WOOD RESEARCH
53 (2): 2008
103-112

SELECTED PHYSICO-MECHANICAL PROPERTIES AND CHEMICAL COMPOSITION OF MACHAERIUM SCLEROXYLON TUL. (SANTOS ROSEWOOD)

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ABSTRACT

The authors of this article made an attempt to evaluate some physical and mechanical properties and to determine chemical and element contents of Santos rosewood (*Machaerium scleroxylon* Tul.) species. The wood was found to contain a very high content of extractive substances reaching 15.55%, the proportion of mineral compounds much higher than in other species of rosewood (at the level of 3.89%) as well as an increased proportion of lignin (approximately 31.89%) characteristic for exotic species. The determined high value of the modulus of elasticity along fibres, on average amounting to 10 700 MPa, is in keeping with the appropriate values for species belonging to the *Dalbergia* genus. Longitudinal tensile strength, on average amounting to 83 MPa, may be considered as high bearing in mind a considerable proportion of non-structural compounds in the examined wood. In comparison with the heartwood, the sapwood is characterised by lower density and higher total volumetric shrinkage.

KEY WORDS: wood, Santos rosewood (*Machaerium scleroxylon* Tul.), density, strength, chemical composition, extractive substances

INTRODUCTION

According to the International Union of Forest Research Organizations, there are over 140 wood genera (and many more species) of significant economic importance in commercial traffic all over the world and the majority of them comprise exotic woods. Numerous functional advantages as well as some exceptional properties of these wood species are recognised fairly widely. In comparison with other materials, exotic wood is characterised by extraordinarily wide variability of traits and properties, e.g. density – a trait well characterising wood physical and mechanical properties – may assume values from an exceptionally wide interval from about 100 to 1300 kg.m^{-3}. The chemical composition of exotic woods is less known and in the case of some exotic wood species also their other properties have been described very superficially. Exotic wood species comprise those which are characterised by exceptionally high natural resistance to the action of biotic and abiotic factors (for example, resistant to the attacks of termites or corrosion in sea water) as well as species which possess other unique properties as, for instance, the self-lubricating properties of the persimmon wood, massaranduba wood resistant to caustic substances or the wood of ebony and rosewood which exhibits unique acoustic properties (Kozakiewicz 2004a, Wagenführ 2007).

The term rosewood is a commercial name given to the wood of broad-leaved trees from the *Dalbergia* genus which can be found in the equatorial forests of America, Asia, Africa and Australia. It is also used to refer to the wood of trees from the *Machaerium* genus whose natural habitat is forests of Central and South America, mainly Bolivia and Brazil (Helińska-Raczkowska 1999, Wagenfűhr 2007). These two genera, which belong to the family of *Fabaceae*, comprise many different species that are very similar to one another with regard to their appearance and properties and are frequently difficult to distinguish from one another. The rosewood is characterised by dark-coloured and richly coloured striped heartwood and narrow, light-coloured sapwood. Rosewood is used, primarily, to manufacture luxury furniture and accessories, veneer, parquet as well as musical instruments and their parts such as, for example: xylophones, flutes, guitar fingerboards (Informationsdienst Holz 1979, Kaiser 2006, Wagenführ 2007). The wood of *Dalbergia nigra* and *Dalbergia stevensonii*, also known under its commercial name of Rio rosewood, is highly valued. Its excessive harvesting caused that at the Species Protection Conference in Montreal in 1992, the Rio rosewood was considered as an endangered species and it was banned from commercial traffic. This led to the popularity on the timber market of Santos rosewood (*Machaerium scleroxylon* Tul.) species whose wood is similar – with regard to its appearance and properties - to that of the Rio rosewood (Kaiser 2006).

For some time now, Santos rosewood has also been processed in Poland leading to certain problems, mainly of health nature (Romankow et al. 2008). Properties of this species have, so far, been described very superficially, especially in European literature since - with the exception of some basic data concerning density, hardness and workability - other information, e.g. about mechanical properties or wood chemical properties, is rarely available.

Wood consists of structural constituents such as cellulose, hemicelluloses and lignin and non-structural substances, often referred to as "extractives" which are responsible, among others, for toxic activities of wood. Non-structural substances, which occur in abundance in many exotic species of wood, can be found primarily in the parenchyma cells but they also supersaturate cell walls and fill intercellular spaces as well as resin and latex ducts. These non-structural substances which include, among others, resins, tannins, dyes, volatile oils, fats, sugars, waxes as well as protein and specific substances such as e.g. alkaloids, glycosides as well as organic and inorganic acids and salts and mineral compounds exert a significant influence on wood properties affecting its colour, smell and taste as well as resistance against fungi and insects but, sometimes, can also result in toxicity (Hausen 1973, Prosiński 1984, Oliveira 2005).

The application and processing possibilities of exotic wood species are sometimes restricted because they may contain non-structural substances exhibiting toxic activities as, for example, is the case with the wood of mansonia (*Mansonia altissima* A. Chev.) which derives from Western Africa and contains noxious substances, the so called "mansonins", which are chemical compounds from the family of ortho-naphthoquinones protecting this tree against a wide range of microorganisms. However, the processing of this wood species belongs to the most dangerous for human health as it causes irritation of upper airways, nose bleedings, general poisoning, headaches and, in the case of longer exposures – strong dermatological changes (Kozakiewicz 2004b).

The content of extractive substances in the wood of broad-leaved tree species varies widely and may range from about 0.5 %, e.g. in the wood of Aningeria (*Aningeria robusta* Aubrév. Et Pellegr.) (Wagenfűhr 2007) to about 42 %, e.g. in the Quebracho colorado (*Schinopsis balansae* Engel.) wood (Nikitin et al. 1978, The Columbia Encyclopedia 2001, Wagenfűhr 2007). Generally speaking, it depends mainly on the species, age and development conditions of trees. In the case of the indigenous wood species, the concentration of extractive substances is smaller and usually does not exceed 8–10 % (Prosiński 1984). Among indicators well characterising the content of these substances in wood is their solubility in water and alcohol.

The objective of the performed investigations was to determine selected physico-mechanical properties as well as chemical and element contents of Santos rosewood (*Machaerium scleroxylon* Tul.) species which, until recently, was unavailable on the Polish wood market. The investigations were undertaken in order to recognise better and supplement the description of this wood species with missing numerical data.

MATERIAL AND METHODS

The experimental material comprised wood of the Santos rosewood (*Machaerium scleroxylon* Tul.) species, imported from Bolivia in the form of 0.6 mm thick veneer sheets 20 – 40 cm wide and 250 – 300 cm long.

The heartwood used in the performed experiments exhibited diverse colour ranging from brown-pink with rare brown streaks ("light"), through brown-red with dark-brown and violet streaks ("dark") to brown-violet with numerous violet-black streaks ("very dark"). That is why samples for investigations of physical and mechanical properties of heartwood were prepared in equal numbers from woods characterised by "light", "dark" and "very dark" colour. Physical properties were also determined on sapwood of uniform, grey-yellow colour.

The density and volumetric shrinkage were determined on samples measuring 30 x 30 mm and 0.6 mm thick. The mass of experimental samples was determined on the Sartorius laboratory balance with 0.001 g accuracy, while their linear dimensions with the accuracy of 0.001 mm – using a TESA electronic gauge and their moisture content was determined using a drier-gravimetric method. Measurements of the linear elasticity modulus along fibres during stretching as well as longitudinal tensile strength were performed on a ZWICK test machine, whereas deformations during the longitudinal tensile test were measured with the assistance of an extension metre. Samples for the determination of mechanical properties were prepared in the shape of double paddles with the length along fibres of 120 mm and 20 mm wide with a narrowing to 10 mm along the section of 50 mm. The gripping parts of samples were covered on both sides with MDF board 3.2 mm thick. Wood mechanical and rheological properties were determined on similar samples obtaining numerical values similar to the values obtained on standard samples (Navi et al. 1996, Krauss 2005).

Chemical investigations were conducted on heartwood – the part of wood applied in wood industry – containing in its composition considerable quantities of non-structural substances. No chemical analyses were carried out on sapwood as this very narrow, lightly-coloured part of wood finds no application in wood industry. The heartwood for experiments was ground with the assistance of a laboratory mill Pulverisette 15 of Fritsch Company and the obtained material was sifted through sieves yielding the analytical fraction of 0.5 to 1.00 mm. The chemical composition analyses were conducted in accordance with the methodology recommended by Prosiński (1984) and the contents of the following materials were determined:

- Cellulose by Seifert method,•
- Lignin by Tappi method,
- Pentosans by Tollens method,
- Holocellulose using sodium chlorite in accordance with PN-75/50092,
- Mineral substances

as well as substances soluble in:

- Cold and hot water,
- Mixture of alcohol : benzene (1 : 1),
- 1% NaOH.

In addition, elementary wood composition, i.e. the content of carbon, hydrogen, nitrogen and sulphur, was also determined.

RESULTS AND DISCUSSION

Physical and mechanical composition

Results of physical and mechanical properties of the examined Santos rosewood are presented in Tab. 1.

Sapwood density determined on thirty samples ranged from 700 to 740 kg.m^{-3} for the wood in the oven-dry state and from 740 to 790 kg/m^3 for the wood of 10-12 % moisture content. The total volumetric shrinkage of sapwood ranged from 10.1 to 14.6 %, with the average for 30 samples being 12.7%.

The heartwood density, also determined on thirty samples, ranged from 720 to 870 kg.m^{-3} for the wood in the oven-dry state and from 770 to 930 kg.m^{-3} for the air-dry state, averaging 800 and 850 kg.m^{-3}, respectively. These values are similar to the values quoted in literature of 850 and 850-950 kg.m^{-3} for the wood of Santos rosewood at 12 % moisture content (Kaiser 2006, Richter and Dallwitz 2000). The authors observed a correlation between the colour and density of the examined wood. The lowest mean density in the oven-dry state of 740 kg.m^{-3} was recorded in the case of samples obtained from "light" wood, while the densities of "dark" and "very dark" heartwoods were distinctly higher and amounted to 820 kg.m^{-3} and 840 kg.m^{-3}, respectively. The values of the total volumetric shrinkage were contained in the interval from 8.2 to 10.5 %. The lowest mean values of 8.8 % were recorded for "light" wood, higher - of 9.1 % - "dark" wood and the highest – 9.8 % - for the "very dark" wood.

Tab. 1: Mean values and variability intervals of density, volumetric shrinkage, modulus of elasticity and longitudinal tensile strength of Santos rosewood (Machaerium scleroxylon Tull.)

Property	Zone of stem transverse section	Units	$x_{min}\ldots x_{av.}\ldots x_{max}$	S.E.	C.V. (%)	N
Physical						
Oven-dry density	Sapwood	kg.m^{-3}	700…720…740	2.2	1.6	30
Air-dry density			740…770…790	2.2	1.5	30
Volumetric shrinkage		%	10.1…12.7…14.6	0.3	12.8	30
Oven-dry density	Heartwood	kg.m^{-3}	720…800…870	8.2	5.6	30
Air-dry density			770…850…930	8.2	5.3	30
Volumetric shrinkage		%	8.2…9.2…10.5	0.2	8.5	30
Mechanical						
Modulus of elasticity	Heartwood	MPa	9000...10700...14600	165.1	11.9	60
Tensile strength			68…83…154	1.8	23.7	60

The mean total volumetric shrinkage of heartwood determined for 30 samples amounted to 9.2 % and was contained in the variability interval of wood species belonging to the *Dalbergia* genus (7–10 %) but it represented only 50 to 65 % of the volumetric shrinkage value of other diffuse-porous wood species such as hornbeam, persimmon, mampataz, wengé and yang whose densities are comparable with the density of the wood of Santos rosewood. This indicates high dimensional stability of *Machaerium scleroxylon* Tul. heartwood characteristic for rosewoods. Relatively small moisture-related deformations at high wood density suggest high degree of cellulose crystallinity. This trait, together with the extraordinary hardness, may be responsible for the exceptional suitability of this wood species for the construction of various musical instruments.

Modulus of elasticity along fibres as well as longitudinal tensile strength was determined on 60 samples of heartwood. No differences were found in the values of the examined properties between wood samples differing in their colour. Therefore, it can be presumed that the density differences of differently coloured portions of *Machaerium scleroxylon* Tul. are not caused by structural factors, for instance differences in the degree of packing of wood substance in a unit of volume but should rather be attributed to the presence of non-structural substances as manifested by variations in the colour of wood within one species as well as individual trees which is a characteristic feature of rosewoods (Informationsdienst Holz 1979). Numerical values of the elasticity modulus ranged from 9000 to 14 600 MPa; therefore, they are comparable with the elasticity modulus for the Rio rosewood which assumes values from 8800 to 12 900 MPa (Wagenführ 2007). The tensile strength of the wood of Santos rosewood fluctuated within the interval of 68-154 MPa, with average of 83 MPa. Since there were no literature data concerning the tensile strength along fibres of *Machaerium* and *Dalbergia* genera woods, the obtained results were compared with the available data for the hornbeam, persimmon, mampataz, wengé and yang woods which, similarly to the Santos rosewood, belong to the group of diffuse-porous species. The mean density of the above-mentioned species in the air-dry state amounts to 830 $kg.m^{-3}$, compressive strength – 70 MPa, the length of wood fibres - 1770 μm and solubility in the alcohol-benzene mixture – 3.3 % (Wagenführ 2007). It is evident from the comparison of these values with those presented in Tab. 1 that the tensile strength of the Santos rosewood is only by about 20 % higher than the compression strength of wood of comparable density of the diffuse-porous broad-leaved species. In the case of Santos rosewood, it appears that special attention should be paid to non-structural substances as well as to the dimensions of wood fibres. It is true that the very high content (over 15 % by weight) of extractive substances (Fig. 2) determined density, but it did not exert a significant influence on wood mechanical properties. In the case of wood species characterised by high contents of non-structural substances, wood mechanical properties evaluated from the point of view of its density may seem relatively high. Apart from density, another important factor exerting influence on wood strength, especially in tests involving bending and stretching along fibres, is dimensions of the anatomical elements creating the network which performs mechanical functions. In the case of broad-leaved species, these elements comprise wood fibres and fibrous tracheids. The mean length of these elements in the wood of the Santos rosewood is exceptionally small as it amounts only to 250 μm (Richter and Dallwitz 2000). On the other hand, according to Wagenfűhr (2007), the average length of fibres of the above-mentioned species is 1770 μm. The observed relatively small values of tensile strength in relation to the longitudinal compression strength between the wood of Santos rosewood and species comparable with it can be attributed, among others, to over 7 times smaller length of fibres of the Santos rosewood. A significantly greater number of fibres found blurred phase means that there are more contact areas between them which can get torn much easier than a thick cell wall.

Chemical composition

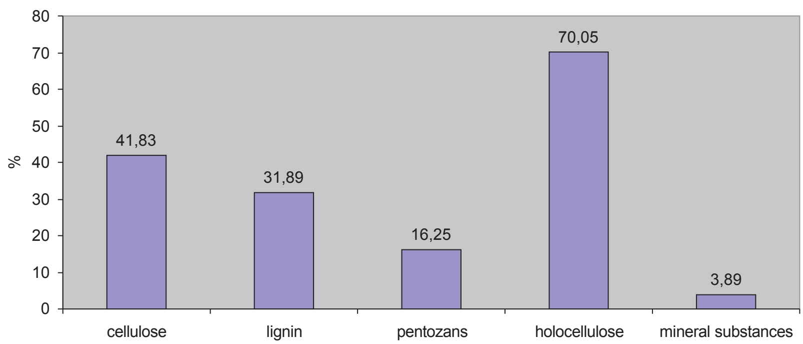

Fig. 1: Content of major wood constituents in Santos rosewood (Machaerium scleroxylon Tul.)

Fig. 1 presents quantities of individual constituents in the wood of Santos rosewood. The content of cellulose, wood basic constituent, in the examined species of rosewood amounted to 41.83 % and was, practically speaking, identical with the amount of this constituent in the wood of the comparable tree species from the temperate zone - oak (*Quercus robur* L.) in which 41.98 % of cellulose was determined (Waliszewska et al. 2006). High temperatures of tropical climates exert a positive influence on the lignin created in wood. This is corroborated by the high content of this constituent in the examined wood reaching almost 32 %, i.e. 6 % higher in comparison with the oak wood. This species of rosewood, according to the classification used in the Philippines concerning the utilisation of wood for cellulose production, can be included in the group of woods characterised by a very high (over 30 %) lignin content. The wood of Santos rosewood is also characterised by a high – 70 % holocellulose content which should be taken under consideration when it is used in chemical processing. The difference between the quantities of holocellulose and cellulose can be used to calculate the content of sugars of lower degree of polymerisation, i.e. hemicelluloses which are made up, primarily, from pentosans and hexosans. Their quantity in the wood of Santos rosewood was determined at over 28 %. The amount of pentosans acting in wood as skeletal substances reached 16.25 % and it can be presumed that hexosans, which function as nutrients, amounted to 11 %. The comparable wood of oak contains 23.3 % hemicelluloses, of which 23 % are pentosans and the remaining trace quantity is hexosans (Prosiński 1984).

The presence of mineral substances is very important in the situations when wood is to be subjected to mechanical processing. The wood of Santos rosewood contains 3.89% ash, i.e. over 10 times more than its average content in the broad-leaved species of trees growing in the temperate zone. This very high content of mineral substances indicates that the examined wood may cause exceptionally strong blunting of tools; the wood of the Rio rosewood contains only 1% ash and it blunts tools quite considerably (Wagenführ 2007). Parenchyma cells of Santos rosewood contain mineral substances in the form of prismatic crystals which, according to Richter and Dallwitz (2000) are not really silica. However, according to Interwood Forest Products Inc. of Shelbyville (Kaiser 2006) some trees of this species do contain silica which becomes apparent during veneer slicing. Also Informationsdienst Holz (1979) claims that Santos rosewood, similarly to other palissanders, is characterised by sporadic, localised occurrence of mineral deposits which can cause considerable blunting of tools.

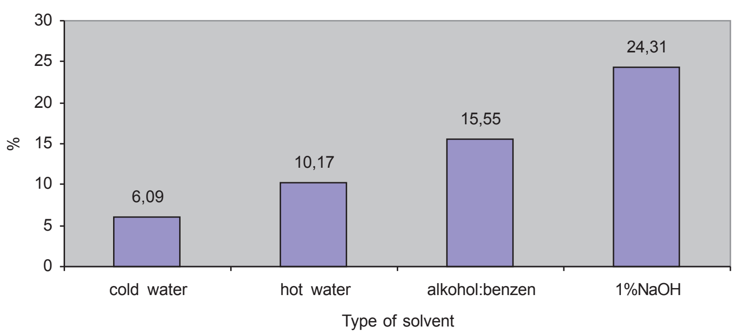

Fig. 2: Content in the wood of Santos rosewood of substances soluble in different solvents.

The content of soluble substances present in *Machaerium scleroxylon* Tul. species is shown in Fig. 2. The amount of substances which passed into the solutions of cold and hot water, 6.09 % and 10.17 %, respectively, was two times higher in comparison with the respective values recorded for the wood of *Quercus robur* L. growing in the temperate zone (Waliszewska et al. 2006). The quantity of substances contained in the wood of Santos rosewood soluble in 1 % NaOH was also high (24.31 %) which was connected with considerable amounts of hemicelluloses.

The content of substances soluble in the mixture of alcohol and benzene (1:1) was also high. It amounted to 15.55 % and was 5 times higher in comparison with the oak (*Quercus robur* L.) wood. High levels of these substances in wood of exotic species are known, according to Wagenführ (2007) the wood of *Dalbergia nigra* Fr. All. contains more than 20 % of them. Sometimes, extractive substances give individual wood species their unique properties. Such significant quantities of non-structural compounds and their possible toxic nature indicate that it is necessary to conduct precise analyses, e.g. by employing chromatographic methods in order to identify specific chemical compounds that could result in some kind of discomfort of workers during processing of the Santos rosewood. The negative impact on health from the wood dust of this species is extensively described in medical journals (Conde-Salazar 1980, Beck et al. 1984, Shimizu et al. 2000, Rojas-Hijazo et al. 2007). *Machaerium scleroxylon* Tul., together with four other species of rosewood, can be found on the list of major tree species which cause contact allergies (INRS 2006).

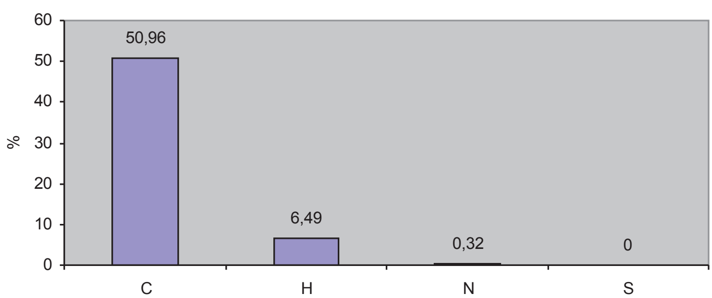

Fig. 3: Element contents of the Santos rosewood (Machaerium scleroxylon Tul.) species

The element contents of the examined exotic wood species is presented in Fig. 3. The contents of individual elements: 50.96 % carbon, nearly 6.5 % hydrogen and a small quantity of nitrogen – 0.32 % are similar to those found in the broad-leaved tree species from the temperate zone. No sulphur was determined in the wood of the Santos rosewood species.

CONCLUSIONS

1. The heartwood of Santos rosewood (*Machaerium scleroxylon* Tul.) species is characterised by a typical for broad-leaved species concentrations of cellulose of 41.83 % and increased content of lignin reaching 31.89 %.
2. The content of mineral substances in the heartwood of Santos rosewood is high (3.89 %) and may cause problems during mechanical processing of wood of this species.
3. The examined heartwood contains up to 15.55 % extractive substances (soluble in the mixture of alcohol and benzene). They may determine some physical wood properties (e.g. density, colour) and contain compounds harmful for health. Precise analysis of the nature of these compounds is essential.
4. The heartwood of this wood species is characterised by high mean density (850 $kg.m^{-3}$) and small mean volumetric shrinkage (9.2 %). On the other hand, its sapwood shows lower than average density (770 $kg.m^{-3}$) and higher mean value of volumetric shrinkage (12.7 %).
5. Dark heartwood density is by about 10 % higher in comparison with the density of light heartwood. Colour differences and differences in the heartwood densities corresponding to them fail to correlate with differences in the values in the modulus of elasticity and tensile strength along fibres whose mean values for the wood in the air-dry state amount to 10 700 MPa and 83 MPa, respectively.

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