Construction and Building Materials 126 (2016) 632–640

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Coefficient of wood bendability as a function of selected factors

Milan Gaff [a,*], Vojtěch Vokatý [a], Marian Babiak [a], Bekir Cihad Bal [b]

[a] Department of Wood Processing, Czech University of Life Sciences in Prague, Kamýcká 1176, Prague 6, Suchdol 16521, Czech Republic
[b] Kahramanmaraş Sütçü İmam University, Faculty of Forestry, Department of Forest Industry Engineering, 46040 Kahramanmaraş, Turkey

HIGHLIGHTS

- The coefficient of bendability was calculated according to the different equations.
- Wood species and degree of densification have significant effect on the coefficient of bendability.
- Material thickness and number of stressing cycles did not show significant effects on the coefficient of bendability.
- The coefficients of bendability based on the basic bending equation are substantially higher than those based on the geometric approach.

ARTICLE INFO

Article history:
Received 13 June 2016
Received in revised form 19 September 2016
Accepted 21 September 2016

Keywords:
Coefficient of bendability
Cyclic loading
Laminated wood

ABSTRACT

Shaping materials by bending is a frequently used technology. The measure of a material bendability can be taken as the smallest achievable curve radius for the bent material. As bendability depends also on material thickness, this property is most frequently expressed as the ratio of the material thickness and the smallest curve radius achieved. Bending is also an important part of many wood processing technologies. The theoretical expression of wood bendability is, however, rather inadequately studied. The present work focuses on various definitions of the wood bendability coefficient as well as the influence of various factors on its value. In the experimental part of the work, coefficients of wood bendability were defined for beech (*Fagus silvatica* L.) and aspen (*Populus tremula* L.) We took the following factors into consideration: wood species (WS) (*Fagus silvatica* L. and *Populus tremula* L.), material thickness (MT) (4, 6, 10, and 18 mm), degree of densification (DOD) (10% and 20% of the original thickness), and the number of stressing cycles (NC) (0 versus 10,000). The study brings a new quantitative expression of a bendability coefficient.

1. Introduction

Solid wood has some favorable advantages when compared to other engineering materials such as concrete, ceramics, glass, brick, steel and other metals. It is a renewable material delivering relatively high strength values with relatively low density, good shock resistance and beautiful appearance [1,2]. It is described as an orthotropic material [3], and is amongst the oldest construction materials [4]. In addition, Solid wood can be easily processed, and easily bent after some operations.

Bendability is a technical property of wood expressing its ability to bend. We express it as the smallest curve radius before which the material is first damaged. The coefficient of bendability K_{bend} is a quantitative characteristic that is defined as the ratio of the bent material thickness h and the minimal curve radius. For most wood species, the limit is h:r = 1:35–1:45.

The critical place when bending wood is the tension zone. Maximum wood deformation in tension in a native unmodified state is 0.75%–1%. This can be increased by plastification to 1.5–2% [5]. Wood compressibility, on the other hand, is higher, and under optimal humidity and temperature conditions, if the porosity allows, it reaches as much as 40%.

Scientific knowledge of this characteristic is very limited. Gaff et al. [6] stated that K_{bend} values decrease and the force necessary for bending increases with growing material thickness.

There is a lack of knowledge, however, of other factors influencing the K_{bend} coefficient, namely the wood species (WS), the material thickness (MT), the degree of densification (DOD), and the number of stressing cycles (NC). In practice wooden materials are commonly exposed to these factors, therefore they must be taken into account when designing wooden products. It is also important to understand this characteristic correctly; otherwise the characteristic cannot be utilized properly.

Wood densification is generally based on the finding that the mechanical properties of wood – its hardness and resilience –

---

[*] Corresponding author.
E-mail address: gaffmilan@gmail.com (M. Gaff).

http://dx.doi.org/10.1016/j.conbuildmat.2016.09.085
0950-0618/© 2016 Elsevier Ltd. All rights reserved.

improve with increasing wood density and the range of their values decreases [7–9].

In creating laminated materials, different materials and various thicknesses are combined [5]. Several authors have studied the influence of material thickness on wood bending characteristics, such as Candan et al. [10] and Çolakoğlu et al. [11]. Thonet also dealt with increasing bendability of wood lamellae by changing the thickness of material used for manufacturing laminated wood [12]. Research findings on the influence of material thickness on K_{bend} in various types of wood are still very limited.

Materials used in construction are rarely exposed only to static loading. In most cases, they must be resistant to cyclic loading, which can have various characters such as changing mechanical stress and/or various humidity or temperature changes among others [13]. Not sufficient attention has been paid to this, even though a number of factors greatly influence the creation of materials used in various furniture and building designs.

Only a thorough understanding of these factors' influence along with the evaluated characteristics can lead to the development of new types of materials with properties suitable for the given purposes. In this work, we would like to correct the determination of R_{min} for the proper calculation of K_{bend}. We originally accepted the definition of R_{minA} in formula (1) published by Gáborík and Dudas [14]:

$$R_{\min A} = \frac{l_0^2}{8y_{\max}} + \frac{y_{\max}}{2} \tag{1}$$

Our derivation of the relationship for the minimal curve radius is stated below.

2. Materials and method

2.1. Material

Wood of European beech (*Fagus Silvatica* L.) and common aspen (*Populus Tremula* L.) from the Polana region in Slovakia were used for the preparation of the specimens. Lamellae of the dimensions of 4, 6, 10, and 18 mm thickness, 35 mm width, and 600 mm length were made of the selected species. The specimens were conditioned to have a moisture content of 8% in a climate chamber maintaining a relative humidity of 40% and temperature of 20 °C. After conditioning we determined the coefficient of bendability K_{bend} before cyclic loading and after cyclic stressing (number of loading cycles = 10,000). The cyclic loading was carried out on a cycler machine with cyclic bending of the test pieces using single-axis loading. The following numbers of cycles were selected for testing: 0 and 10,000. During the preliminary experimental testing, the test pieces were loaded with static bending to determine the breaking strength and proportionality limit because the test pieces had to be loaded up to 90% of the proportionality limit.

The acquired results were compared with those measured in test specimens subjected to 10% and 20% densification perpendicular to the grain. Ten test specimens were used for each test. Fig. 1 provides an overview of the test specimens.

3. Methods

3.1. Determining minimal curve radius

In our study we applied three different equations to calculate the minimal curve radius R_{min} (1, 4 and 9), with which we then determined the coefficient of bendability K_{bend}. Eq. (1) was taken from Gáborík and Dudas [14]. Eqs. (4) and (9) were derived from bending geometry and the basic equation of bending. Subsequently, we compared the results thus obtained.

Bending geometry is illustrated in Fig. 2.

By analyzing the geometry of bending in accordance with Fig. 2 we obtain the following equations:

$$X^2 + \frac{l_0^2}{4} = \left(R + \frac{h}{2}\right)^2 \tag{2}$$

From Fig. 2 it is clear that the maximum deflection consists of two parts: R-X and h/2.

$$R - X + \frac{h}{2} = y_{\max} \tag{3}$$

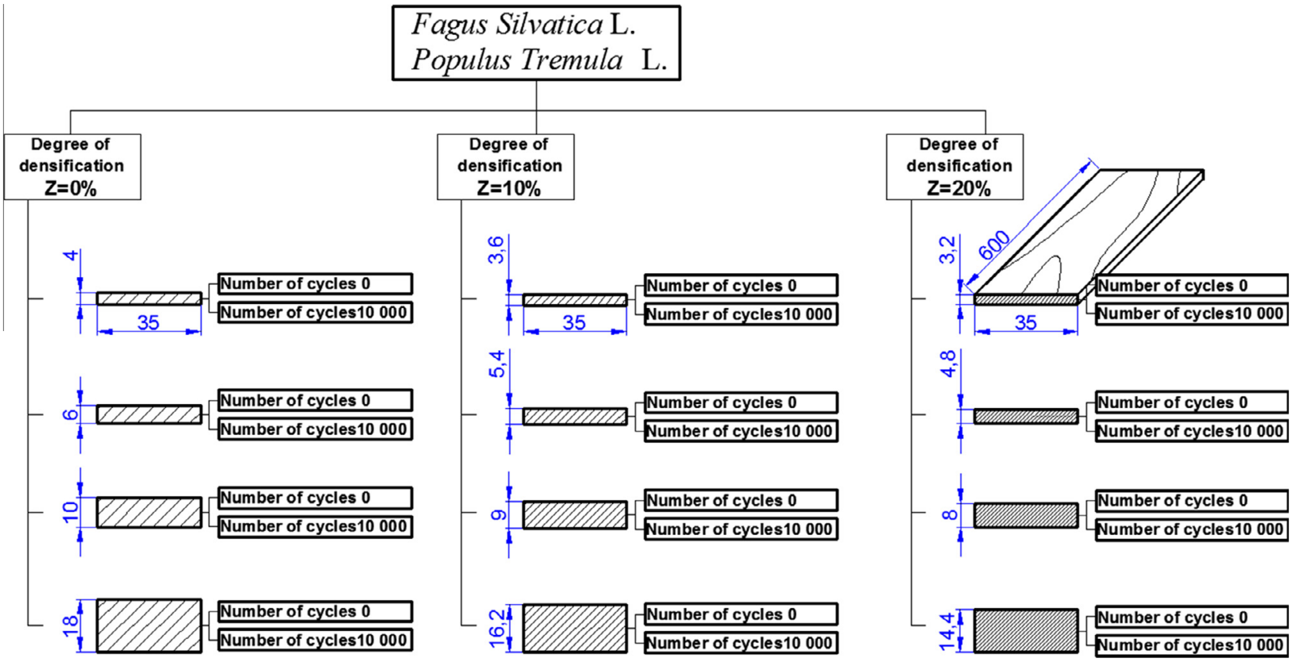

Fig. 1. Categorization of test specimens.