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Anatomical, Physical and Mechanical Properties of Lesser-Known Wood Species of Simpur (*Dillenia serrata*) from Indonesia and Its Potential Uses

Anatomska, fizikalna i mehanička svojstva manje poznate vrste drva simpura (*Dillenia serrata*) iz Indonezije i njegova potencijalna uporaba

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ABSTRACT • *Simpur (Dillenia serrata Baehni) is a lesser-known wood species extracted from the natural tropical forest in East Luwu District, South Sulawesi Province of Indonesia. This research examined its basic properties and determined its potential use by considering those properties. The wood properties examined were anatomical, physical, and mechanical. General characteristics were observed using whole wood or plank-shaped samples that had been placed on the surface; incision preparations were made following the Sass procedure; anatomical characteristics were observed according to the IAWA list of microscopic features for hardwood identification and fibers dimensions using maceration. The method for testing the physical and mechanical properties follow the Japanese Industrial Standard (JIS). The results showed that simpur is reddish brown and its heartwood and sapwood are distinguishable. The wood has a plain style figure, straight grain or occasionally slightly interlocked, slightly coarse and even texture, somewhat dull gloss, and a slightly rough touch impression. The growth rings are vague, diffuse, vessels with large radii, very long fibers, a very wide fiber diameter, and thin to thick cell wall thickness. The wood is classified as medium specific gravity, very high shrinkage, and second-class strength. The wood can be potentially used for medium-to-weight construction structural materials, veneer and plywood, particle board, pulp, and paper.*

KEYWORDS: *lesser-known wood species; Dillenia serrata; wood properties; potential use*

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SAŽETAK • *Simpur (Dillenia serrata Baehni) manje je poznata vrsta drva iz prirodne tropske šume u okrugu East Luwu, pokrajina Južni Sulawesi u Indoneziji. Ispitana su anatomska, fizička i mehanička svojstva drva kako bi se odredile mogućnosti njegove potencijalne uporabe. Opća su svojstva drva određena promatranjem trupca ili piljenica. Napravljene su pripreme za rez prema Sass postupku, anatomska obilježja promatrana su prema IAWA popisu mikroskopskih značajki za identifikaciju tvrdog drva, a dimenzije vlakana analizirane su uz pomoć maceracije. Fizička i mehanička svojstava ispitana su prema japanskom standardu (JIS-u). Rezultati su pokazali da je drvo simpura crvenkastosmeđe boje, s uočljivom razlikom drva srži i bjeljike. Drvo je neutralnog izgleda, ima ravnu do blago uvijenu žicu, pomalo grubu i ujednačenu teksturu, zagasit sjaj i blago hrapavu površinu. Pripada difuzno poroznim vrstama drva sa slabo vidljivim godovima, trahejama velikog promjera, vrlo dugačkim i širokim vlaknima, a debljina stanične stijenke drva simpura varira od tanke do debele. Klasificirano je kao drvo srednje gustoće, izrazitog utezanja i čvrstoće druge klase. Drvo se potencijalno može upotrebljavati za izradu srednjih do teških građevnih konstrukcijskih materijala, furnira i furnirskih ploča, iverica, celuloze i papira.*

KLJUČNE RIJEČI: *manje poznate vrste drva; Dillenia serrata; svojstva drva; potencijalna uporaba*

1 INTRODUCTION
1. UVOD

The Plant Resources of South East Asia categorized wood species in Southeast Asia based on their trades: least-known, lesser-known, minor, and major wood species. Due to intensive exploitation, major and minor wood species (commercial wood) are becoming scarcer, affecting their supply, which continuously declines (Lemmens *et al.*, 1995). On the other hand, commercial wood demand for building and industrial materials tends to increase. The severely reduced availability of commercial woods can be replaced by lesser-known and underutilized woods found in various regions. Unfortunately, the properties of most wood species are not known enough to promote their use (Marbun *et al.*, 2023), so the wood-based industry is not fully ready to use all wood species. According to Lempang (2014), wood of lesser-known species can be used and act as a substitute for commercial wood; it is necessary to identify the properties of the wood and evaluate its potential use. Until now, many studies have examined lesser-known wood species from Southeast Asia and other countries to find a substitute for commercial wood. Some of them are *Artocarpus altilis* wood from Nigeria (Areo, 2021), *Schima wallichii, Duabanga grandiflora, Callicarpa arborea, Castanopsis tribuloides, Anogeissus acuminata* wood from India (Hedge, 2019), such as *Myristica linifolia, Pterospermum acerifolium* and *Trewia nudiflora* wood from Bangladesh (Chowdhury *et al*., 2017), Malaysia (Hamdan *et al*., 2020), and *Artocarpus odoratissimus*, *Duabanga moluccana*, *Horsfieldia hellwigii*, *Octomeles sumatrana* wood from Indonesia (Marbun *et al*., 2019). The use of wood is generally based on its basic properties. These properties can be used to predict the proper processing and utilization of wood (Hidayat *et al*., 2017; Purusatama *et al*., 2018), and they can also influence its commercial value (Riki *et al*., 2019).

Dillenia is a genus of about 100 species of flowering plants in subtropical and tropical trees of Southern Asia, the Indian Ocean Islands, and Australasia (Yazan and Armania, 2014). Some species of *Dillenia* grow naturally in the evergreen and moist forests of the Philippines, West Malaysia, Brunei Darussalam, and Indonesia (Yazan and Armania, 2014). *D. serrata* Thunb. is an endemic species of Indonesia (Marbun *et al.,* 2019), widely found and distributed in the islands of Sulawesi, Sumatera, Jawa, and Kalimantan (Marbun *et al.,* 2023), and commonly known as Simpur (Indonesia) and Simpor or Simpoh (Malaysia) (Yazan and Armania, 2014). Simpur is one of the lesser-known species, fast-growing (Adi *et al*., 2015), species with a tree habitus, medium size, and evergreen, up to 30 m tall with free-branching stems up to 16 m and up to 70 cm in diameter (Pitopang, 2008). Accurate information about the properties of a wood species is essential, especially when selecting raw materials, to produce a high-quality product. The aim of this research is to examine the wood properties (anatomical, physical, and mechanical) and predict its potential use.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Material
2.1. Materijal

The wood material for this study was obtained from two trees of simpur (*D. serrata*) with a trunk diameter of 40.2 and 43.0 cm. Three samples were taken from each tree, from the bottom, medium and top part. The wood originates from natural tropical forests in the South Sulawesi Province of Indonesia with GPS location: latitude 2°38’50.82” N and longitude 121°5’47.53.71 E. The test sample trees had an average (bottom and top part) trunk diameter of 42.6 cm, a clear bole (branch-free stem) length of 4.8 m, a sapwood thickness of 2.5 cm, a bark thickness of 2.0 cm, reddish-colored bark, scaly bark, and flaky bark scales. The schematic of the sample preparation is shown in Figure 1. Three discs with a thickness of 5.0 cm and three logs with a length of 100.0 cm were taken from each position (bottom, middle, and top) part of the tree trunk. The discs were used to make

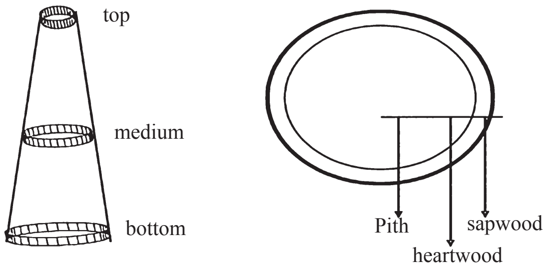


Figure 1 Schematic of sample preparation
Slika 1. Shema pripreme uzorka

samples for anatomical observation and chemical analysis, while the logs were used to make samples for testing of physical and mechanical properties.

2.2 Methods
2.2. Metode

2.2.1 Anatomical observation
2.2.1. Analiza anatomskih svojstava

Anatomical characterization of wood includes general properties, structure and fiber dimensions. General properties were observed using solid wood and samples in the form of planks that had been planned for the surface, including color, figure, grain direction, texture, gloss, and touch. The wood structures (bottom, medium and top part) were observed using incision preparations made following the Sass procedure (Rulliyati, 2014). The observations of wood cell type, including vessels, rays, parenchyma, fibers, and others, were carried out accordingly by the IAWA Hardwood List of the International Association of Wood Anatomists Committee (Wheeler *et al.,* 2008). Fiber dimensions were measured through maceration preparations made based on a modification of Franklin's method (Rulliyati, 2014). The quality class of wood fiber could be determined by derived values of fiber dimensions, namely Muhlsteph ratio (MR), Runkel ratio (RR), flexibility ratio (FR), coefficient of rigidity (CR), and felting power (FP) (Marbun *et al*., 2023). The fiber quality of simpur was assessed based on wood fiber quality criteria for pulp and paper (Marbun *et al.,* 2023).

2.2.2 Physical and Mechanical Testing
2.2.2. Ispitivanje fizičkih i mehaničkih svojstava

Logs taken from the base, middle, and ends of the simpur stems were sawn into blocks with a size of 6 cm × 6 cm × 120 cm for physical and mechanical test samples. The size of the test samples and the method for testing the physical and mechanical properties followed the Japanese Industrial Standard (JIS, 2003). The determination of the simpur strength class followed the wood strength classification used in Indonesia, which is based on wood specific gravity, bending strength at failure (*MOR*), and compressive strength parallel to grain (Oey, 1990).

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

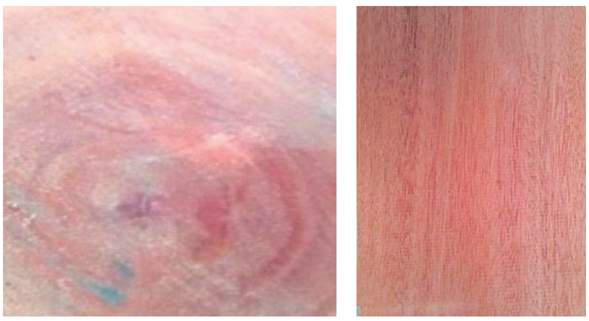
3.1 Wood anatomical characteristics
3.1. Anatomska svojstva drva

3.1.1 General characteristics
3.1.1. Opća svojstva drva

There was no clear distinction between the heartwood and sapwood. The color of both the heartwood and sapwood was brown and reddish brown. The growth rings were vague. The figure was in plain style. The grain directions were straight and somewhat interlocked. The texture was rather coarse and even. The gloss of the wood surface was rather dull. The texture of the wood surface was rather rough. The impression of touch or roughness on the surface of the wood was not only caused by the tools used to work the wood; it was also caused by the internal structure of the wood, which has cavities in the form of pores and cell lumens (Csanady and Magoss, 2013).

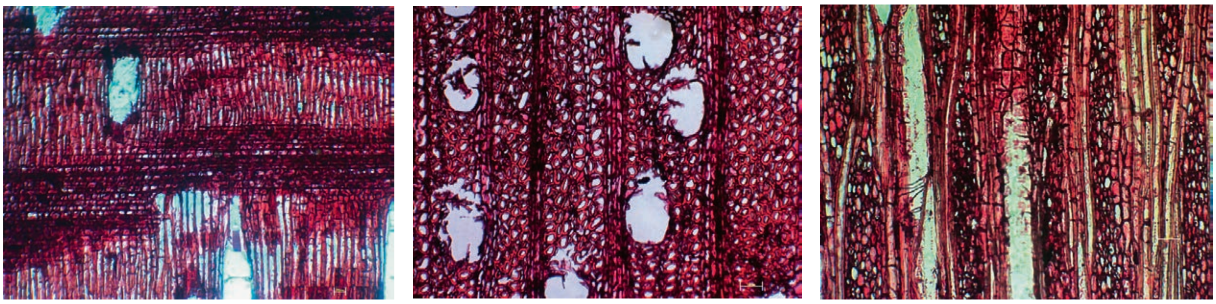
3.1.2 Wood structure
3.1.2. Struktura drva

The wood was diffuse and the distribution of vessels on cross section was almost entirely solitary. The vessel length was 526.61 µm, with the diameter of 170.01 µm and frequency of 5 mm^{-2}. The perforation plate was scalariform; inter-vessel pits were alternate with medium size (>7-10 µm); vessel-ray pits with narrow to simple pages; pits were horizontal or vertical. The apotracheal axial parenchyma was scattered and scattered in clusters, with strand lengths of 8 (5 – 8) cells per strand. The rays were large, generally 4 – 10 series, with a ray cell composition of more than 4 upright cell rows and/or square marginal cells and a ray height >1 mm. The fiber elementary tissue was with well-defined page pits. There were graffiti crystals included in ray cells. The existence of crystals may be important for mechanical support in certain cells (Cipta *et al*., 2022). Wood macro– and microstructures of simpur are shown in Figures 2 and 3.



a) b)

Figure 2 Wood macrostructure of simpur (*D. serrata*):
(a) cross section / transversal surface; (b) tangential surface
Slika 2. Makrostruktura drva simpura (*D. serrata*):
a) poprečni presjek; b) tangentni presjek



a) b) c)

Figure 3 Wood microstructure of simpur (*D. serrata*): a) radial surface, b) tangential surface, c) transversal surface
Slika 3. Mikrostruktura drva simpura (*D. serrata)*: a) radijalni presjek; b) tangentni presjek, c) poprečni presjek

3.1.3 Fiber dimensions and quality
3.1.3. Dimenzije i kvaliteta vlakana

Simpur is classified as a hardwood species (broadleaf). Hardwood generally has short fibers (200 – 1.200 μm in length) and is slender (about 20 μm in diameter) (Shmulky and Jones, 2019). Wood fiber dimensions of simpur are presented in Table 1.

Wood fibers of simpur were classified into very long, very wide diameter, very wide lumen diameter, and thin to thick wall thickness. Although simpur fiber has a wall thickness of 10.61 μm (very thick), the fiber wall of this wood is classified as thin to thick, because it has a lumen diameter (40.05 μm) less than three times the thickness of its two fiber walls and still looks open (Wheeler *et al*., 2008).

Anatomical properties, particularly the fiber dimensions, can predict the quality of wood for pulping purposes. The fiber quality between species of wood varies greatly. The role of fiber dimensions such as fiber length, fiber diameter, and wall thickness has complex relationships with each other and fundamentally influences the physical properties of pulp, and paper, and other wood products (Lempang, 2016). The dimension of fiber and its derivatives is one of the important properties of wood, which can be used to predict the properties of the pulp produced (Syafii and Siregar, 2006). The wood fiber quality of simpur as a raw material for paper pulp is presented in Table 2.

Fiber length has a significant relationship with paper strength, especially in the tear index, tensile index, and folding index (Rizqiani *et al.*, 2019). Fiber length affects the tensile strength and slightly affects the crease resistance of the paper (Rizqiani *et al.,* 2019); the longer the fiber, the greater the tear resistance of the paper; thin to thick fiber walls will flatten easily when milled, and very long fibers produce strong weaving power. The fiber wall of simpur is classified as thin to thick, but the lumen diameter is wide enough so that the

Table 1 Wood fiber dimension of simpur (*D. serrata*)
Tablica 1. Dimenzije vlakana drva simpura (*D. serrata*)

Fiber dimensions *Dimenzije vlakana*	**Average, μm** *Srednja vrijednost,* μm	**Standard deviation** *Standardna devijacija*	**Classification*** *Klasifikacija vlakana**
Length / *duljina*	3,234.78	± 360.43	Very long / *vrlo dugačka*
Diameter / *promjer*	61.26	± 11.16	Very wide / *vrlo širok*
Lumen diameter / *promjer lumena*	40.05	± 9.26	Very wide / *vrlo širok*
Wall thickness / *debljina stijenke*	10.61	± 1.90	Thin to thick / *tanka do debela*

*IAWA classification of fiber dimension of hardwood / *IAWA klasifikacija dimenzija listača*

Table 2 Wood fiber quality of simpur (*D. serrata*) as raw material for pulp and paper
Tablica 2. Kvaliteta vlakana drva simpura (*D. serrata*) kao sirovine za proizvodnju celuloze i papira

Fiber dimension and fiber dimension-derived values *Dimenzija vlakana i vrijednosti izvedene iz tih dimenzija*	**Average** *Srednja vrijednost*	**Standard deviation** *Standardna devijacija*	**Score*** *Rezultat**
Fiber length, μm / *duljina vlakana,* μm	3,234.78	± 360.00	100
Runkle ratio / *Runkelov omjer*	0.55	± 0.12	50
Felting power / *brzina filcanja*	55.23	± 0.05	50
Flexibility ratio / *omjer fleksibilnosti*	0.65	± 0.05	75
Muhlsteph ratio, % / *Muhlstephov omjer*, %	57.61	± 5.57	75
Coefficient of rigidity / *koeficijent krutosti*	0.18	± 0.03	50
Total / *ukupno*			400
Class of fiber quality / *klasa kvalitete vlakana*			II

*Oey, 1996

Runkel ratio obtained is relatively low. The lower the Runkel ratio (≤1), the better the quality of the pulp produced because the fibers will be easily flattened in the manufacture of pulp sheets (Rulliyati, 2014).

In general, the data in Table 2 shows that the simpur fiber studied has a total score of fiber length and fiber derivative dimension of 400. This indicates that simpur fiber is classified as good quality (quality class II) as a raw material for making paper pulp. Wood in this category has short to long fibers, thin to thick fiber walls, and narrow to wide lumen diameters, so that the fibers will flatten quite easily when milled and the fiber bonds are quite good. This type of fiber is thought to be able to produce sheets with relatively high tear, crack, and tensile strength.

3.2 Physical properties
3.2. Fizička svojstva drva

The important physical properties of wood are moisture content, specific gravity, and shrinkage. The physical properties of simpur wood are presented in Table 3.

The moisture content of wood in living trees varies from 25 % to 250 % or more (Djarwanto *et al*., 2017). Variations in freshwater content in each wood species depend on the location where it was grown, age, season when harvested, and tree size (Shmulky and Jones, 2019). Indonesian National Standards (SNI 7973-2013) require a maximum moisture content of 19 % for wood used for dry conditions in closed structures (Badan Standardisasi Nasional, 2013). In practice, wood is generally used at a moisture content of 6.2-13.1 (Djarwanto *et al*., 2017).

Simpur has a specific gravity of 0.69 and 0.64 g/cm^3 density. Most of the physical and mechanical properties of wood are closely related and can be predicted by the specific gravity of the wood (Machado *et al*., 2014). The research results on mangium (*Acacia mangium* Wild.) showed that the specific gravity of wood had a significantly positive correlation with radial and tangential shrinkage and compressive strength parallel and perpendicular to the grain (Hidayat *et al*., 2016). Therefore, the specific gravity of wood is a good indicator for predicting other physical and mechanical properties of wood. The strength and toughness of wood increase with increasing specific gravity. Likewise with the machining properties of wood, the higher the specific gravity of wood, the better the machining properties (Rianawati *et al.,* 2015). The yield of paper pulp per unit volume of raw material is directly related to the specific gravity. Based on IAWA criteria (Wheeler *et al.,* 2008), the specific gravity of wood was divided into three groups, namely low (< 0.40), medium (0.40 – 0.75) and high (> 0.75). Wood, often used as raw material for paper pulp, is a wood species with a medium-specific gravity. A hardwood species widely used as raw material for paper pulp is mangium, with a specific gravity of 0.60 (Arsad, 2012). The specific gravity of simpur (0.69) is higher than that of mangium, but both mangium and simpur are classified as wood species with a medium specific gravity (0.40 – 0.75).

Dimensional stability is one of the properties of wood that must be considered in determining its use (Basri and Saefudin, 2021). This is related to temperature and humidity fluctuations where the wood will be installed or placed (Schonfelder *et al*., 2018). The shrinkage of simpur from wet to oven-dry in the radial axes (R) is 3.37 %, and the tangential axes (T) are 10.30 %. Since the T shrinkage from the wet to oven-dry state is higher than 3.5 %, simpur is classified as a wood with very high shrinkage. T shrinkage of the wood is generally greater (1.5 – 3.0 times) than R shrinkage, partly due to the presence of ray cells, and the frequency of pitch on the cell walls in R is higher than in T (Shmulky and Jones, 2019). The shrinkage

Table 3 Wood physical properties of simpur (*D. serrata*)
Tablica 3. Fizička svojstva drva simpura (*D. serrata*)

Physical properties *Fizička svojstva*	**Average** *Srednja vrijednost*	**Standard deviation** *Standardna devijacija*
Green moisture content, % / *sadržaj vode u sirovom drvu,* %	37.73	± 3.32
Air dry moisture content, % / *sadržaj vode u drvu sušenom na zraku*, %	11.23	± 0.20
Nominal green specific gravity / *specifična gustoća sirovog drva*	0.55	± 0.01
Air dry specific gravity / *specifična gustoća drva sušenog na zraku*	0.69	± 0.02
Density, g/cm^3 / *gustoća,* g/cm^3	0.64	± 0.02
Shrinkage from green to air dry: *Utezanje od sirovog do zrakosuhog stanja*		
-Radial, % / *radijalno,* %	2.25	± 0.42
-Tangential, % / *tangentno,* %	6.87	± 0.58
Shrinkage from green to oven dry: *utezanje od sirovog do apsolutno suhog stanja*		
-Radial, % / *radijalno,* %	3.37	± 0.55
-Tangential, % / *tangentno,* %	10.3	± 0.75

Table 4 Wood mechanical properties of simpur (*D. serrata*)
Tablica 4. Mehanička svojstva drva simpura (*D. serrata*)

Mechanical properties *Mehanička svojstva*	**Average** *Srednja vrijednost*	**Standard deviation** *Standardna devijacija*
Air dry specific gravity / *specifična gustoća drva sušenog na zraku*	0.69	_
Strength class / *klasa čvrstoće*	II	_
Bending stress at proportional limit, kPa *čvrstoća na savijanje u linearnom području,* kPa	61,412.18	± 10736
Bending stress at failure (*MOR*)*, kPa / *modul loma,* kPa	94,127.17	± 9958
Modulus of elasticity, MPa / *modul elastičnosti,* MPa	10,467.33	± 1538
Compression parallel to grain, kPa / *čvrstoća na tlak u smjeru vlakanaca,* kPa	7,710.97	± 4785
Compression perpendicular to grain, kPa *čvrstoća na tlak okomito na vlakanca,* kPa	16,737.99	± 1805
Shear parallel to grain, kPa / *smična čvrstoća u smjeru vlakanaca,* kPa	11,726.79	± 1736

**MOR* – Modulus of rupture / *MOR – modul loma*

ratio of T to R (T/R ratio) of simpur is 3.06. Wood with a T/R ratio of more than 2 has relatively low dimensional stability compared to wood with a balanced T/R ratio of less than 2 (Basri *et al*., 2012). Ideally, the T/R ratio of wood is 1, where the T shrinkage equals the R shrinkage (Anish *et al*., 2015). However, the results of a study of 87 Indonesian wood species revealed that only ares (*Gmelina moluccana* Backer ex K. Heyne) showed a T/R ratio equal to 1 (Basri *et al*., 2020). The shape of a wood piece can be distorted by the combined effect of shrinkage in the radial and tangential axes. Wood with low dimensional stability (T/R ratio > 2) tends to undergo deformations such as cupping, bowing and twisting when dried (Basri and Wahyudi, 2013). Simpur has a very high shrinkage, a very high T/R ratio, and very unstable dimensions. It is suspected that besides being difficult to glue, it is also difficult to dry because it will be deformed when dry. The dimensional stability of wood is related to fluctuations in temperature and humidity where the wood will be installed or placed (Schonfelder *et al*., 2018). Therefore, dimensional stability is one of the properties of wood that must be considered in determining its use.

3.3 Mechanical properties
3.3. Mehanička svojstva drva

The mechanical properties of wood are the wood's ability to withstand a load. Important mechanical properties are known for the use of wood in civil construction (Nascimento *et al*., 2017). Several factors affect the mechanical properties of wood, including specific gravity, moisture content, anatomical structure of wood, temperature, duration of loading, and repetition of loading. Wood mechanical properties of simpur are presented in Table 4.

Table 4 shows that the bending stress at failure/ *MOR* is 94,127.17 kPa, and the compression parallel to grain is 7,710.97 kPa. The mechanical properties of simpur wood are relatively the same compared to conventional teakwood aged 14 years, with *MOR* of 92,280 kPa and compression parallel to grain is 7,910 kPa (Hidayat *et al*., 2017). Wood strength classification is determined using the relationship between air-dry specific gravity, bending stress at failure (*MOR*) and compression parallel to grain (Oey, 1990). The strength of wood is classified into five classes, from very strong (strength class I) to very weak (strength class V) (Oey, 1990). The wood strength class of simpur is II.

4 CONCLUSIONS
4. ZAKLJUČAK

Heartwood and sapwood of simpur (*D. serrata)* can be distinguishable. The heartwood color is reddish brown and has the same color as the sapwood: plain-style figure, straight grain or occasionally slightly interlocked, slightly coarse and even texture, somewhat dull gloss, and a slightly rough touch impression. The growth rings are vague, diffuse vessels with large radii, very long fibers, a very wide fiber diameter, and a thin to thick cell wall thickness. The wood is classified as medium specific gravity, very high shrinkage, and strength class II. Potential uses for medium to heavy construction structural materials include low-cost furniture, veneer and plywood, particleboard, pulp, and paper.

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