Preliminary

Relationship between Bending Quality and Wood Species*[1]

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Introduction

Wood bending is an effective technique to obtain various curved parts and members required for wood-made products such as furniture, musical instruments, barrels, sporting goods, boats and so on. However, the bending quality (BQ) of wood varies widely not only among the different species but also within the same species[1–3]. Wood suitable for wood bending is restricted to some species. Factors influencing the BQ of wood are very complicated depending not only on various levels of wood structure but also on physical and chemical properties of wood. This paper investigates factors concerning the BQ of sixteen kinds of wood species including softwood, temperate and tropical hardwood.

Materials and Methods

Wood specimens of *Zelkova serrata* (Japanese zelkova, oven-dry density : 0.76 g/cm^3), *Quercus mongolica* (Japanese oak, 0.55 g/cm^3), *Ulmus darrdiana* var. *japonica* (Japanese elm, 0.55 g/cm^3), *Liriodendron tulipifera* (yellow poplar, 0.50 g/cm^3), *Fagus crenata* (Japanese beech, 0.65 g/cm^3), *Quercus myrsinaefolia* (Japanese white oak, 0.85 g/cm^3), *Podocarpus imbricatus* (igem, normal wood: 0.48 g/cm^3 and compression wood : 0.52 g/cm^3), *Pinus densiflora* (Japanese red pine, 0.56 g/cm^3), *Chamaecyparis obtusa* (Japanese cypress, 0.48 g/cm^3), *Homalium foetidum* (malas, 0.80 g/cm^3), *Ochroma lagopus* (balsa, 0.10 g/cm^3), *Populus maximowiczii* (poplar, 0.37 g/cm^3), *Pinus radiata* (radiata pine, 0.46 g/cm^3), *Cryptomeria japonica* (Japanese cedar, 0.37 g/cm^3), *Chamaecyparis pisifera* (sawara cypress, 0.29 g/cm^3) and *Gingo biloba* (ginkgo, 0.44 g/cm^3) were used. The dimension was 33.8 cm (L) by 2 cm (T) by 1 cm (R). A jig made of an iron strap with wood handles at both ends was used in the bending operation. By using this device, the outer side of the specimen sticks to the iron strap while the handles limit the stretching of the specimen by applying end pressure (Thonet-method) and most of the specimen is stressed in compression. After the specimens were conditioned at 20°C in oven-dry state, at 20°C in wet state and at 100°C in wet state, they were subjected to the bending operation. The radii of wooden forms were 12 cm, 6 cm and 4 cm. The bent specimens were dried under restraint at 105°C to fix the deformation. The BQ was evaluated by the ratio (r/t) of the radius of the form (r) to the thickness of the specimen (t). Wood pieces with the dimension of 2 cm (T) by 2 cm (L) by 1 mm (R) were cut from the one end of each bent specimen and they were subjected to X-ray diffraction measurements to determine the mean microfibrillar angle (MMA). The rough estimation of ray content was made through a microscopic observation of the bent specimens.

Results and Discussion

At 20°C in oven-dry state, the specimens of all wood species used could not be bent to $r/t=12$. At 20°C in wet state, the specimens of Japanese zelkova, Japanese oak, Japanese elm and yellow poplar could be bent to $r/t=4$ and those of Japanese beech, igem (compression wood) and Japanese cypress could be bent to $r/t=12$. The specimens of other species could not be bent to $r/t=12$. At 100°C in wet state, the specimens of Japanese zelkova, Japanese oak, Japanese elm, yellow poplar and Japanese beech could be bent to $r/t=4$ and those of Japanese white oak and igem (compression wood) could be bent to $r/t=6$. However, the specimens of other species could not be bent to $r/t=12$. These results showed that the softening by moistening and heating played an important role to enhance the BQ of wood. It is known that the softening temperature of wood in wet condition is generally in the order, temperate hardwood < tropical hardwood < coniferous wood[4]. Since it is considered that most curved parts and members of wood products can be produced using the wood with $r/t \leqq 6$, the BQ of species was classified into two groups by the critical value of $r/t=6$.

In the group of good quality, Japanese zelkova, Japanese oak, Japanese elm, Japanese beech and Japanese white oak, which are temperate hardwood, had a large ray content (about 11–18%), a high density (0.55–0.85 g/cm^3) and a small MMA (< 10 deg.). In longitudinal bending, ray cells are compressed transversely. The scanning electron microscopic observation on the concave face of the bent Japanese zelkova specimen shows that the honeycomb-like structure of ray cells is remarkably deformed[5]. When ray cell walls are sufficiently softened by moistening and heating, it is considered that the wood with a large ray content can be compressed to a large extent in L direction by crushing and folding of the honeycomb-like structure of ray cells. Yellow poplar, temperate hardwood, had a middle ray content, a middle density (0.50 g/cm^3) and a relatively large MMA (15

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deg.). When the wood with a large MMA is compressed in L direction, it is speculated that microfibrils in the S_2 wall layer move in close one another in fully softened matrix substance and this leads to a large compressive breaking strain of the wood. The good BQ of this species may be ascribed to multiple effects due to a low softening temperature, a large MMA and a middle ray content. Compression wood of igem, tropical coniferous wood, had a very small ray content and a large MMA (22 deg.). Tracheid shapes in the cross section were considerably round and spiral checks were observed on surfaces. Multiple effects due to a large MMA, spiral checks and a large lignin content of compression wood may contribute to a larger breaking strain in L direction.

In the group of inferior quality, igem (normal wood), radiata pine, Japanese cedar, sawara cypress, ginkgo, Japanese red pine and Japanese cypress, coniferous wood, have a low or middle density (0.29–0.48 g/cm^3) except Japanese red pine (0.56 g/cm^3), a small ray content and a high softening temperature[4]. Igem (normal wood), Japanese cedar, sawara cypress, Japanese red pine and Japanese cypress had a small MMA (<10deg.), while MMAs of ginkgo and radiata pine were 18 deg. and 21 deg., respectively. In the longitudinal compression of coniferous wood, wavelike deformations of thin tracheid walls themselves occur locally near the concave face of the bent specimen and grow to macroscopic creases at a small strain[5,6]. The inferior quality of these species may be ascribed to a large softening temperature[4] and thin tracheid walls in early wood. Coniferous wood is generally unsuitable for wood bending, but the BQ of Japanese cedar and Japanese cypress changes with MMA[3] and coniferous wood with a very large MMA (>30 deg.) and a very low crystallinity has exceptionally good BQ[7,8]. Malas, tropical hardwood, had a middle ray content and a small MMA (<10 deg.). In the bending operation with a radius of 12 cm, such shear failure bands in the specimen as observed in the oven-dry state appeared even at 100°C in wet state, suggesting a very high softening temperature of this species[1]. Balsa, tropical hardwood, had a small ray content, an extremely low density (0.1 g/cm^3) and a small MMA (<10deg.). These causes and a large softening temperature may be ascribed to the low quality of this species. Most of tropical hardwoods are unsuitable for wood bending[2]. Poplar, temperate hardwood, had a low ray content, a low density (0.37 g/cm^3) and a relatively large MMA (14 deg.). The low quality of this species may be attributed to very low densities of wood fibers in early wood in which concentrated wavelike deformations are easy to occur near ray-crossing areas.

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