MODELING MOISTURE CONTENT-MECHANICAL PROPERTY RELATIONSHIPS FOR CLEAR SOUTHERN PINE

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ABSTRACT

The objective of this study was to determine the effect of moisture content on a wide range of clear wood properties. Specimens were cut from commercially dried 38- by 140-mm (nominal 2- by 6-in.), southern pine lumber and sorted, based on specific gravity, into five matched moisture groups of approximately 40 specimens each. Empirical models are presented for predicting the effect of moisture content on strength and stiffness for the various test properties. Results indicate that tensile stress parallel- and perpendicular-to-grain and both Mode I and Mode II stress intensity factors for fracture toughness increase with decreasing moisture content from green to a peak between 7% and 13% moisture content. Upon additional drying, these properties decrease. Maximum fiber stress in bending, compression parallel- and perpendicular-to-grain, shear parallel-to-grain, and all elastic modulii increase with decreasing moisture content from green to 4% moisture content. For some of these properties, the increase is not linear at lower moisture content levels. Because specific gravity is known to affect clear wood properties, models were also developed to account for using moisture content and specific gravity. Theoretical approaches to moisture absorption that may explain experimental results are discussed.

Keywords: Moisture content, specific gravity, clear wood, tension, bending, compression, shear, stress intensity factor, Poisson's ratio, southern pine, empirical models, dimension lumber, drying.

INTRODUCTION

In the United States, lumber equilibrates to a wide range of moisture content (MC) levels in use. For example, lumber installed green in timber bridges may remain at or near the fiber saturation point for several years after bridge installation. In contrast, lumber used in attics in the dry southwestern parts of the country or over heat sources in commercial buildings may be reduced to moisture levels as low as 2% to 4% the year after installation. This study is part of a program to gain a fundamental understanding of the effect of MC on the mechanical properties of wood. The program was initiated because: (1) previous research indicates that lumber strength, especially ultimate tensile stress (UTS) parallel-to-the-grain, does

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not always increase with decreasing moisture content, and (2) limited, but persistent, failures have been reported in timber structures subjected to environmental conditions that lead to very low MC levels.

Each year, for the past 15 years, the Forest Products Laboratory has received one to three inquiries about failures in structural members that were subjected to ambient environmental conditions that resulted in member MC levels in the range of 2% and 4%. A significant number of these inquiries are from consulting engineers knowledgeable in the design of wood structures. Some telephone inquiries may be followed by written reports, including pictures, or receipt of samples of wood cut from failed members. Virtually all these inquiries involve commercial buildings. Some member failures have occurred at connections, but a surprising number have also exhibited failure in the middle of the member far removed from a joint. In some instances, there is evidence of thermal degradation, and in others, no evidence of thermal degradation. However, in each member failure, low MC was suspected as a contributing factor.

In the past few years, several studies have been conducted on the effect of MC on the bending, tensile, and compressive strength of nominal 38-mm- (2-in.-) thick commercial lumber (Green and Evans 1989; Barrett and Lau 1991). This work established that bending and tensile strength did not necessarily increase with decreasing MC. For example, UTS parallel-to-grain, at most percentile levels, first increases with decreasing MC below the fiber saturation point and then decreases as MC falls below about 10% to 15% (Green et al. 1990). However, the experimental design of this research was driven by the needs of the U.S. In-Grade Testing Program (Green 1983). Because only a small amount of structural lumber is intentionally dried to less than about 10% MC, this level was the lowest MC for which UTS data were obtained.

Persistent reports of structural failures at low MC levels, coupled with the experimental evidence of a decrease in lumber strength at lower MC levels, suggest the need for a better understanding of the effect of MC on properties, especially UTS at low MC levels. The objective of this study was to determine the effect of MC on a wide range of clear wood properties. Empirical models fit to these data will serve as input to an analytical model that predicts strength (Cramer and McDonald 1989) for comparison with lumber MC test results.

BACKGROUND

Experimental studies on the effect of low MC on the UTS of structural lumber are expensive and time-consuming. The need to obtain a more fundamental understanding of the effect of MC on properties was recognized by Dr. David W. Green in the mid-1980s. However, other priorities and the lack of an adequate analytical model to predict the strength of lumber using fundamental mechanisms prevented such a study at that time.

Considerable literature exists on the effect of MC on the mechanical properties of clear, straight-grained wood. A detailed discussion of the literature is contained in Green and Kretschmann (1994). In general, in any one study, data are given for only a few properties, and only a limited number of specimens were tested for a given property-MC combination. The number of researchers who have data on properties of clear wood at less than 6% MC is much more limited than those with data greater than 6% MC. From the studies reported (Green and Kretschmann 1994), it appears that modulus of elasticity (MOE) in bending and compressive strength parallel- and perpendicular-to-grain increases linearly with drying below the fiber saturation point. Some data indicate that the MOE parallel- and perpendicular-to-grain MC curves flatten for levels less than about 6% MC. Tensile strength parallel- and perpendicular-to-grain, shear strength parallel-to-grain, and Mode I and II fracture toughness also increase with decreasing MC from green to about 12% to 15%. Several studies have indicated that a significant decrease in these clear wood property values may occur with additional drying (Green and Kretsch-