ALTERNATIVE COMPOSITIONS OF ORIENTED STRAND BOARDS (OSB) MADE WITH COMMERCIAL WOODS PRODUCED IN BRAZIL

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ABSTRACT

This work aimed to investigate the feasibility of using and mixing *Toona ciliata, Eucalyptus grandis/urophylla* and *Pinus oocarpa* woods in OSB production. Three one-species and four mixed-species combinations were compared. Layer structure varied by positioning different wood species in the surface and core of the panels. Phenol-formaldehyde *(PF)* adhesive was applied at 9% for all OSB panels. Three-layer mats with mass proportion of 25/50/25% for surface/core/surface were produced. Pressing time was 8 min, under a 4 MPa pressure and temperature of 180 °C. Physical and mechanical properties were evaluated and compared to EN (300) commercialization standard. Most OSB panels did not fully attain such requirements. OSB panels made with *Eucalyptus grandis/urophylla* and *Pinus oocarpa* woods have potential to be commercialized as *OSB/1* and *OSB/2* types, respectively. Among panels made with *T. ciliata* wood, those produced with this species in the surface and *Eucalyptus grandis/urophylla* wood in the core met the requirements established for *OSB/1* commercialization. *Eucalyptus* wood has great potential to substitute *Pinus* wood in *OSB* production. The utilization of *T. ciliata* wood for OSB production decreased mechanical performance, but remarkably enhanced water resistance properties.

Keywords: Compression ratio, *Eucalyptus grandis x urophylla,* hardwoods, mechanical properties, physical properties, *Pinus oocarpa, Toona ciliata.*

INTRODUCTION

Oriented strand board (OSB) was introduced into the construction market in the early 1980s. The OSB industry posted rapid growth and is now well established across North America and Europe (Barbuta *et al.* 2011). Along with Medium Density Fiberboard (MDF), OSB is slowly replacing the use of sawn wood for furniture and moulding in developed countries. In South America, Chile and Brazil are the main producers, where OSB is currently replacing more expensive plywood (EFORWOOD 2013, Okino *et al.* 2004). The use of small-diameter, low quality logs as raw material for OSB production is the main advantage of this wood-based product (Barbuta *et al.* 2011). In Brazil, the OSB industrial plant is located at Ponta Grossa in Paraná state (south region) with a capacity of 350000 m³year $^{-1}$. Main applications in Brazil include I-beams, wood frame and steel frame systems, coatings, roofs and walls.

Silvicultural activity in Brazil is mainly focused on *Eucalyptus* and *Pinus* species because they have relatively fast growing rates and are low-cost raw materials for the wood industries, in comparison to commercial tropical woods (Pincelli *et al.* 2012). OSB national production is exclusively represented by *Pinus* species. A drawback to this current scenario is the decreasing production of softwoods in Brazil that may hinder particleboard production. From 2010 to 2011 *Eucalyptus* planted area increased 2,5% from 2010

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to 2011, while *Pinus* planted area decreased 6,5%. Even in Paraná state, which is the main producer, *Pinus* planted area reduction was remarkable (ABRAF 2012). This new context of planted forest strongly suggests the need for wood diversification as raw materials for OSB production.

Highly-prized hardwoods, which have formerly been resourced from native forests, are now being cultivated in plantations. Australian red cedar (*Toona ciliata* M. Roem var. *australis*), which belongs to the valuable Meliacea family has stood out as a planted forestry species in tropical and subtropical American countries (Dordel *et al.* 2010). *T. ciliata* extends naturally from eastern Pakistan and India through Southeast Asia and Southern China and through Hainan Island to the Philippines and Eastern Australia (Heirinch and Banks 2006). This natural habitat has been widely destroyed due to exploitation. Damage by the *Hypsipyla robusta* shoot borer is the main factor hindering the regeneration of *T. ciliata.* However, this plague does not naturally occur in America (Bygrave and Bygrave 2005, Cunningham *et al.* 2005). In Brazil this species found favorable environmental conditions in Southeast and South Bahia regions. Its expected national productivity is from 250 to 300 m³ha^{-1} for 20-year-old plantations (CIflorestas 2013).

Previous works have shown the potential of *T. ciliata* wood for the production of a wide range of wood-based products, among which high quality-saw wood (Silva *et al.* 2010), conventional particleboards (Bufalino *et al.* 2012a), plywood (Albino *et al.* 2011) and cement-wood boards (Sá *et al.* 2012, Sá *et al.* 2010). Until the present, there are no works in the literature that applied *T. ciliata* wood in OSB production. *T. ciliata* from the Meliaceae family produces high value wood, but its primary processing will result in waste generation. In addition, thinning is necessary to grow high-diameter trees for sawing. Wood wastes such as slabs and thinning sub-products could be used for the production of several types of boards as an interesting alternative to assure a more sustainable use of biomass. This work aimed to investigate the feasibility of using and mixing *T. ciliata, Eucalyptus* hybrid and *Pinus oocarpa* woods in OSB production.

MATERIALS AND METHODS

Materials
Raw materials used to manufacture OSB in this study were: (1) 18-year-old *Pinus oocarpa* wood obtained from an experimental plantation located at Lavras, Minas Gerais, Brazil; (2) 7-year-old *Eucalyptus grandis/ urophylla* hybrid clone wood, obtained from the Companhia Mineira de Metais located at Vazantes, Minas Gerais, Brazil, and (3) residual slabs from the primary processing of 18-year-old *Toona ciliata* var. *australis* obtained from a commercial plantation located at Marechal Floriano, Espírito Santo, Brazil. Commercial phenol-formaldehyde *(PF)* adhesive with solid content of 46,8% was used. The wood species were characterized by basic density, determined according to the NBR 11942 (ABNT 2003) and chemical analyses. Total extractives and lignin contents were determined in accordance with M3/69 (ABTCP 1974a) and M70/71 (ABTCP 1974b) standards respectively, using three replicates.

OSB Manufacture and Evaluation
The slabs from *T. ciliata* and *E. grandis/urophylla* and *P. oocarpa* lumbers were transformed into 20 cm x 9 cm x 2,5 cm pieces which were reduced to strand particles with target dimensions of 9 cm x 2,5 cm x 0,7 mm in a laboratory slicer. Previous laboratory studies showed that OSB made with *T. ciliata* blow during pressing (Bufalino *et al.* 2012b). This result was mainly attributed to high content of volatile extractives. Therefore, previously to board making, *T. ciliata* wood strands were immersed in water for 24 h at a ratio of 5 kg of wood particles to 1000 l of water, at room temperature. The particles were subsequently dried and screened in order to eliminate fines and wood dust. The final moisture content of the strands ranged from 1,5% to 3%.

The blending of the strands with adhesive and wax was performed using a laboratory drum blender. *PF* adhesive was applied at 9% for all OSB panels, both in the surface layers and the core layer. The adhesive loading used in this study is above the usually used in the literature and in the OSB industry because *T. ciliata* has a remarkably low basic density, hence a high superficial area to be covered by the adhesive and glued. Previous laboratory studies showed that lower adhesive levels did not allow board consolidation. Strand orientation was achieved by dropping the strands through a mesh with adjustable parallel plates. Three-layer mats were formed in such a way as to ensure that the surface layers were perpendicular to the core layer. The mass proportion was 25/50/25% for surface/core/surface of the boards.

A manual press machine was used to perform a pre-pressing procedure until 2000 kg. The mats were then put in a hydraulic press and the boards were pressed using a press time of 8 min, under a 4 MPa pressure and a temperature of 180 ˚C. Target apparent density of 650 kgm^{-3} and board dimension of 48,5 cm x 48,5 cm x 1,5 cm were held constant. Three OSB panels of each combination depicted in Table 1 were produced.

Table 1. Wood composition of the OSB panels.

Symbol	Surface	Core	Surface
T-OSB	*T. ciliata*	*T. ciliata*	*T. ciliata*
P-OSB	*P. oocarpa*	*P. oocarpa*	*P. oocarpa*
E-OSB	*E. grandis/urophylla*	*E. grandis/urophylla*	*E. grandis/urophylla*
PTP-OSB	*P. oocarpa*	*T. ciliata*	*P. oocarpa*
ETE-OSB	*E. grandis/urophylla*	*T. ciliata*	*E. grandis/urophylla*
TPT-OSB	*T. ciliata*	*P. oocarpa*	*T. ciliata*
TET-OSB	*T. ciliata*	*E. grandis/urophylla*	*T. ciliata*

The samples were stabilized in a conditioning room (20 ± 1 °C and 65 ± 3% RH). The following physical and mechanical properties were evaluated: water absorption after immersion for 2 h *(WA2h)* and 24 h *(WA24h)*; thickness swelling after immersion for 2 h *(TS2h)* and 24 h *(TS24h)*; measured apparent density; modulus of elasticity *(MOE)* and modulus of rupture *(MOR)* in static bending; and internal bond *(IB)*. Compression ratio *(CR)* was calculated by dividing the average measured apparent density of the panels by the respective wood basic density. For panels made from two wood species (50% each), an arithmetic average of their basic densities was considered. Static bending test was performed in specimens with particles in the parallel (//) and perpendicular (⊥) directions in relation to their surface layer. For mechanical tests, a universal testing machine (EMIC DL-30000) was used. Physical properties and internal bond were determined in accordance with ASTM D 1037-100 (ASTM 2006) standard procedures. Static bending test was carried out following DIN 52362 (DIN 1982) standard recommendations. Figure 1 depicts specimen distribution and number obtained in the OSB panels.
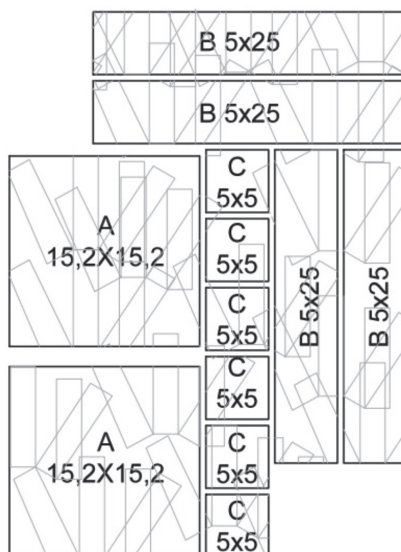
Figure 1. a) Measured apparent density, water absorption 2h *(WA2h)*, water absorption 24h *(WA24h)*, thickness swelling 2h *(TS2h)* and thickness swelling 24h *(TS24h)*; b) Static bending; c) Internal bond *(IB)*.

Data was statistically analyzed by means of average and standard deviation. The boards were evaluated according to EN 300 (2003) standard, which classifies OSB types as follows: 1) *OSB/1* – General purpose boards and boards for interior fitments (including furniture) for use in dry conditions; 2) *OSB/2* – Load-bearing boards for use in dry conditions; 3) *OSB/3* – Load bearing boards for use in humid conditions; 4) *OSB/4* – Heavy duty load-bearing boards for use in humid conditions.

RESULTS AND DISCUSSION

Wood species and OSB basic characterization
The characterization of the wood species investigated is depicted in Table 2. *T. ciliata* and *P. oocarpa* woods have similar basic density, while *E. grandis/urophylla* wood has higher basic density. Wood basic density is the most important property to be considered in OSB production; it should range from 300 to 500 kgm-³ in order to result in panels with a high *CR*, which is the ratio given by the mean apparent board density divided by the mean wood basic density (Maloney 1993).

Regarding chemical composition, high extractive content found for *T. ciliata* may result in gluing and pressing problems during board production. During a previous laboratory study OSB produced with *T. ciliata* blew during pressing process due to evaporation of volatile extractives. A previous study with the same T. ciliata wood material used in this work showed that water immersion treatment decreased extractive content from 12,93 to 9,56% and allowed board production (Bufalino *et al.* 2012b). On the other hand, high contents of extractive in this species results in high natural resistance to termites and fungi (Ribeiro 2011, Almeida 2012).

Higher lignin content accounts as an advantage for board production because this chemical component imparts hydrophobicity to wood cells (Joseleau 2004). In addition, lignin is natural binder that may contribute to bond enhancement of the board strength (Khedari *et al.* 2004).

Table 2. Physical and chemical characterization of the wood species.

Wood	Basic density (kgm^{-3})	Extractive content (%)	Lignin content (%)
T. ciliata	320	12,9	24,4
P. oocarpa	360	6,3	26,7
E. grandis/urophylla	530	6,8	22,8

Measured apparent density was close to the established value of 650 kgm^{-3}, while high variation was obtained for *CR* of the OSB panels (Table 3).

Table 3. Measured apparent density and compression ratio values of the OSB panels.

OSB specification	Measured apparent density of panels (kgm^{-3})	Average wood basic density (kgm^{-3})	Compression Ratio
T-OSB	590 (30*)	320	1,84
P-OSB	680 (62)	360	1,89
E-OSB	684 (24)	530	1,29
ETE-OSB	647 (19)	420	1,54
TET-OSB	651 (45)	420	1,55
PTP-OSB	655 (18)	340	1,93
TPT-OSB	653 (12)	340	1,92

* Standard deviation values

Compression ratio *(CR)* is closely related to the physical and mechanical properties of all particleboards. Better mechanical performances of the boards are expected with higher *CR*, while effects for physical properties may vary (Bufalino *et al.* 2012a).

Water resistance properties

WA values varied among different OSB wood composition and ranged from 32 to 66% for *WA2h* and from 55 to 85% for *WA24h* (Figure 2). Among panels produced with one species, *T-OSB* panels had remarkably low *WA* values. Considering high *CR* of such boards, this result could be mainly attributed to few voids in the mat microstructure. High densification works as a barrier to water entrance resulting in lower *WA*. On the other hand, *CR* value of *P-OSB* panels was very similar to that found for *T-OSB* panels. Therefore, the higher resistance found for *T-OSB* panels may also be related to the presence of hydrophobic extractives in the wood surface. It should be noticed that by placing *T. ciliata* particles in the surface of *TPT-OSB* and *TET-OSB* panels, water resistance improved in comparison to *P-OSB* and *E-OSB* panels.
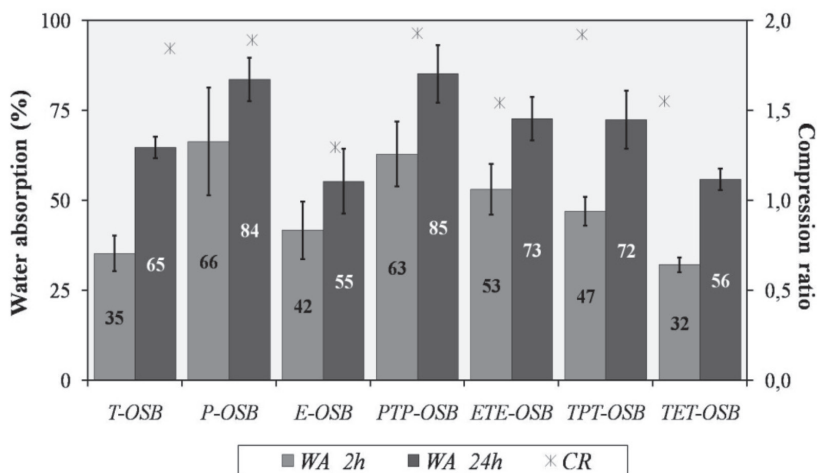
Figure 2. Average values and standard deviation of water absorption 2h (*WA2h*)
and water absorption 24h (*WA24h*).

Although *E-OSB* panels had the lowest *CR, WA* values were lower than those found for *P*-OSB panels. Lower total superficial wood area available for water entrance certainly leaded to this result. The inclusion of *P. oocarpa* in the *TPT-OSB* and *PTP-OSB* panels increased water absorption in relation to *TET-OSB* and *ETE-OSB* panels, respectively.

EN (300) standard does not establish maximum values of *WA*. Comparisons to the literature show that *WA24h* values obtained in this investigation were similar to those presented for OSB panels produced with *PF* applied at 8% and *Pinus taeda* (Okino *et al.* 2004). For most OSB compositions *WA* values were in accordance to those found for non-treated *Picea abies* wood particles and 5% of *PF* (Papadoulos and Traboulay 2002). However, OSB panels comprised of *T. ciliata* showed lower values when compared to the same investigation. It is important to mention that higher adhesive content and lower board density were used in the present work.

TS values of the OSB panels along with the maximum value of *TS24h* required by EN 300 (EN 2003) standard for board commercialization are depicted in Figure 3. *TS2h* varied from 10 to 26%, while for *TS24h* the values ranged from 14 to 30%.

The dimensional changes in OSB panels during water soaking result mainly from the swelling of the fiber cell walls due to water absorption that resides in the inter-strand voids, disintegration of particles due to bonding strength reduction, and spring-back of the compression set imposed during the hot pressing operation (van Houts *et al.* 2004, Zhang *et al.* 1998).

High *TS* values found for boards produced with *P. oocarpa* may be related to high *CR*. Although increases in *CR* are usually desirable due to mechanical strength improvement, higher dimensional instability can be a negative effect. When OSB panels are submitted to water submersion, internal forces are released and result in panel swelling. This phenomenon is called spring back and it is stronger when highly densification occurs during pressing process, which in turn, is related to low basic density-woods or higher board density (Hiziroglu 2009, Zhang *et al.* 1998). On the other hand, *T-OSB* panels had high *CR*, but high swelling was not observed which corroborates with *WA* results and possible wood extractive effect. The inclusion of *T. ciliata* wood enhanced dimensional stability of the boards made from this species mixed with *P. oocarpa* and *E. urophylla/grandis*, especially when positioned in the surface. A similar effect on *TS24h* was observed in the literature for conventional particleboards produced with the same species of this work (Bufalino *et al.* 2012a).

Regarding *TS* for board commercialization, *PO-OSB, PTP-OSB* and *ETE-OSB* panels are not feasible. The same may be considered for *TPT-OSB* panels, if standard deviation is considered. *TET-OSB* and *E-OSB* panels have potential to be commercialized as *OSB/1*, but not as *OSB/2*. Only *T-OSB* have potential to be commercialized as *OSB/2*, when *TS24h* is considered.
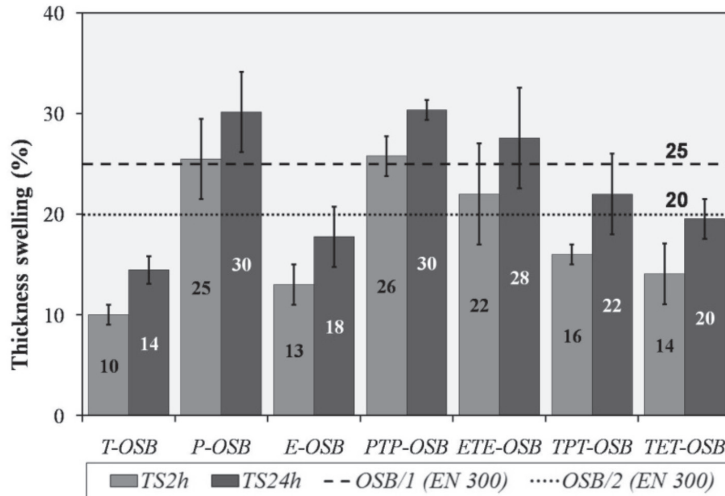

Figure 3. Average values and standard deviation of thickness swelling 2h *(TS2h)* and thickness swelling 24h *(TS24h)*.

Mechanical properties of OSB panels

Among one-species OSB panels, higher *IB* was found for *E-OSB* and *P-OSB* in comparison to *T-OSB* panels. Considering mixed panels, the highest bond strength was found for *TET-OSB* panels (Figure 4). The utilization of low-density species increases the number of strands used, resulting in a higher total wood surface area of the strands and a lower area covered by the adhesive (Barbuta *et al.* 2011). Such effect may have occurred in *T-OSB* panels. On the other hand, *P-OSB* panels had similar *CR*, and *IB* was remarkably higher. Besides high *CR*, poor *IB* strength found for *T-OSB* panels may also be attributed to high extractive content in *T. ciliata* wood species.

Extractives on wood contribute to surface inactivation through both physical and mechanical means. Most wood adhesives are water-based and hence do not properly wet and penetrate extractive-covered surfaces. Physical blocking occurs when the wood is submitted to high temperatures causing extractive migration to the surface where they concentrate and physically block contact with wood (Frihart and Hunt 2010). Although water pre-treatment was performed in *T. ciliata* wood, stronger chemical extractive removal should be considered in further studies in order to improve bond strength. By comparing *TET-OSB* with *ETE-OSB* panels, it can be noticed that by placing *T. ciliata* in the core, *IB* strength decreases. Combination between *P. oocarpa* and *T. ciliata* resulted in poor *IB* strength.
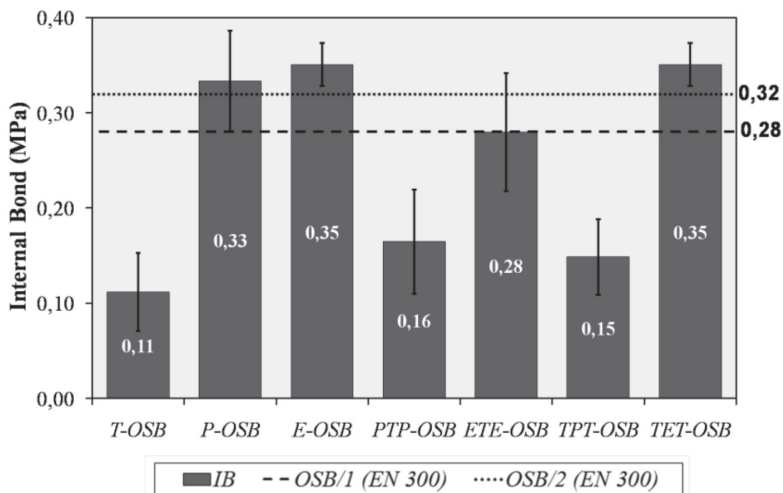
Figure 4. Average values and standard deviation of internal bond *(IB)*.

According to the requirements established by EN (300) standard for *IB* strenght, *P-OSB, E-OSB* and *TET* panels have potential to be commercialized as both *OSB/1* and *OSB/2* board types. Most *IB* strengh values were poor and did not met the standard requirements.

The results from static bending test are depicted in Figures 5-8. Regarding one-species OSB, overall static bending results place *P-OSB* as most resistant. This result may be partially ascribed to higher *IB* and *CR* found for such boards. A greater volume of wood particles compacted during pressing process increases inter-particle contact. Along with adequate bonding quality, panels will have higher strength to external forces. Although *T-OSB* panels had high *CR*, bonding strength was poor and certainly influenced static bending properties. Considering standard deviation, OSB composed by two species had similar static bending strength.

Higher mean values obtained in tests performed in specimens with parallel alignment of particles in the core (//) compared to those obtained in perpendicular alignment (⊥) suggests that face/core/face ratio (% mass) used is not adequate in terms of balanced composition (Mendes *et al.* 2009). Among compositions studied, most similar results between test directions were found for *P-OSB*, while results for *TET-OSB* suggest that another surface/core/surface ratio should be used.
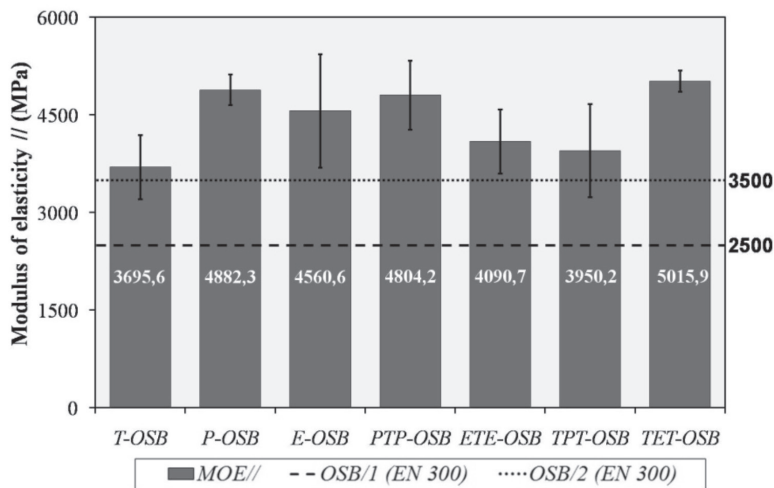

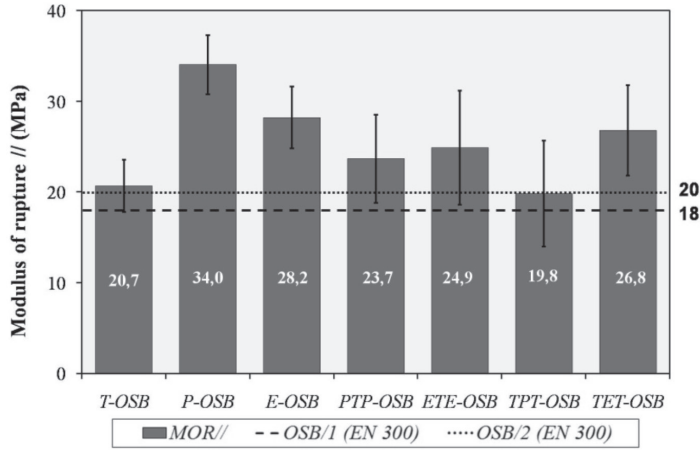**Figure 5.** Average values and standard deviation of modulus of elasticity *(MOE//)*.

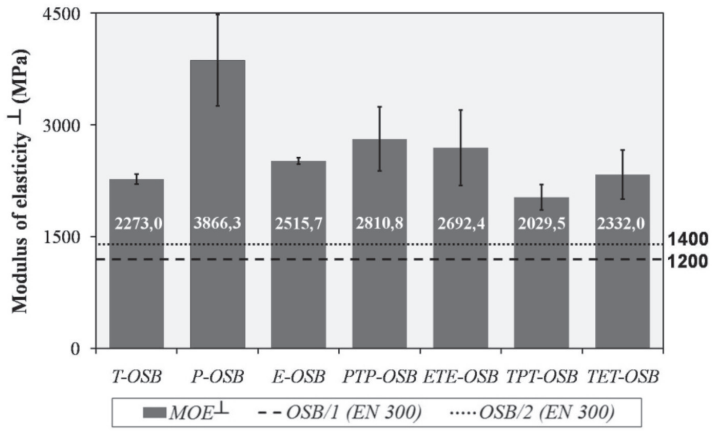**Figure 6.** Average values and standard deviation of modulus of rupture *(MOR//)*.

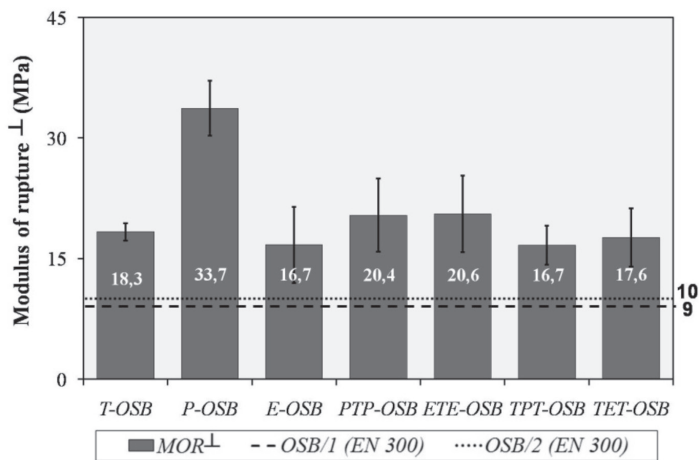**Figure 7.** Average values and standard deviation of modulus of elasticity *(MOE⊥)*.

Figure 8. Average values and standard deviation of modulus of rupture *(MOR⊥)*.

Most board compositions showed bending strength values in both directions of strands alignment (// and ⊥) superior to those required by EN (300) standard, for boards classified as *OSB/1* and *OSB/2*. *T-OSB* have potential to be commercialized only as *OSB/1*, while *TPT-OSB* did not met the requirement for *MOR//*.

CONCLUSIONS

Considering all mechanical and physical properties evaluated in the present work, *P-OSB* type has potential to be commercialized as *OSB/1* type, while *E-OSB* and *TET-OSB* met all the requirements for *OSB/2* type. The others OSB compositions did not fully attend the requirements for commercialization.

In general, bonding performance is the main drawback in the use of *T. ciliata* for OSB production; hence an improvement has to be attained in order to reach standard requirements. In general, static bending strength was lower when this species was included in panel composition. However, all panel compositions proposed met the European standard requirements for *MOR⊥* and *MOE⊥* properties, while most compositions attended the requirements for *MOE//* and *MOR//*.

Low basic density of *T. ciliata* requires the use of high adhesive level, which increases the production cost of the boards. In order to assure commercial feasibility of the compositions proposed in this work, further studies are needed to provide strong bond quality with lower adhesive contents. On the other hand, remarkable improvement of water uptake resistance and dimensional stability was observed with this species utilization. High extractive content found in this species may represent a negative effect on mechanical resistance, but a positive effect on water resistance properties. Since high TS is one of the main issues in OSB applications, *T. ciliata* wood species has great potential for the production of these wood-based products.

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