) veneer samples

Sample: beech, veneer (Fagus Sylvatica)		1.2mm thick	
Theoretical width of remaining part	Average actual width ($\bar{t}$)	Standard Deviation	Remark
1.0 mm	0.82	0.02	-
0.9 mm	0.72	0.02	-
0.8 mm	0.63	0.01	-
0.7 mm	0.52	0.02	-
0.6 mm	0.38	0.02	-
0.5 mm	0.31	0.03	-
0.4 mm	0.14	0.01	-
0.3 mm	-	-	No measurable data
0.2 mm	-	-	No measurable data
0.1 mm	-	-	No measurable data

Table 5

Cut dimensions obtained for 5mm thick hardboard samples

Sample: HDF		5mm thick	
Theoretical width of remaining part	Average actual width ($\bar{t}$)	Standard Deviation	Remark
1.0 mm	0.77	0.01	-
0.9 mm	0.68	0.01	-
0.8 mm	0.63	0.02	-
0.7 mm	0.48	0.02	-
0.6 mm	0.44	0.06	-
0.5 mm	0.40	0.02	-
0.4 mm	0.27	0.03	-
0.3 mm	-	-	No measurable data
0.2 mm	-	-	No measurable data
0.1 mm	-	-	No measurable data

Table 6

Cut dimensions obtained for 4mm thick hardboard samples

Sample: HDF		4mm thick	
Theoretical width of remaining part	Average actual width ($\bar{t}$)	Standard Deviation	Remark
1.0 mm	0.85	0.02	-
0.9 mm	0.77	0.02	-
0.8 mm	0.68	0.02	-
0.7 mm	0.55	0.02	-
0.6 mm	0.48	0.02	-
0.5 mm	0.37	0.01	-
0.4 mm	0.21	0.04	-
0.3 mm	0.13	0.04	-
0.2 mm	-	-	No measurable data
0.1 mm	-	-	No measurable data

Table 7

Cut dimensions obtained for 3mm thick hardboard samples

Sample: HDF		3mm thick	
Theoretical width of remaining part	Average actual width ($\bar{t}$)	Standard Deviation	Remark
1.0 mm	0.84	0.01	-
0.9 mm	0.77	0.03	-
0.8 mm	0.67	0.05	-
0.7 mm	0.58	0.01	-
0.6 mm	0.51	0.01	-
0.5 mm	0.37	0.01	-
0.4 mm	0.25	0.02	-
0.3 mm	0.13	0.01	-
0.2 mm	-	-	No measurable data
0.1 mm	-	-	No measurable data

Table 8

Cut dimensions obtained for 2.5mm thick harboard samples

Sample: HDF		2.5mm thick	
Theoretical width of remaining part	Average actual width ($\bar{t}$)	Standard Deviation	Remark
1.0 mm	0.84	0.01	-
0.9 mm	0.77	0.05	-
0.8 mm	0.68	0.03	-
0.7 mm	0.56	0.01	-
0.6 mm	0.45	0.09	-
0.5 mm	0.35	0.01	-
0.4 mm	0.25	0.01	-
0.3 mm	0.13	0.02	-
0.2 mm	-	-	No measurable data
0.1 mm	-	-	No measurable data

The actual widths obtained by laser cut were plotted against the theoretical (nominal), see Fig. 10. The plotted values in each case represented the average of the three replicates. As seen in Fig. 10, a straight line can be fitted to the data points in the case of all samples.

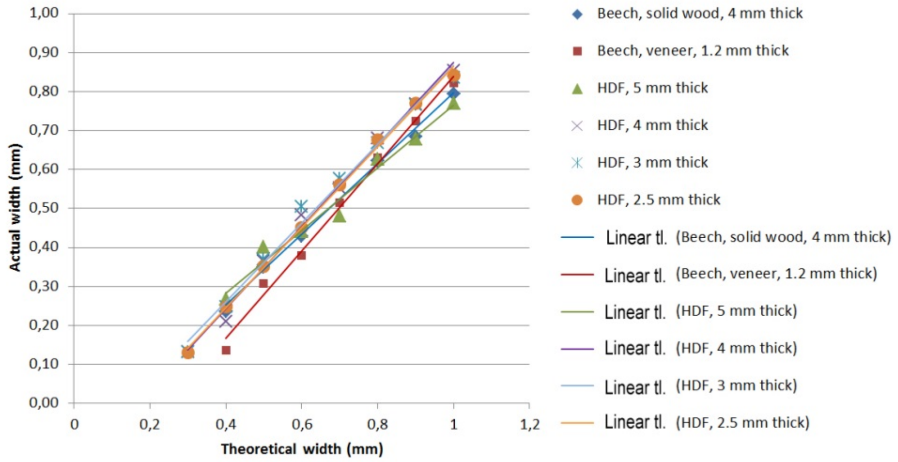

Fig. 10.
Linear trend lines fitted to the actual width measurements as a function of nominal width values in the case of the different samples tested.

Table 9

Parameters of linear regression of nominal and actual widths

Sample	Slope	Intercept	R^2
Beech solid (4 mm)	0.9055	-0.109	0.9901
Beech veneer (1.2 mm)	1.1205	-0.2819	0.9926
HDF (5 mm)	0.8036	-0.0392	0.9771
HDF (4 mm)	1.0544	-0.1799	0.9935
HDF (3 mm)	1.0107	-0.1445	0.9907
HDF (2.5 mm)	1.0337	-0.1686	0.9975

It can be seen from Fig. 10 and Table 9, that straight lines fit the measured data quite well. Furthermore, their slope is close to unity (~0.8 to1.2) for all tested materials, which means that the deviation between the nominal and actual width in the case of a material type is constant, not depending on the nominal pattern thickness. The deviation in all cases takes a negative value; i.e. the actual width is always smaller than the nominal one. This is explained by the kerf of infinite size produced by the pencil of the laser beam.

CONCLUSIONS

It was found that with all types of samples, that all three replications of laser made cuts, with the established speeds, resulted in complete through cut. Furthermore, performing the cut-outs, the remaining widths of the material did not scatter much in a given sample type. Indeed the coefficient of variation was found to be between 2.5% and 13.6%, most often remaining well below 10.0%. From these facts it follows that the materials of the tested samples are homogeneous enough and the performance of the equipment is uniform so that the results can be utilised for practical applications.

It was desired to verify, through the cut tests and measurements, the practical feasibility of worked dimensions that can be relied on in the course of processing wood-based raw materials for high value added applications. The measured results seem to be consistent for a given type of material, hence they can be taken as guidance for practical application in jewellery making, inlay decoration as well as model making when deciding on the detail dimensions.

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