

Abrasive Water Jet Cutting vs. Laser Jet Cutting of Oak Wood Panels

Camelia Cosereanu^{1*}, Gheorghe Cosmin Spirchez¹, Antonela Lungu¹, Sergiu-Valeriu Georgescu¹,
Alexandru Catalin Filip², Sergiu Racasan¹

¹ Transilvania University of Brasov, Department of Wood Processing and Wood Products Design,
Bdul Eroilor nr.29, 500036-Brasov, Romania

² Transilvania University of Brasov, Department of Manufacturing Engineering, Bdul Eroilor nr.29,
500036-Brasov, Romania.

E-mail: cboieriu@unitbv.ro; cosmin.spirchez@unitbv.ro; antonela.petrascu@unitbv.ro;
sergiu.georgescu@unitbv.ro; filipal@unitbv.ro; sergiu.racasan@unitbv.ro

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ABSTRACT

Two oak (*Quercus Robur*) wood panels were cut by abrasive water jet and laser jet respectively, using a pattern composed of circles with various diameters. The processing accuracy and the kerf widths were determined both for the holes and circles cut from the panels using the masks generated by ImageJ software, for which the area is calculated as an output data. The dimensional stability, the size of the kerf and the smoothness of the contour evaluated by microscope investigation, the visual assessment of the panel surfaces after cutting are the objects of the comparison between the abrasive water jet cutting and the laser jet cutting methods. The results show that a better processing accuracy was obtained by using the laser jet cutting method. The dimensional stability in terms of flatness was affected by the wood sensitivity to water, so deformations occurred after abrasive waterjet cutting of panels. They decreased in time, but cracks occurred along the wood grains in some areas.

INTRODUCTION

Water jet and laser jet cutting of wood are alternative methods to cut wood panels, offering thus solutions to problems like difficult-to-machine by conventional machining processes, high noise and dust exposure, contributing thus to an environment friendly production.

Water jet cutting method is based on micro erosion occurring when large volume of water is forced through a nozzle of reduced cross section at high velocity and high pressure (Babu Rao et al. 2009).

Generally, the studies on waterjet cutting of wood involve the assessment of moisture uptake, kerf width and surface roughness (Gerencsér and Bejő 2007, Kminiak and Barcik 2011, Kminiak and Gaff 2014, Kvietková 2014, Sreekesh and Govindan 2014). Among the factors that have influence on the quality of the processed wood surface, the water jet pressure is the most important one, followed by the abrasive size, wood density and feeding speed (Wang 2012). An abrasive flow of 450 g/min at a feed speed of 400 mm/min were considered to be optimum for cutting wood-based composites (Kvietkova et al. 2014), and the feed rate of 250 mm/s, cutting pressure of 310 KPa and abrasive flow rate of 35 kg/h were considered the optimum processing parameters to cut red oak wood (Xie et al. 2020). It was found (Pelit and Yaman 2020) that the roughness parameters increase with the increase of the specimen thickness and of the system feed rate during abrasive water jet cutting. An aspect that cannot be neglected in the use of this technology is the wettability of wood. Two researchers (Cioppa and Papetti 2014) have shown that the objects cut with water jet presented deformations because of the property of wood to absorb water. Still, the fields of application of this cutting method are expanding to other sectors, such as agriculture and agricultural engineering (Perotti et al. 2021, Cui et al. 2022).

The cutting process of wood products with a CO₂ laser beam is evaluated as a highly precise method having as result a narrow kerf width, and a smooth surface (Kubovský et al. 2020). The precision of cut by laser have shown that the remaining width of the material did not scatter much, the variation against the nominal width being in the range 2.5% -13.6% (Horvath 2016). It was also demonstrated that the increase of the focal point position and of the laser power decreases the roughness of the cut section, whilst the increase of the cutting speed and of the air pressure decreases the roughness of the processed surface (Eltawahni et al. 2011). One of the drawbacks of this technology is the colour changes and some chemical modifications of wood (Li et al. 2018, Gurau et al. 2022). The processing accuracy can be

assessed by various methods of measurement and calculate the deviations, such as the circularity deviation (Costa Souza et al. 2011).

The present paper deals with the investigation of the accuracy of cutting oak wood panels with two environment friendly methods, namely abrasive water jet and laser cutting. The accuracy is assessed by measuring the various diameters of the holes and of the circles cut with the two methods with the help of the masks generated by ImageJ software, and by calculating the kerf width. The influence of the water uptake by the wood during the abrasive water jet cutting upon the dimensional stability was evaluated by measuring the panel thickness before and after cutting. The microscopic investigation of the contour is also the objects of the comparison between the abrasive water jet cutting and the laser jet cutting methods.

MATERIALS AND METHODS

Materials

Two oak (*Quercus Robur*) wood panels with dimensions of 440 mm x 440 mm x 16 mm, densities of 750 kg/m³ and 760 kg/m³ respectively, and moisture content of 8.5% for the first one and 8.2% for the second one were cut by abrasive water jet and laser jet respectively, using a pattern composed of seven rows of circles with various diameters, the smallest one being of 5 mm and the biggest one of 90 mm, with an increment of 5 mm (Figure 1a).

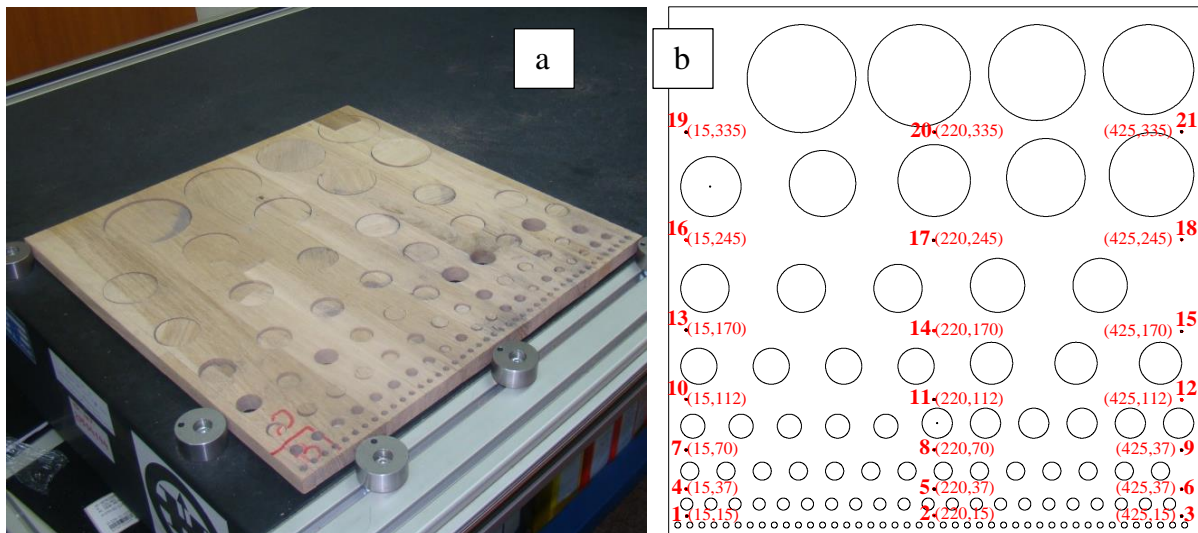


Figure 1: Oak panel after cutting (a) pattern and the measuring points for dimensional stability (b)

The 2D drawing of the pattern was drawn in AutoCAD 2012 version from Autodesk (San Francisco, California, United States) and transferred as .dxf file for processing. The twenty one points marked in the Figure 1b are the points in which the thickness was measured before and after cutting the panels with the two methods.

Equipment

The laser equipment used to cut the circles from the oak wood panel was a CO₂ laser engraver and cutting machine OmniBEAM 150 (Coherent manufacturer, Santa Clara, California, USA) with nitrogen assist gas, maximum power of 150 W, wavelength of 10.6 μm and maximum cutting speed of 50.8 m/min. The imported .dxf file drawn in AutoCAD software was used by BeamHMI software to set the cutting parameters at 100% power (150 W) and a speed of 40 m/min. The MAXIEM 1530 Abrasive Waterjet equipment (designed and manufactured at the OMAX factory in Kent, Washington, USA) was used for the abrasive waterjet cutting the second oak panel (Figure 2a). High pressure of 3448 bar, low pressure of 1379 bar, jewel diameter of 0.279 mm, abrasive flow rate of 0.340 kg/min, abrasive size of 80 mesh were used as setup. The average speed when cutting was of 498.73 mm/min.

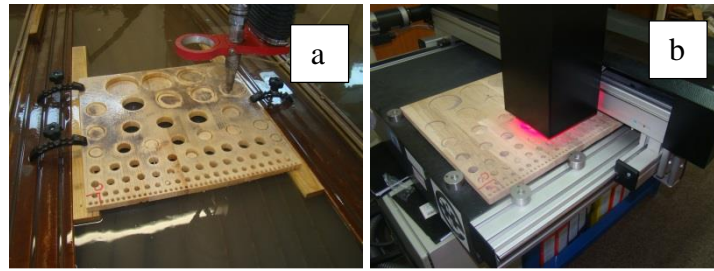


Figure 2: Abrasive waterjet cutting method with Maxiém 1530 equipment (a) OPTODesq equipment used to measure the flatness of the panels (b)

The OPTODesq equipment (Hecht manufacturer, Besigheim, Germany) presented in Figure 2b was used to measure the flatness of the panels before and after abrasive waterjet cutting, in order to assess the deformation of the panel after its immersion in water for 18 min, as long as the cutting process took place. The equipment is non-contact measurement one, having an accuracy of 0.01 mm.

Image processing software

After cutting, the panels were scanned and the traced images were processed for the holes and circles in CorelDraw X7 software. ImageJ software, an image processing program, was used to identify the shape and contour of the holes and circles cut from the panels, and to return a mask image, which transforms the traced image into grey scale with enhanced contrast (Figure 3), removing the unnecessary features. The software provided the measured area of the holes and circles masks.

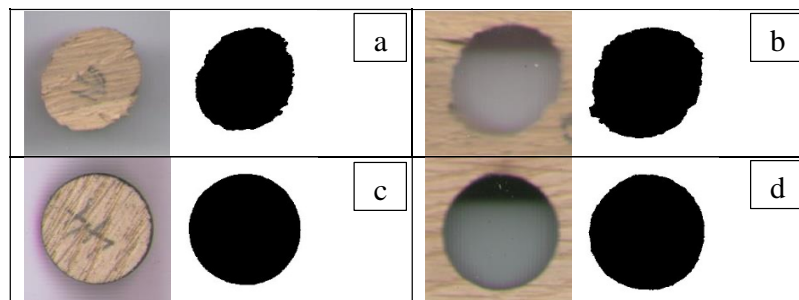


Figure 3: The mask generated by ImageJ software for circle with diameter of 15 mm circle cut by abrasive water jet method (a) and laser jet method (b) hole cut by abrasive waterjet method (c) and by laser jet (d)

RESULTS AND DISCUSSION

The processing accuracy

The results of the measurements obtained by ImageJ software are presented in Table 1. The ratios between the average values of the areas measured for holes and the theoretical area are higher in case of applying the laser cutting method compared with waterjet cutting one (in the range 0.32% to 32.5%), the highest differences being recorded for the smallest diameters. That means that the tolerances of the holes processed by laser cutting are higher than in the case of waterjet cutting. As regard to circles, the ratios between the theoretical area and the measured areas by ImageJ software are smaller in case of abrasive waterjet cutting compared with laser cutting (in the range 0.86% to 20.77%), which means that the tolerances of the circles are higher in this case. Based on the results in Table 1, the kerf widths were calculated from the differences between the holes areas and the circles areas. The average values of the kerf width were 1.16 mm when applying laser cutting method and 1.06 mm when applying abrasive waterjet cutting. As seen in the examples in Figure 3a and b, the deformations suffered by the holes and the circles were more pregnant in case of using abrasive waterjet method, especially for small diameters. The contours of the cuts microscopically revealed with 22.5x magnification show a smoother surface for laser cutting compared with the other method (Figure 4). The panels cut by abrasion waterjet method were deformed because of their capacity to absorb water. In order to evaluate the magnitude of the panel deformation, the measurements of the thicknesses in the 21 points marked on the drawing in Figure 1 were done before cutting and after 24 hours, 1 week and 1 month. The results are shown in Table 2. The

flatness is calculated as the difference between the maximum and the minimum measured thicknesses divided by the length of the panel.

Table 1: Results of the mask measurements with ImageJ software for the circles and holes

Diameter of the circle [mm]	Theoretical area [mm ²]	Average measured area by laser cutting [mm ²]		Average measured area by abrasive waterjet cutting [mm ²]		Ratio between measured and theoretical areas by laser cutting [%]		Ratio between measured and theoretical areas by abrasive waterjet cutting [%]	
		Holes	Circles	Holes	Circles	Holes	Circles	Holes	Circles
90	6358.5	6453.8	6280.4	6389.6	6185.4	101.50	98.77	100.49	97.28
85	5671.6	5761.5	5568.8	5743.3	5492.5	101.58	98.19	101.26	96.84
80	5024.0	5118.3	4917.3	5077.9	4852.3	101.88	97.88	101.07	96.58
75	4415.6	4531.6	4315.8	4452.6	4287.7	102.63	97.74	100.84	97.10
70	3846.5	3957.3	3751.7	3891.1	3718.0	102.88	97.53	101.16	96.66
65	3316.6	3389.9	3249.7	3345.2	3218.2	102.21	97.98	100.86	97.03
60	2826.0	2886.2	2754.9	2835.7	2732.1	102.13	97.49	100.34	96.68
55	2374.6	2426.2	2324.6	2385.2	2277.2	102.17	97.89	100.45	95.90
50	1962.5	2030.7	1906.2	1998.8	1861.9	103.47	97.13	101.85	94.87
45	1589.6	1652.3	1537.4	1624.9	1509.7	103.95	96.71	102.22	94.97
40	1256.0	1300.7	1209.2	1282.5	1169.9	103.62	96.27	102.11	93.15
35	961.6	995.9	927.4	980.4	895.3	103.56	96.44	101.95	93.10
30	706.5	735.3	674.3	728.1	646.1	104.08	95.44	103.06	91.44
25	490.6	519.9	466.1	505.6	439.9	105.97	94.99	103.05	89.65
20	314.0	328.1	293.4	326.3	274.3	106.40	93.44	103.93	87.34
15	176.6	193.6	162.6	187.9	148.3	109.62	92.06	106.42	83.95
10	78.5	92.09	71.0	83.2	58.5	117.32	90.5	105.96	74.47
5	19.6	27.4	16.3	21.0	12.2	139.64	82.96	107.14	62.19

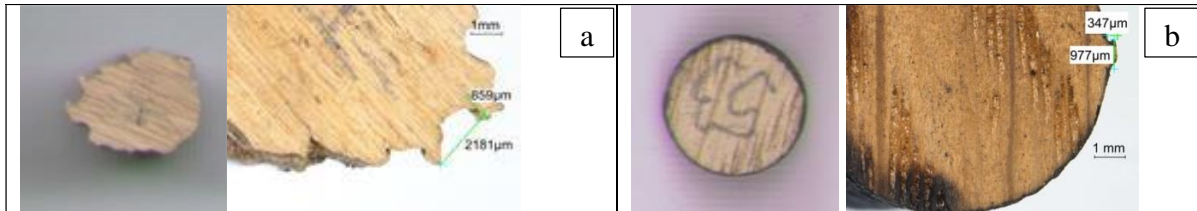


Figure 4: The circle of 10 mm diameter cut by abrasion waterjet method (left) and the contour with 22.5x magnification (right) (a) and the same by laser technology (b)

Table 2: Flatness of the oak panels measured before and after abrasive waterjet cutting

Characteristics	Before cutting	24 h after cutting	1 week after cutting	1 month after cutting
Flatness [mm/m]	0.95	5.43	4.05	2.43
Moisture content [%]	8.5	12.9	11.2	10.7

CONCLUSIONS

The calculated kerf widths based on the area measurements of the holes and circles with ImageJ software have narrow values of 1.16 mm when applying laser cutting method and 1.06 mm when applying abrasive waterjet cutting. The deformation of the oak panels increased after abrasive waterjet cutting of circles, but the deformation decreased in time, as the measurements after one week and one month show, but the decreasing of deformation had as drawbacks the occurrence of cracks in wood parallel to the grains, in some narrow areas between the holes. In case of laser jet cutting, the colour of the cut edges and of the surfaces around them became dark as the effect of the laser beam, whilst in the case of the water jet cutting, the entire surfaces of the resulted circles and of the remained panel were affected by the presence of the sand used in the combination with water, which printed a grey colour on the wood surface. The accuracy increased with the increasing of circles diameters for both methods, but the

microscopic investigation revealed an irregular contour of the circles and of the holes in case of applying the water jet cutting method.

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