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BRIEF ORIGINAL

Review of wood properties of *Acacia koa* A. Gray (koa)

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Abstract Koa wood is highly valued primarily because it has unique color, figure, and favorable working characteristics; however, little is known about its properties. Current information is inconsistent and is limited to few sources. Understanding the properties of diminishing old growth koa is important so that comparisons to planted koa can be made. Planted koa will serve as a substitute only if the value adding properties are present. This review reveals how difficult it is to characterize old growth and potentially plantation grown wood.

1 Introduction

Acacia koa (koa) is a hardwood tree, endemic to Hawaii, USA and the wood and veneer is used in furniture, cabinetry, musical instruments, and a wide variety of other decorative and craft products (Dudley 2007; Baker et al. 2009). Koa is sold for between 5.00 and $15.00 US per board foot and can sell for over $100 US per board foot for premium instrument grade with vertical grain and heavy figure (Dudley 2007; Baker et al. 2009).

All koa currently harvested is considered old growth (Dudley 2007). No harvesting of koa is permitted on state owned land in Hawaii (Potter as cited in Loudat and Kanter 1996), with the recent exception of limited salvage harvesting for fallen dead koa on the islands of Hawaii and Kauai. Sources of koa are diminishing and there appears to be increasing interest in developing an alternative supply (Dudley 2007). Koa has been identified as adaptable to plantation management (Dudley 2007) and planted koa could theoretically become a substitute source. Any development towards commercial planting must consider the properties for which it is highly valued; however, little is currently known. This review highlights the lack of knowledge about the wood properties of koa, which is of great importance in understanding the value of future commercial plantings.

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2 General properties

2.1 Color

Heartwood color is commonly reported as reddish brown and ranges from pale blond to dark brown. Sapwood is described as light colored and ranges from yellowish white to pale brown (Gerry 1955; Skolmen 1974; Loudat and Kanter 1996; Dudley and Yamasaki 2000; Shi and Brewbaker 2004; Dudley 2007; Potter 2006; Baker et al. 2009). Literature suggests that variation in color is related to both genetics and environment. Rock (1974) documented the wood of short stem, open-grown trees, typical of drier areas, having “better” color. Gerry (1955) stated that color is influenced by growth conditions, and noted that the wood from old growth trees can have nearly black streaks. Loudat and Kanter (1996) suggested that color is affected by tree age, where older trees have darker wood than younger trees. They also suggested that color is related to the elevation of the original seed stock, where trees grown with seed sourced from high elevation has darker wood than trees grown from seed sourced at lower elevations.

Dudley and Yamasaki (2000) observed consistency in the color of stem and branch wood within trees but that color varied with geographic location.

2.2 Figure

Figure in koa wood, like color, is highly variable but is most commonly reported as curly. Curly figure in koa has been described as wavy, twisted, or interlocked grain (Gerry 1955; Skolmen 1974; Dudley and Yamasaki 2000; Potter 2006). A light-refractive characteristic, termed chatoyance, is often found in curly koa wood and can create a three dimensional quality to finished wood surfaces (Potter 2006). Potter (2006) also reported four general categories of figure and color combinations: blister figure, curl with color banding, dark light curl, and plain with light flame (Fig. 1). Although curly figured wood does occur with some regularity, Gerry (1955) reported that large trees tend to have straight grain and can be absent of figure. Straight grain in koa was also reported by Dudley and Yamasaki (2000) and Baker et al. (2009).

Variation in figure appears to be related to both genetics and environment. Rock (1974) documented that more figure is found in the wood of short stem, open-grown trees. Gerry (1955) reported figured wood occurring near the base of trees. Dudley and Yamasaki (2000) found that figure varied between the four main Hawaiian Islands but was consistent between stem and branch wood within trees. Dudley (2007) commented that figure can be found in pockets of compression wood and commonly at the base of large trees or under heavy branches, but also noted that figured wood can be found systematically throughout entire trees. This is consistent with Baker et al. (2009) who reported physical stress within trees affecting figure.

2.3 Seasoning and shrinkage

Koa is reported to season well without major defects (Gerry 1955; Skolmen 1974); however, defects can occur in boards with abnormalities if drying is too rapid (Potter 2006). Koa is considered relatively easy to dry and stable because of the small difference between radial (5.5 %) and tangential (6.2 %) shrinkage (Potter 2006; Skolmen 1974; Table 1). Skolmen (1974) suggested drying to 12 % moisture content or lower to avoid grain lifting and fuzzy surfaces when planning.

2.4 Workability

Straight grained koa machines and carves well (Gerry 1955; Skolmen 1974), but figured portions can result in tear-out due to irregular grain orientation (Skolmen 1974; Potter 2006; Baker et al. 2009). Baker et al. (2009) reported that variation in density and hardness can also make koa difficult to work. Koa will finish to a high polish (Gerry 1955; Skolmen 1974; Dudley and Yamasaki 2000) and takes many natural finishes (Skolmen 1974). Working koa while green is desirable as it cuts easier and roughed out products, including bowls, can be dried without splitting (Potter 2006) owing to even shrinkage and because it cuts easier (Potter 2006).

2.5 Durability

There are conflicting reports on the durability of koa. Early reports suggested that the heartwood of mature koa is durable, resisting decay by insect and fungus (Lamb as cited in Gerry 1955). Conversely, Skolmen as cited in Skolmen (1974) categorically stated that the wood is

Fig. 1 Four general categories of *Acacia koa* A. Gray (koa) figure and color combinations (Potter 2006). Left to right: *blister figure*, *curl with color banding*, *dark light curl*, *plain with light flame*

Table 1 Reported properties for clear specimen of *Acacia koa* A. Gray (koa) and *Juglans nigra* (black walnut)

Wood property	Test details	*Acacia koa* A. Gray (koa)		*Juglans nigra* (black walnut)	
		Converted from inch–pound			
		Gerry (1955)	Skolmen (1974)	Alden (1995)	Forest Products Laboratory (2010)
	Sample size	Limited	3 Trees	Variable	Extensive
Density	Green (kg/m^3)			929[b]	
	Air dry (~12 % MC, kg/m^3)			609[b]	
	MC NR (kg/m^3)	~480 to 832[a,]*	608[d,]*		
Specific gravity	Green		0.53[e]	0.51[f]	0.51
	Air dry (~12 % MC)	0.46*	0.55[e,]*	0.55[f]	0.55
	Oven dry	0.49*		0.56[b]	
Static bending	Stress at proportional limit (green, kPa)		37,921[e]		
	Stress at proportional limit (air dry ~12 % MC, kPa)	69,395*	Reported Gerry (1955)		
	MOR (green, kPa)		62,052[e]	65,503[f]	66,000
	MOR (air dry ~12 % MC, kPa)	91,927*	Reported Gerry (1955)		101,000
	MOR (oven dry, KPa)			100,667[f]	
	MOE (green, MPa)		10,480[e]	9,791[f]	9,800
	MOE (air dry ~12 % MC, MPa)	10,845*	Reported Gerry (1955)		11,600
	MOE (oven dry, MPa)			11,584[f]	
	Work to proportional limit (green, kJ/m^3)		8.13[e]		
	Work to proportional limit (air dry ~12 % MC, kJm^3)	24.68*	Reported Gerry (1955)		
	Work to maximum load (green, kJm^3)		88.96[e]	100.667[f]	101
	Work to maximum load (air dry ~12 % MC, kJm^3)	62.96*	Reported Gerry (1955)		74
	Work to maximum load (oven dry, kJm^3)			73.777[f]	
Impact bending	Drop causing complete failure (air dry ~12 % MC, 23 kg hammer, mm)	737*			860
Compression parallel to grain	Max crushing strength (green, kPa)			29,649[f]	29,600
	Max crushing strength (air dry ~12 % MC, kPa)	50,504*			52,300
	Max crushing strength (oven dry, kPa)			52,264[f]	
	Max crushing strength (MC NR, kPa)		26,889[e]		
	Stress at proportional limit (MC NR, kPa)		17,926[e]		

Table 1 continued

Wood property	Test details	*Acacia koa* A. Gray (koa) Converted from inch–pound		*Juglans nigra* (black walnut)	
		Gerry (1955)	Skolmen (1974)	Alden (1995)	Forest Products Laboratory (2010)
	Sample size	Limited	3 Trees	Variable	Extensive
Compression perpendicular to grain	Stress at proportional limit (green, kPa)			3,379[f]	3,400
	Stress at proportional limit (air dry ~12 % MC, kPa)				7,000
	Stress at proportional limit (oven dry, kPa)			6,964[f]	
	Crushing strength at proportional limit (air dry ~12 % MC, kPa)	9,404*	Reported Gerry (1955)		
Shearing strength	Parallel to grain (green, kPa)			8,412[f]	8,400
	Parallel to grain (air dry ~12 % MC, kPa)	9,893*	12,276–Av. Gerry		9,400
	Perpendicular to grain (air dry ~12 % MC, kPa)	14,658*	1955		
	Parallel to grain (oven dry, kPa)			9,446[f]	
Hardness	Cross section (air dry ~12 % MC, N)	5,538*			
	Cross section (MC NR, N)		4,225[e] and 5,960[d]		
	Radial (air dry ~12 % MC, N)	3,883*			
	Tangential (green, N)				4,000
	Tangential (air dry ~12 % MC, N)	3,683*			4,500
	Tangential (MC, NR, N)		3,869[e] and 4,937[d]		
	NR (green, N)			4,003.20[f]	
	NR (oven dry, N)			4,492.48[f]	
Shrinkage	Radial (green to oven dry, %)	5.47[c,*]	5.5[d,*]	5.5[f]	5.5
	Tangential (green to oven dry, %)	6.19[c,*]	6.2[d,*]	7.8[f]	7.8
	Longitudinal (green to oven dry, %)	0.49[c,*]			

MOR modulus of rupture, *MOE* modulus of elasticity, *MC* moisture content, *NR* not reported

* Not stated if clear specimen

[a] Howard, 1934 (as cited in Gerry 1955)

[b] Markwardt and Wilson, 1935 (as cited in Alden 1995)

[c] Harrar 1941–42 (as cited in Gerry 1955)

[d] Harrar 1941–42 (as cited in Skolmen 1974)

[e] Gerhards 1963 (as cited in Skolmen 1974)

[f] US Department of Agriculture, 1987 (as cited in Alden 1995)

nonresistant to decay. Lamb as cited in Gerry (1955) also noted seasoned wood having resistance to decay by insects and fungus. The sapwood is susceptible to boring beetles (Baker et al. 2009). Koa is particularly susceptible to termite damage, from both subterranean (*Coptotermes lormosanus* and *Coptotermes formosanus*) and the drywood termite *Cryptotermes brevis* (Skolmen 1974; Dudley and Yamasaki 2000; Dudley 2007).

2.6 Heartwood and sapwood

Heartwood color is second in importance for koa wood value and its formation is not well understood. Heartwood formation begins after age ten and before age 15 years for unsuppressed trees and in suppressed trees it may never develop (Dudley and Yamasaki 2000). Where heartwood has developed, the thickness of the remaining sapwood appears to vary with age and is thicker in younger trees (Skolmen 1974; Loudat and Kanter 1996). In old butt logs sapwood is typically around 25–50 mm thick (Skolmen 1974; Loudat and Kanter 1996), and in younger trees may be 50 mm or more (Skolmen 1974). The formation of heartwood and sapwood thickness in koa is probably influenced by both environment and genetics (Dudley and Yamasaki 2000).

3 Mechanical properties

Information on the mechanical properties of koa is severely limited and what does exist is based on very small sample size. Koa is considered to be comparable to *Juglans nigra* (black walnut) in most mechanical properties (Skolmen, as cited in Skolmen 1974).

3.1 Density and specific gravity

The reported density of koa is highly variable, ranging from 480–1281 kg/m^3 depending on the source. A portion of this variability may result from measurement at different moisture contents, and the moisture content at time of measurement is not always reported (Gerry 1955; Skolmen 1974; Dudley and Yamasaki 2000). The high variability in density is not well understood, and is unusual considering that koa is a diffuse porous species. A relationship between wood color and density was proposed in Loudat and Kanter (1996) where yellow colored wood has lower density than dark colored wood and the Hawaiian koa wood classification system is based on this relationship (Dudley and Yamasaki 2000). Loudat and Kanter (1996) reported a potential relationship between wood grain and density, where curly grain wood is denser than straight grained wood. Dense wood can come from both old and young trees, and Loudat and Kanter (1996) suggest that growth rate has more impact on density than age, where slower growing trees produce denser wood. The same variability exists in the variation of reported specific gravity values, with reported values ranging from 0.53–0.55 (green), 0.46–0.55 (air dry $\sim$12 % moisture content) and 0.49 (oven dry) (Potter 2006; Baker et al. 2009) (Table 1).

3.2 Bending, compression, and shearing strength

Generally koa is considered strong (Gerry 1955); however Baker et al. (2009) described koa as moderately brittle. Only Gerry (1955) and Skolmen (1974) provide specific bending, compression and shear strength values and in many cases these values compare closely to those of black walnut (Table 1). The test details associated with koa values from Gerry (1955) and Skolmen (1974) are different and evaluating variability between these values is not possible (Table 1).

3.3 Hardness

Koa is dent resistant (Gerry 1955) and is suitable for scratch-resistant furniture, but it is not recognized as being hard enough for use as flooring (Harrar as cited in Skolmen 1974; Table 1.) and it has been suggested that growth conditions affect hardness (Gerry 1955).

4 Conclusion

Little is known about the wood properties of koa and often reported information is conflicting, contains large variability and is limited to few sources. Naturally existing trees are diminishing and any significant future supply will likely come from plantings. Koa wood commands a high value primarily because it has unique color, figure, and favorable working characteristics; therefore any development towards commercial planting must consider these properties. This review of the wood properties of koa identifies the difficulties associated with characterizing the wood from old growth and how difficult it would be to compare plantation grown wood.

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