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主　論　文　の　要　旨

論文題目	Construction of Nondestructive Online Spectroscopic Systems for Wood Products (木質材料の非破壊オンライン分光システムの構築)
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論　文　内　容　の　要　旨

Wood products of lumber and veneer from sugi (*Cryptomeria japonica*) are important materials in Japan. They are commonly used as building materials in daily life. High production stock of sugi wood in Japan nowadays leads high demands of this wood species in all area of the nation. People also adore sugi wood from their beautiful features and color from this species. In order to having high demands of lumber and veneer of sugi in wood industry, it needs to acquire strength information of the materials in proper and quick way for the efficiency. Modulus of elasticity (MOE) value of lumber and veneer of sugi is one of the important criteria to obtain the description of the stiffness and strength information.

Nondestructive testing and evaluation (NDE) using near-infrared (NIR) spectroscopy for wood materials have been being developed since many years ago. NIR region from 800–2500 nm of electromagnetic spectrum can be used as nondestructive method for studying the organic materials. Wood is composed principally of carbon (C), hydrogen (H), and oxygen (O), which make wood as measurable for NIR light. These quick and nondestructive measurements on the lumber and veneer of sugi for quality grading in industry line is strongly required for saving cost and time. This research tried to construct prediction model of MOE from lumber and veneer of sugi using online NIR spectroscopic systems. The online NIR spectroscopic system was constructed to acquire NIR spectra from both kind of samples from the tangential surface in the wavelength range of 900–1600 nm which were running above conveyer belt in the speed of 120 m/min to suit the online system of wood industry. On the veneer samples

measurement, there was additional parameter on the moisture content (MC) prediction model and Douglas-fir (*Pseudotsuga menziesii*) veneer samples as the comparison species for sugi. As the wood materials are formed naturally, it cannot be released from natural defects like knot, which can affect the MOE values. Lumber of sugi are covered with knots on the surface, while veneer of sugi are covered from both knots and holes on the surface. Beside constructing prediction model of MOE for lumber and veneer of sugi using online NIR spectroscopic system, this research also observed the effect of knots and holes on the MOE prediction and mapping of veneer using NIR hyperspectral imaging (HSI) technology.

Cross-validation partial least squares (CV-PLSR), a multivariate data analysis or chemometrics, was used to construct the prediction model from the NIR spectra data and the conventional measurement data or reference data. Among the all properties in wood material, MOE was chosen to represent the strength and stiffness as for quality grading for wood products. In this research, MOE was the main property used as reference data for constructing the prediction model. Sugi lumber samples measurement for the MOE prediction model resulted root-mean-square error for cross-validation (RMSECV) of 0.88 GPa with coefficient of determination for cross-validation (R^2CV) of 0.77, while sugi veneer samples resulted RMSECV of 0.95 GPa and R^2CV of 0.43. Douglas-fir veneer samples resulted 1.80 GPa for RMSECV and 0.52 for R^2CV. Prediction accuracy of R^2CV on the MC prediction model obtained from this high speed online NIR spectroscopic system measurements for veneer samples were very high, 0.95 and 0.96 for sugi and Douglas-fir, respectively.

Lumber samples measurement using online NIR spectroscopy system was concluded that the use of the online NIR spectroscopic system to analyze the tangential surface of sugi lumber running at very high speed of 120 m/min showed sufficient prediction accuracy for lumber quality screening. The second derivative (2der) pre-processing treatment with 19 smoothing-point (Savitzky-Golay algorithm, second polynomial) spectra gave the best result in the CV-PLSR analysis, yielding the lowest error of RMSECV value and the highest accuracy of R^2CV value. The combination of CV-PLSR and test-set validation partial least squares regression (TSV-PLSR) gave certainty to the robustness of the MOE prediction model. Veneer samples measurement using online NIR spectroscopic system was concluded that this research examined online NIR spectroscopic system as a novel technology for quick assessment for MOE and MC of veneer materials in the plywood industry. Prediction models for both MOE and MC for sugi and Douglas-fir veneers were successfully constructed with sufficient

prediction accuracy. Even though the fast speed of online NIR spectra measurement has shown satisfactory results for MOE and MC to generate a prediction model for application, more developments to increase the R^2CV from this device need to be done to convince the wood industry the technology is ready for widespread use.

Imaging NIR spectroscopy of NIR-HSI technology can provide NIR spectral data as a set of images, so that this technology is suitable for imaging explanation of prediction values on the wood properties (in this research MOE) from the point of view of sample surface. The collected image data is arranged into three-way data matrix (hypercube data). The first two axes (x and y) of the matrix and are the vertical and horizontal pixel coordinates (spatial dimension), while the third (z) axis represents the spectral dimension (wavelength). MOE prediction and mapping on the veneer samples using NIR-HSI system resulted the best RMSECV of 0.88 GPa and R^2CV of 0.69 from the 2der pre-processing spectra from *wood including knot hole* (WiKH) spectra. Mapping of the MOE prediction values could be imaged on the whole veneer sample which was arranged from mapping of the MOE prediction values of the small section veneer samples. Knots had a significant negative correlation with MOE values due to the weakened surrounding area, which was clearly shown by lower predicted MOE values. Mapping could also successfully differentiate latewood from earlywood as well as sound knots from dead knots in this research by observation on the predicted MOE values.