Simulation Enables Better Heating and Drying Processes for Wood

U.S.D.A. Forest Products Laboratory

U.S.D.A.

Materials Engineering

United States

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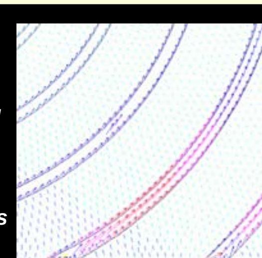
ANSYS® Mechanical™
ANSYS Parametric Design Language

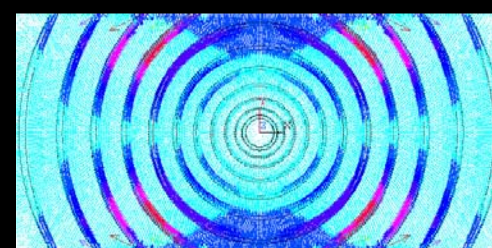
Overview

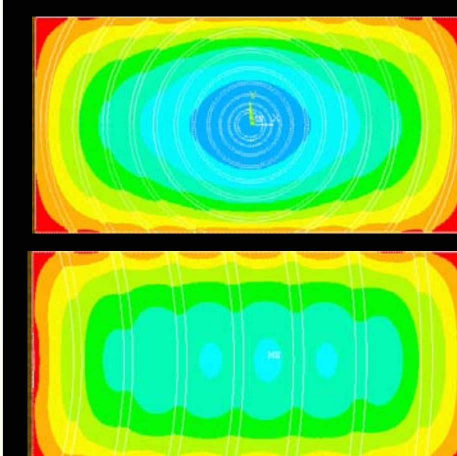
Established in 1910 by the U.S. Department of Agriculture Forests Service, the Forest Products Laboratory in Madison, Wisconsin, serves the public as the nation's leading wood research institute. It is internationally recognized as an unbiased technical authority on wood science and utilization. The lab is the public side of the public–private partnership needed to create technology for the long-term sustainability of forests. According to a recent study, tax dollar investments in forest products research generates as much as a 300 percent return to society.

One particular area of research at the lab focuses on more precisely establishing thermal conductivity of wood. This is critical in the drying process, since too little heat treatment results in retained moisture and long drying times, while too much treatment (or too fast) may damage the structure of the wood. Conventional equations developed more than 50 years ago serve as a rough guideline in calculating an average thermal conductivity for certain types of wood. However, because of the inherent inaccuracies of this approach, lumber mills and wood processing companies must perform trial-and-error tests to determine proper temperatures and drying times — a costly, time-consuming process that often results in high scrap rates.

Vector plot of heat flux showed high and low thermal transfer in earlywood and latewood due to different cell densities in these regions.







Contour plots indicate transient temperature profiles for two locations with different ring structures in the same wood board.

Testimonial

"Finite-element models provide valuable analysis tools to examine the fundamental thermal conductivity differences for radial and tangential heat transfer at the micro level, and also to estimate the transient heat transfer effects at the macro level in a board of wood. A parametric method enabled the numerous simulations to be run efficiently and provide a broad range of data needed in determining the heat transfer coefficients. Such an approach in studying heat transfer issues in wood has numerous practical applications that include optimizing drying schedules for different board cuts, determining heat treatment times to kill insects, and determining heat curing times for solid wood as well as composites. In this respect, FEA software is a valuable tool to explore and review fundamental laws of science."

John Hunt
Research Mechanical Engineer
USDA Forest Products Laboratory

Challenge

Heat transfer coefficients of wood depend on many variables including ring density, tree age, initial moisture content and cell orientation. Porosity can range from 70 to 90percent in earlywood and 10 to 30 percent in latewood growth. Moreover, in softwood, cells tend to align in straight rows in the radial direction and are offset in the tangential direction. Compounding the difficulty, these characteristics usually are not uniform across all sections of the same tree, with wood structure affected by seasonal weather differences. Also, ring density (and thus heat transfer) in small- versus large-diameter trees varies widely depending on growth rates for different conditions such as surrounding vegetation and climate.

Solution

On the micro level, ANSYS Parametric Design Language (APDL) programmed models were developed to simulate the structural variation of cell porosity and alignment in determining effective heat transfer coefficients. For the macro level, boards cut from different locations in a typical log were modeled, solved and plotted to examine the effects of wood structure on the transient heat transfer process using thermo conductivity values obtained from the micro-level analyses. Dozens of simulations were required to determine the heat transfer rate for a range of wood geometries and structural conditions, and APDL performed repetitive analyses of these varying parameters by enabling different values to be inserted and multiple analysis re-run without manually rebuilding multiple simulation.

Benefits

FEA simulations showed significant effects of cell alignment, cell density, ring width and ring orientation on thermal conductivity of wood. The study concluded that porosity of wood as well as growth rate of the tree play major roles in determining effective thermal conductivities, which can be developed as equations or a look-up table for further use in macro wood models. Further, heat transfer in a piece of wood is significantly affected by ring density and orientation, and quarter-sawn boards have higher heat transfer rates than flat-sawn boards due to the shorter pathway through latewood cells. This insight will enable more effective wood heat treating processes and help better utilize this critical natural resource.