Is interlocked grain an adaptive trait for tropical tree species in rainforest ?

Pierre Cabrolier[1,], Jacques Beauchêne[1], Bernard Thibaut[2]

1(*) CIRAD, UMR "Écologie des Forêts de Guyane", 97310 Kourou, French Guiana
2 CNRS, UMR "Écologie des Forêts de Guyane", 97310 Kourou, French Guiana

Abstract

Many trees in tropical rain forest exhibit interlocked grain. This phenomenon was observed, using a splitting method, on 10 trees from different genera in French Guiana. There were rather strong variations between and within trees. Different indexes were used and compared to describe this interlocked grain. Previous results have shown that the rupture energy necessary to create a radial-longitudinal surface by wood splitting grows more than 2 or 3 times with interlocked grain occurrence. Moreover, radial splitting of large tropical trees with high density wood is more prone to appear due to the decrease of the ratio between rupture energy and Young's modulus when wood density increases. Finally the long lasting high level of maturation stress in tropical trees growing in primary forest means a very high level of stored elastic energy in the trunk that could be dangerous for the living tree. Interlocked grain can be a good solution to prevent the risk of radial splitting for these adult trees.

Introduction

Interlocked grain (IG) is a particular structure of wood present in a great number of tropical species. It is formed when the grain inclination changes from S or Z helix to the opposite slope during growth (Fig1.A). Due to differences in absorption and reflection of light, bands appear on the radial plane of IG wood, often called ribbon wood [5]. These bands are not always aligned with the longitudinal direction, due to a combination of interlocked and wavy grain (Fig1.B).

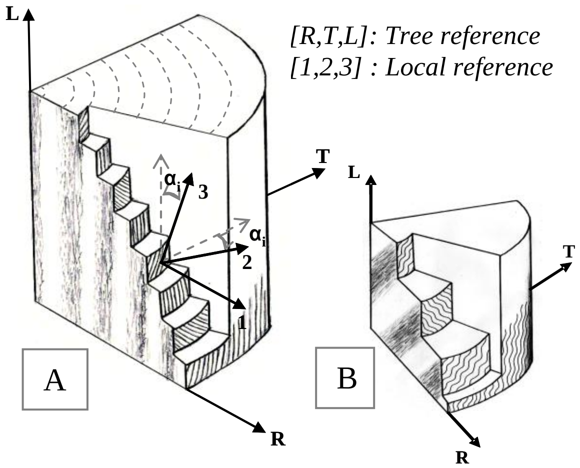


Fig1. A - B

A: Principle of interlocked grain (IG). The grain direction changes during the tree growth and make an angle α_i with the longitudinal direction witch oscillate on the radius. Bands appear on the radial plane, often called ribbon wood.

B: Principle of IG coupled with wavy grain. During the growth the global direction of the grain make an angle with the longitudinal direction of the tree, and a wavelength of few millimetres to many centimetres in length.

According to Kribs (1950) cited by Hernandez and Almeida [6], 75% of 258 tropical trees analyzed had IG. Several theories have been considered for the genesis of spiral or IG. Détienne [4] observed on

* *Present address: LERFOB "Laboratoire d'Etude des Ressources Forêt-Bois » AgroParisTec/ENGREF/INRA, 54000 Nancy, France*

Faro (*Daniellia spp.*), which has a storied cambium, a small IG with a period of some millimeters and an amplitude lower than 10°. He showed that every oscillation fitted with one vegetative year, implying that the period is a function of growth speed in the case of Faro. He tried to explain the change of grain direction by some constant radial rearrangement between the cambial cells of one storey, in relation to the adjoining storeys. But he didn't explain the origin of the phenomenon. According to Kojs & al. [7], who has worked on the history of cellular events in the storeyed cambium of *Lonchocarpus sericeus* (Poir.) DC, the parenchyma arrangement is constant, but the cells' orientation varies quickly with IG. He observed a tangential intrusion on the top of cells during the periclinal division, which takes part in the change of direction. Schulgasser and Witztum [10] showed with a mechanical approach that the spiral angle of the grain could be formed during the process of cell division and maturation in the cambial region. They tried to explain this phenomenon by the evolution of microfibril angle (MFA) between juvenile and adult wood, along with the senescence phases in the case of older trees. The microfibrils apply a shear on the cells, inducing a tendency to twist. He suggested that trees with straight grain block this effect and avoid twisting, while spiral trees do not. In a previous work, Brémaud & al. [2] have measured MFA in relation with grain angle on an IG species (*Pterocarpus soyauxii* Taub.). We observe a tendency of MFA to decrease with increasing grain angle, but the variations are not clearly synchronous (grain angle variation of 40° against MFA variation of 8°). Anyway, the issue of the IG formation seems to remain open.

In this study, we have observed the diversity of IG in ten French Guiana species and address the following question: how does wood IG benefit to the tree?

Material and methods

Ten trees from 10 different species were collected from the tropical rain forest of French Guyana (Table 1). Several methods exist to describe the IG in a tree. The two most used are anatomical successive cuts in the TL plane [4, 7]; and the radial splitting [13, 6, 12, 5]. For reasons of availability, we chose to use the method of radial splitting, with image analysis in the software ImageJ. After splitting, Webb [13] or Hernandez and Almeida [6] measured two parameters to describe and characterize the IG: the maximum angular deviation (MAD) in degrees, estimated as the maximum left spiral angle plus the maximum right spiral angle, and the interlocked grain index (IGI) in millimeters, calculated by dividing the area between the projection of the median radial line EF and the tracing resulting of the split, by the length of the line EF (Fig2).

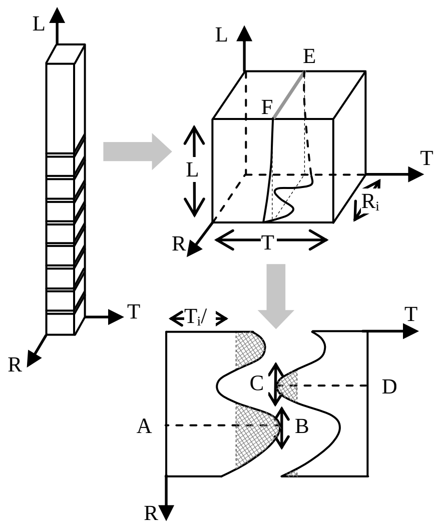


Fig 2. Protocol on cubes splitting and measurements done. The maximum angular deviation (MAD) in degrees, and the interlocked grain index (IGI) in millimeters.
Between 5 and 9 cubes have been machining on the longitudinal direction for each species.

$$\mathrm{MAD} = \mathrm{Atan}\left(\frac{AB - T_i/2}{L_i}\right) + \mathrm{Atan}\left(\frac{CD - T_i/2}{L_i}\right)$$

$$\mathrm{IGI} = \frac{\text{Atched area}}{R_i}$$

The measurements of the radial Young's modulus (E_R) and rupture energy were made on 10 French Guiana species of various densities as described in Bardet & al [1], the method to measure the rupture energy is describe in Beauchêne [3].

Results and discussion

A strong relationship was found between the two IG parameters (MAD and IGI) with a R^2 of 0.81 for the whole sample. This is in agreement with the observations by Hernandez and Almeida [6] and Webb [13]. It is important to note the strong variability of IG between trees and species. Table 1 summarizes the IG types. Some species, such as *Dipteryx odorata* or *Tabebuia* sp. have a small IG with a period of a few millimeters and amplitude of 2 or 3°. At the opposite *Parkia nitida* or *Erisma uncinatum* have a large IG with a period of about 50mm and small amplitude of 2 or 3°.

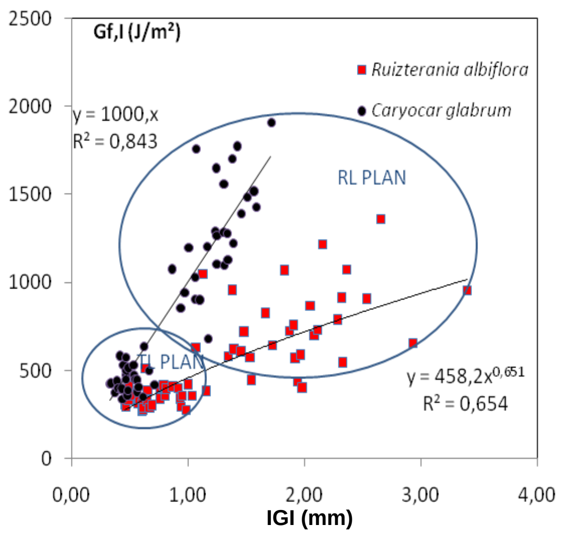


Fig3. Evolution of rupture energy in TL and RL planes against IGI for 2 species with large interlocked grain

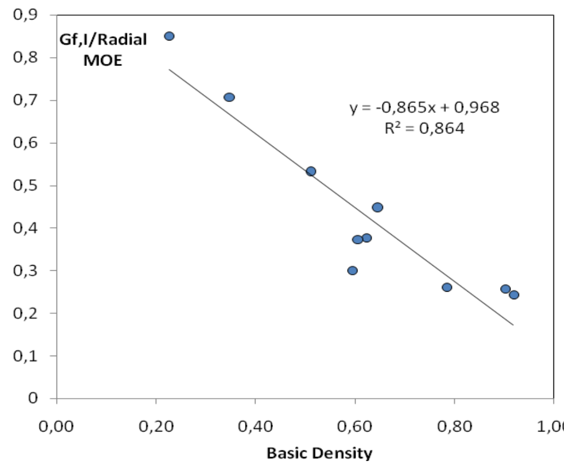


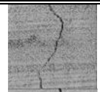
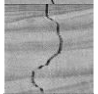
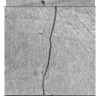
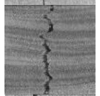
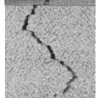
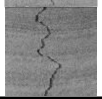
Fig4. Evolution of the ratio: rupture energy radial MOE equivalent against Basic Density for ten French Guiana species

The rupture energy Gf,I necessary to create a radial-longitudinal surface by wood splitting increases when the rupture changes to the tangential-longitudinal plane due to IG occurrence. As we show in Fig3, the effect of the IG plays a great role in the level of rupture energy, for 2 species with relative similar visual IG *Qualea rosea* and *Caryocar glabrum*, the values of Gf,I is around 2 times greater in the RL plan that in the TL plan for *Ruitzenaria* and around 3 times greater for *Caryocar*. The influence of the IGI on the rupture energy is very different for the two species, suggesting a more complex influence of the micro rupture in the middle lamella between the two species.

The rupture energy Gf,I necessary to create a radial-longitudinal surface by wood splitting increases with the density of the wood species [3], but much less than E_R as shown in Fig4, the slope of the ratio Energy/E_R decreases significantly as wood density increases, which means that the denser the wood, the higher the radial splitting risk.

Therefore, the trees of high wood density (basic density above 0.6) are more sensitive to radial splitting. As the mean basic density of sapwood for 555 French Guiana species by Saramento & al [11] is 0.63; this could be a good reason to explain the frequency of IG in tropical families.

Table 1. Summary of the ten species studied, the splitting cubes and showdown between the mean MAD and IGI indices, (COV % is the coefficient of variation, and ROV the range of variation)

Pilot name *(Botanical Name)*	**Number of cubes**	**MAD (°)**			**IGI (mm)**			**Picture**	**Remarks**
			(ROV)	*(COV)*		*(ROV)*	*(COV)*		
Tatajuba *(Bagassa guianensis)*	8	15,2	*(3,7)*	*(7%)*	2,8	*(0,6)*	*(7%)*		*IG constant on the longitudinal axis + IG similar between different trees*
Cupiuba *(Goupia glabra)*	9	15,8	*(11,1)*	*(24%)*	2,5	*(2,4)*	*(35%)*		*Interlocked and wavy grain important but irregular + important variations on the longitudinal axis*
Timborana *(Pseudopitadenia suaveolens)*	8	15,9	*(7,6)*	*(17%)*	2,9	*(1,3)*	*(15%)*		*Specific growth of the cambium + variation on L*
Faveira *(Parkia nitida)*	8	7,2	*(1,0)*	*(4%)*					*Small MAD and long period (about 50mm)*
Cumaru *(Dipteryx odorata)*	5	11,9	*(7,4)*	*(24%)*					*Interlocked and wavy grain + small period and MAD + very little fissile*
Mandioqueira *(Ruizterania albiflora)*	7	16,3	*(9,5)*	*(22%)*	2,8	*(1,3)*	*(20%)*		*Important interlocked and wavy grain*
Satine *(Brosimum rubescens)*	7	12,9	*(5,4)*	*(15%)*					*Variation between trees often important*
Ipe *(Tabebuia sp.)*	9	6,1	*(5,9)*	*(30%)*	0,9	*(1,4)*	*(48%)*		*small period and MAD + Link between interlocked and growth rings*
Jaboty *(Erisma uncinatum)*	9	4,3	*(6,1)*	*(55%)*					*Little MAD and long period*
Araracanga *(Aspidosperma sp..)*	7	11,1	*(6,9)*	*(21%)*	1,8	*(0,8)*	*(18%)*		*Important variability along the radius + important variation on L but no wavy grain*

Conclusion

There is a very important variability of IG (form, wave and angle) between the species observed. Thus, it is difficult to correlate directly the geometrical characteristics and the amplitude of the IG to the real advantage for the radial cohesion of the wood. Nevertheless, the presence of the IG causes a systematic increase of the rupture energy necessary to create a radial-longitudinal surface.

The long-lasting high level of maturation stress in tropical trees growing in primary forest results in a very high level of stored elastic energy in the trunk that could be dangerous for the living tree [9]. Interlocked grain can be a good solution to prevent the risk of radial splitting for these adult trees.
So, given the fact that a lot of tropical trees species present interlocked grain, it may be reasonably assumed that it presents a significant environmental benefit. Rudinski and Vite (1959), quoted by Webb [13], developed the theory that the interlocked grain improves the distribution of water from the roots to the crown. Détienne [4] also supported this hypothesis.

The most significant disadvantage is in the domain of woodworking. Webb [13] noted some significant problems, such as torsion, or lifting, when machining veneer or furniture. But it is also a feature sought after for its aesthetic appearance. On the radial plane, bands appear due to differences in absorption and reflection of light. They are often call "ribbon wood". Some interlocked species are used in woodworking, and considered as "noble woods", like the Satiné / Bloodwood (*Brosimum rubescens)*, or African Mahogany *(Khaya spp.)* for African species.

Acknowledgements

We thank all members of the Laboratory of Wood Sciences of CIRAD who participated in field and laboratory collection and treatment of specimens.

References

1. Bardet S., Beauchêne J., Thibaut B. (2003), Influence of basic density and temperature on mechanical properties perpendicular to grain on ten tropical species », *Annals of Forest Science*. 60 (2003) p. 49-59
2. Beauchêne J. (1996) Evolution du comportement mécanique du bois vert avec la température : application à l'étude du déroulage de quelques bois guyanais *Doctorat de l'ENGREF en sciences du bois*, Kourou.
3. Brémaud I., Cabrolier P., Gril J., Clair B., Gérard J., Minato K, and Thibaut B. (accepted 2009), Identification of anisotropic vibrational properties of Padauk wood with varying grain angle, *Wood Science and Technology* (accepted under minor revisions).
4. Détienne P. (1979). Contrefil à rythme annuel dans les Faro, Daniellia sp. *Bois et Forêts des Tropiques*, n°183
5. Hejnowicz, Z. and Romberger J. A. (1979). The common basis of wood grain figures is the systematically changing orientation of cambial fusiform cells. *Wood Science and Technology* 13: 89-96.
6. Hernandez, R.E. and G. Almeida. (2003). Effects of wood density and interlocked grain on the shear strength of three Amazonian tropical hardwoods. *Wood and Fiber* Sci. 35(2): 154-166.
7. Kojs P. Wloch W. Rusin A. (2004) Rearrangement of cells in storeyed cambium of Lonchocarpus sericeus (Poir.) DC connected with formation of interlocked grain in the xylem. *Trees* 18:136-144
8. Ogata Y. and Fujita M. (2005). New anatomical method of grain angles measurement using confocal microscopy and image cross-correlation. *Trees* 19: 73-80

9. Ruelle J., Beauchene J., Thibaut A. & Thibaut B. 2007 Comparison of physical and mechanical properties of tension and opposite wood from ten tropical rainforest trees from different species, *Annals of Forest Sciences*, 64 (5): 503-510

Schulgasser K. and Witztum A. (2006). The mechanism of spiral grain formation in trees. *Wood Science and Technology*. 41(2): 133-156.

10. Saramento C., Patino S., Paine C.E. T, Beauchêne J., Thibaut A., Baraloto C. (2009); Wood density in tropical trees, Within-individual variation in tropical tree wood density (*Submitted*).

11. Thinley C.,Palmer G., Vanclay J.K., and Henson M. (2005). Spiral and interlocked grain in Eucalyptus dunnii. Holz als Roh- und Werkstoff 63: 372-379.

12. Webb C.D. (1969). Variation of interlocked grain in Sweetgum. Forest Products Journal Vol. 19, No. 8.

.