Some machining properties of 4 wood species grown in Turkey

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Abstract: Determining wood machining properties and defining convenient usage areas for native wood species is important for evaluating surface quality. Wood machining is a performance criterion indicated after planing, shaping, turning, mortising, boring, and sanding. This study selected 2 softwood species (European black pine and cedar of Lebanon) as well as 2 hardwood species (sessile oak and black poplar), which are commonly used and grown in Turkey. Preparation of samples and machining were carried out according to the 2004 ASTM D 1666 standards for determining machining properties. Sessile oak (*Quercus petraea*) had an excellent performance in all machining processes. Black poplar (*Populus nigra* L.) yielded the lowest results for the sanding test. A perfect surface quality was obtained with a feed rate of 8.6 m/min for hardwoods at a 25° cutting angle in planing, and at a 15° angle for softwoods.

Key words: Wood, machining properties, planing, shaping, boring, sanding

1. Introduction

The wood products industry plays a very important role in the world economy. Wood has traditionally been the basic raw material for the furniture and joinery industries. One of the most important advantages of wood is its easy machinability in contrast to metal and plastic products. However, its nonuniform characteristics within and between species plays a significant role on its efficient and effective machining. Any surface defects due to an improper machining process will also reduce the quality of the final product, resulting in an increase in the cost of the manufactured unit. Therefore, it is important to evaluate machining parameters and relate them to raw material characteristics (Malkoçoğlu and Özdemir, 2006).

Davis and Nelson (1954) reported the machining effects of certain factors on wood finish quality and on power consumed in operating a molder. Davis (1959) reported that good machine work requires a machine in good mechanical condition with reasonably sharp cutting tools. Davis (1960) studied the machining properties of ponderosa pine and Douglas fir, as well as their density and growth rate. Stumbo (1960) compared the surface textures of sawn, planed, molded, and sanded surfaces. Davis (1962) gave information about fuzzy grain in planing operations. Cantin (1965) determined the machining properties of 16 eastern Canadian woods. Peters and Lutz (1966) determined some machining properties of 2 wood species grown in Hawaii. Woodson and McMillin

(1972) investigated boring operations in massive wooden material. Örs et al. (1991) investigated the machining of the tooth geometry of band saws on the surface quality of timber. Gürtekin (1996) investigated the machining of the cutting and feed rate of the wood planing machines used in the woodworking industry. Williams and Morris (1998) determined machining and related mechanical properties of 15 British Columbia wood species. Lihra and Ganev (1999) determined the manufacturing properties of 9 eastern Canadian softwood species. The best planing condition was obtained at a 15° rake angle and 20 knife marks per 2.54 cm of feed speed by Hernandez et al. (2001). Sandak and Tanaka (2005) presented a new type of sensor for 3-dimensional evaluation of surface geometrical properties. Malkoçoğlu and Özdemir (2006) determined the treatment properties of 5 Oriental beech woods grown in the eastern Black Sea region. Malkoçoğlu (2007) studied the planing properties and surface roughness of woods from Oriental beech. Ratnasingam and Scholz (2007) determined the planing properties of rubberwood grown in the Southeast Asian region. Sofuoğlu (2008) determined the machining properties of 2 softwood species and 2 hardwood species commonly used and grown in Turkey. Bustos et al. (2008) determined the hardness, planing, and molding properties of tamarack wood from natural forests. Farrokhpayam (2010) studied the characterization of surface defects in dark red meranti, melunak, and rubberwood in the planing process.

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Determining and upgrading wood machining properties and defining convenient usage areas for some native wood species of Turkey (European black pine, cedar of Lebanon, sessile oak, black poplar) are important for evaluating the effects of wood machining properties (for planing, shaping, boring, sanding, mortising, and turning) on surface quality.

2. Materials and methods

In the present experiments, different species of softwoods and hardwoods (Table 1) were used. The 2 softwood species selected for the study were European black pine (*Pinus nigra* Arnold) and cedar of Lebanon (*Cedrus libani* A.Rich.); the 2 hardwood species were sessile oak (*Quercus petraea* Liebl.) and black poplar (*Populus nigra* L.). All 4 are commonly used and grown in Turkey (Göker, 1977; Öktem and Sözen, 1994; Bozkurt and Erdin, 2000; Doğu et al., 2001). A total of 50 specimens were used for each machining test according to the ASTM D 1666 standard (ASTM International, 2004). The boring, mortising, and shaping tests were performed with the same specimens, as were the planing and sanding tests. Specimens without any defects were obtained from 1.28-m-long planed pieces based on the ASTM D 1666 standard, as illustrated in Figure 1.

The samples were all randomly selected from naturally growing forests in Turkey (İstanbul and Kütahya regions). They were conditioned at temperatures of 20 ± 2 °C and 65 ± 5 °C, with a relative humidity to the moisture

content (MC) of about 12%. Before planing and sanding, a sample with a length of 30 mm was cross-cut from each specimen in order to determine the density at 12% MC and the number of annual rings per 25.4 mm (according to ASTM D 1666 and TS 2472; Turkish Standards Institution, 2005). After testing, each specimen was visually examined and classified based on 5 quality grades (1 = excellent or defect-free; 2 = good; 3 = fair; 4 = poor; 5 = very poor). The performance criteria used for the machining tests are presented in Table 2.

Specimens measured 2.5 × 10.2 × 91 cm for planing and sanding machining tests. They were conditioned at temperatures of 20 ± 2 °C and 65 ± 5 °C with relative humidity to the MC of about 12%. The tests were performed with a planer (TÖRK brand K500–X250 machine) using 3 cutting angles: 15°, 20°, and 25°. Cutting angles were formed by grinding a "back-bevel" on knives (ASTM D 1666). In all cases, the cutting depth was 1.6 mm. The machining parameters for the planing tests are shown in Table 3.

A sanding test was performed on a Melkuç Kombi 650 wide belt sander with a 1-head 80- and 120-grit belt (65 × 190 cm). A feed rate of 5.5 m/min was used. The planing test specimens were used for the sanding test after all planing tests were completed. In this study, 2 passes were used with 80- and 120-grit belts. A boring test was performed with a stile single-spindle boring machine (rotation speed = 1400 rpm; feed speed = 0.6 m/min). Two bits were used in the boring tests: a multiple spur

Table 1. Average density, average number of growth rings per 2.54 cm, and moisture content of the 4 species.

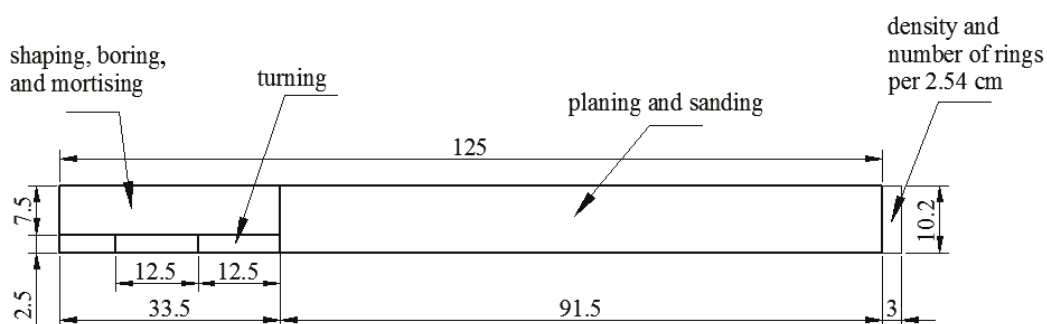| Wood species	Density (g/cm³)	Number of rings per 2.54 cm	Moisture content (%)	Properties	Age of trees
European black pine	0.6526	8.8517	12%	Softwood	40
Cedar of Lebanon	0.5019	4.4923	12%	Softwood	75
Sessile oak	0.7767	11.8365	12%	Hardwood	142
Black poplar	0.3412	1.9829	12%	Hardwood	12

Figure 1. Dimensions of the specimens in cm for wood machining tests.

Table 2. Quality grades used in determining overall performance for each machining test (ASTM D 1666).

Machining test	Performance criteria
Planing	Grades 1 and 2 (excellent and good)
Shaping	Grades 1 and 2 (excellent and good)
Mortising	Grades 1, 2, and 3 (excellent, good, and fair)
Boring	Grades 1 and 2 (excellent and good)
Turning	Grades 1 and 2 (excellent and good)
Sanding	Grade 1 (excellent)

Table 3. The machining parameters for the planing tests.

Processes	Feed rate (m/min)	Cutter number	Cutter marks (numbers per 25.4 mm)	Cutting angle (°)
Run 1	8.6	4	12	25
Run 2	18	4	6	25
Run 3	8.6	4	12	15
Run 4	8.6	4	12	20

bit [high speed steel (HSS)] and a ship auger bit (HSS). Two holes were bored across the grain through the same specimens used for shaping and mortising. A shaping test was performed on a single-spindle shaper (molder machine) operated at a spindle speed of 6400 rpm. To hold and guide the specimens during the shaping process, a massive wooden material jig was used. The specimens used for the shaping test were the same as for the boring and mortising tests. A mortising test was performed with a hollow chisel mortiser. Two mortises with sides parallel and perpendicular to the grain were made for each specimen. A piece of massive wooden material was placed under each specimen to prevent damage on the outgoing side of the hollow chisel. The mortiser was equipped to produce a rectangular mortise. A turning test was performed with a single point lathe. The turning profile is referenced in the ASTM D 1666–87 standards. The rotational speed of the specimens on the single-point lathe was 2000 rpm. The initial dimensions of specimens were 1.9 × 1.9 × 12.7 cm. The machine permitted only manual feed by an authorized person. The rate, however, was kept uniform. Test specimens that were shaped, bored, and mortised are shown in Figure 2 and turning test specimens are shown in Figure 3.

Figure 2. Test specimen (sessile oak) that is shaped, bored, and mortised.

Figure 3. Turning test specimens (sessile oak, European black pine, black poplar).

3. Results

Wood species with different densities were selected: European black pine (0.6526 g/cm³), cedar of Lebanon (0.5019 g/cm³), sessile oak (0.7767 g/cm³), and black poplar (0.3412 g/cm³). The mean for the number of rings per 2.54 cm was also calculated for each species: European black pine (8.8517), cedar of Lebanon (4.4923), sessile oak (11.8365), and black poplar (1.9829).

Comparisons of the planing properties are based on the percentage of grade 1 and 2 samples in each species. Each of the 4 runs was evaluated separately. Table 4 provides a summary of the results for each planing test. The planing operations may be considered between pine types (sum of grade 1 and grade 2). The sample percentage

is ordered as run 1, run 2, run 3, and run 4 type cutting conditions, from the highest to the lowest rate. For black poplar, the order is run 1, run 3, run 4, and run 2 type cutting. For sessile oak, run 1 type cutting and run 4 type cutting were found at the highest rate with 100% acceptable, followed by run 3 and run 2 type cutting. For cedar of Lebanon, the order is run 3, run 1, run 4, and run 2 type cutting. For cedar, grade 2 samples formed the majority of the 'acceptable' rate in the studied conditions; moreover, there was a possibility to encounter perfect samples under all machining conditions. When one looks at planing operations carried out under various conditions in general (Table 4), the acceptable rate is highest (96%) in oak and lowest in cedar (56%). The samples of poplar

Table 4. Summary of planing tests and percentage of grades.

Species	Surface grades	Run 1 %	Run 2 %	Run 3 %	Run 4 %	Average %
Black pine	Grade 1	54.0	16.3	57.1	36.4	41.0
	Grade 2	30.0	38.8	30.7	38.6	34.5
	Grade 3	12.0	32.7	12.2	22.7	19.9
	Grade 4	2.0	12.2	-	2.3	4.1
	Grade 5	2.0	-	-	-	0.5
	Grades 1 and 2	84.0	55.1	87.8	75.0	75.5
Black poplar	Grade 1	86.0	42.0	67.3	64.0	64.8
	Grade 2	8.0	28.0	24.5	22.0	20.6
	Grade 3	6.0	30.0	8.2	14.0	14.6
	Grade 4	-	-	-	-	-
	Grade 5	-	-	-	-	-
	Grades 1 and 2	94.0	70.0	91.8	86.0	85.4
Sessile oak	Grade 1	98.0	62.0	86.0	93.5	84.9
	Grade 2	2.0	24.0	12.0	6.5	11.1
	Grade 3	-	12.0	2.0	-	3.5
	Grade 4	-	2.0	-	-	0.5
	Grade 5	-	-	-	-	-
	Grades 1 and 2	100	86	98	100	96
Cedar of Lebanon	Grade 1	24.0	10.4	26.1	22.4	20.7
	Grade 2	46.0	14.6	47.8	32.7	35.3
	Grade 3	28.0	35.4	13.0	26.5	25.7
	Grade 4	2.0	29.2	13.1	18.4	15.7
	Grade 5	-	10.4	-	-	2.6
	Grades 1 and 2	70.0	25.0	73.9	55.1	56.0

and pine with acceptable surface quality are close to each other. However, for poplar, among the acceptable ratios, the sample percentage of the grade 1 is 10.7% higher than pine. As a general average, the best sample percentages are 96% for oak, 85.5% for poplar, 75.5% for pine, and 56% for cedar. In planing, the different cutting angles and number of cutters had different effects on surface quality in terms of wood species (Burdurlu et al., 2005; Peters and Lutz, 1966; Williams and Morris, 1998; Lihra and Ganev, 1999; Örs and Baykan, 1999; Hernandez et al., 2001; Malkoçoğlu and Özdemir, 2005; Ratnasingam and Scholz, 2007).

Table 5 shows the percentage of grade 1, 2, and 3 specimens of each species for the sanding test. According to the sanding properties, the wood species showed different performances. In the sanding operation, the best surface ratio was for oak with 96%. This was followed by cedar with 94%, pine with 79.6%, and poplar with 68%. Because the density of black poplar is low, grains lack adequate strength to withstand pressure from the cutter in sanding. Consequently, due to the grains becoming detached, roughness formed on the sanding surface. Similar results were reported in a previous study (Williams and Morris, 1998).

Comparisons of boring properties using the 2 types of boring bits (ship auger bit and multiple spur bit) are based on the percentages of excellent and good samples (grades 1 and 2) present in each species, as given in Table 6. With the ship auger bit, the best perforation operation was done on the oak trees (4.16%); the acceptable rate for the other wood species was achieved only by grade 2 samples. The highest acceptable rate was obtained in oak (85.41%) and the lowest in cedar (10.41%). With the multiple spur bit, both grade 1 and grade 2 samples were obtained in all wood species except cedar. For cedar, all acceptable rates were seen only with grade 2 samples. Similar results were reported in other studies (Cantin, 1965; Woodson and McMillin, 1972; Williams and Morris, 1998; Kacal and Sofuoglu, 2013).

Table 7 shows the results of the shaping test. Comparisons of the shaping properties are based on the percentage of grade 1 and 2 samples (excellent and good specimens, respectively). In the shaping operation, the sample percentages from highest to lowest for the grade 1 were pine (72.1%), oak (56.0%), cedar (40.0%), and poplar (24.5%). The same order was found for the perfect and near-perfect samples as shown in Table 6: pine (95.3%), oak (90.0%), cedar (76.0%), and poplar (65.3%). The most common defect in specimens was fuzzy grain. Fuzzy grain, as well as cracks at the edges, reduces the processing quality (Cantin, 1965; Lihra and Ganev, 1999; Sütçü, 2013).

Table 5. Summary of sanding test.

Species	Grade 1 (%)	Grade 2 (%)	Grade 3 (%)
Black pine	79.6	20.4	-
Black poplar	68.0	30.0	2.0
Sessile oak	96.0	4.0	-
Cedar of Lebanon	94.0	6.0	-

Table 6. Summary of boring properties by multiple spur bit and ship auger bit.

Species	Bits	Machining properties (%)					
		Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grades 1 and 2
Black pine	Ship auger bit	-	36.6	61.0	2.4	-	36.6
	Multiple spur bit	21.4	45.3	33.3	-	-	66.7
Black poplar	Ship auger bit	-	43.8	54.1	2.1	-	43.8
	Multiple spur bit	-	12.5	66.7	20.8	-	12.5
Sessile oak	Ship auger bit	4.2	81.2	14.6	-	-	85.4
	Multiple spur bit	56.3	41.6	2.1	-	-	97.9
Cedar of Lebanon	Ship auger bit	-	10.4	66.7	22.9	-	10.4
	Multiple spur bit	-	33.3	58.3	6.3	2.1	33.3

Table 7. Summary of shaping properties.

Species	Machining properties (%)					
	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grades 1 and 2
Black pine	72.1	23.2	4.7	-	-	95.3
Black poplar	24.5	40.8	32.7	2.0	-	65.3
Sessile oak	56.0	34.0	10.0			90.0
Cedar of Lebanon	40.0	36.0	24.0			76.0

Table 8 shows the results of the mortising test. Comparisons of the mortising properties (parallel to grain, perpendicular to grain, and average) are based on the percentage of grade 1, 2, and 3 samples (excellent, good, and fair species). As shown in Table 8, in both cross-to-grain and parallel-to-grain operations, no perfect samples were obtained for any tree type. For poplar trees, only samples with medium flaws (grade 3 samples) were used for cross-to-grain operations, and they were all in the acceptable sample rate. In the parallel-to-grain operation, the acceptable rates exhibited close values for the tree types, while extreme values were exhibited in the cross-to-grain operations. For instance, the rate of the acceptable samples was 93.9% for oak but only 12% for poplar. However, this difference between poplar and oak was not observed in the parallel-to-grain operation, where 98% and 93.9% were obtained, respectively. Reasons for the decrease in the processing quality in mortising (splintering on the out-going side of the mortise followed by torn and crushed grain inside the mortise) were parallel to those in the literature (Cantin, 1965; Peters and Lutz, 1966; Lihra and Ganev, 1999).

Table 9 shows the results of the turning test. Comparisons of the turning properties are based on the percentage of grade 1 and 2 samples (excellent and good specimens). In turning experiments, 4 tree types were used, as in other experiments; however, the samples prepared in the dimensions and shapes stated in the standard for cedar experiments cracked open as a result of pressure due to the tack welds used to fix the samples or due to turning. For these reasons, it was not possible to carry out turning operations on cedar samples. The best surface was obtained in oak (77.6%), followed by poplar (56.0%) and pine (42.5%). Hardwood species have shown better turning properties than softwood species (Malkoçoğlu and Özdemir, 2006). However, in spite of the observations of Cantin (1965), in this study the density and number of rings per 2.54 cm had no effect on turning operations.

Table 8. Summary of mortising properties.

Species	Parallel to grain (%)	Cross to grain (%)	Average (%)
Black pine	48.8	100.0	74.4
Black poplar	10.2	93.9	52.1
Sessile oak	93.9	98.0	96.0
Cedar of Lebanon	46.0	82.0	64.0

Table 9. Summary of turning properties.

Species	Machining properties (%)					
	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grades 1 and 2
Black pine	17.5	25.0	17.5	25.0	15.0	42.5
Black poplar	32.7	26.5	12.2	22.4	6.0	59.2
Sessile oak	38.8	38.8	14.3	8.1	-	77.6

4. Discussion

This research showed that the sessile oak (*Quercus petraea*) had an excellent performance for all machining processes. Black poplar (*Populus nigra* L.) yielded the lowest results for the sanding test.

Perfect surface quality was obtained for the hardwoods (black poplar and sessile oak) at a 25° cutting angle of planing; this was obtained for the softwoods (black pine and cedar of Lebanon) at a 15° cutting angle of planing. According to the relevant standard in shaping, our study revealed acceptable sample proportion hierarchies of black pine > sessile oak > cedar of Lebanon > black poplar. Superior machining performance was obtained in boring with a multiple spur bit compared to a ship auger bit. Performance in turning, on the other hand, ranged from sessile oak > black pine > black poplar. Excellent (defect-free) surface proportion in sanding was observed in sessile oak, cedar of Lebanon, black pine, and black poplar. It was observed that cedar of Lebanon was not suitable in turning.

For good machining quality, the cutters used in the machining of the material should be sharpened; machinery should be maintained and stable. All cutters should be used equally, with many blades inserted in the blade head. Generally, deep cuts should not be made. The number of blade traces in unit distance should be high. The combination of the most suitable feeding speed and the number of blades should be provided for each wood species. The wooden materials should be smooth-grained and should be free from formations that cause grain deviations, such as knurls. The most suitable cutters should be selected for each wood species and should be sharpened at appropriate angles.

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