Non-destructive assessment of moisture content and modulus of rupture of sawn timber *Hevea* wood using near infrared spectroscopy technique

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Abstract. The sawn timber Para rubber (*Hevea brasiliensis*) wood is an important wood product accounting for the highest export value of Thailand. The objective of this research was to build a prediction model of moisture content and modulus of rupture of sawn timber *Hevea* wood samples using desktop near infrared spectrometer. The timber samples were collected from the southern region and eastern region of Thailand and scanned using Fourier transform near infrared (FT-NIR) spectrometer in a range of 12489–3594 cm⁻¹ (800–2700 nm) in diffuse reflectance mode. Then they were determined for moisture content and modulus of rupture (MOR) following ASTM. The predictive models were built by the partial least squares regression (PLSR). The result showed high performance in prediction of moisture content with correlation coefficient of prediction, $R_p = 0.89$ and root mean square error of prediction; RMSEP = 0.70%db. Regarding a predictive model of modulus of rupture, the results showed fair performance giving $R_p = 0.78$ and RMSEP = 17.11 MPa. Therefore, using near-infrared spectroscopy technique to predict the moisture content and strength based on the modulus of rupture of *Hevea* wood offered a rapid and non-destructive measurement as an alternative to the destructive checking the quality of sawn timber *Hevea* wood.

1. Introduction
In the year 2017, Thailand has the export value of processed rubber wood up to 50,824.29 million baht [1]. Before exporting the wood to foreign countries, not only must the quality of wood be separated into grades such as AB grade, which has damage lower than 80% of length by human eye, but also it must be inspected to ensure that the moisture content is lower than 12% dry basis following Thai Industrial Standards Institute [2]. The sawn timber companies generally use commercially available pin moisture meter and digital moisture meter to determine the moisture content. But there are limits of both meters. For instance, the pin meter leaves the hole damage in the wood. Regarding the digital moisture meter, specific gravity (SG) of wood must be known to program in meter. Besides the strength of timber is a parameter used to indicate the quality of sawn timber. However, the strength of timber has never been tested by any non-destructive method yet. Near infrared (NIR) spectroscopy is an interesting method to verify the quality of agricultural product as it is non-destructive, rapid and friendly with environment. In the past, there were many researches about non-destructive methods which used NIR technique to predict moisture content and modulus of rupture of others wood product [3] with no report in sawn...
timber *Hevea* wood. The objective of this research was to build a prediction model of moisture content and modulus of rupture of sawn timber *Hevea* wood samples by desktop near infrared spectrometer.

2. Experimental

2.1. Sample preparation

The 216 of sawn timber *Hevea* wood samples were collected from the southern region; Nakhon Si Thammarat and eastern region; Rayong of Thailand in 3 grades as AB grade, C grade and pallet (P) grade. The samples were trimmed to 2.54 x 2.54 x 40 cm3 then were smooth polished. The samples were stored at room temperature of 25°C for 24 h before measuring near infrared absorption.

2.2. NIRS collection

The samples were scanned using Fourier transform near infrared (FT-NIR) spectrometer (Bruker, MPA, Germany) in a range of 12489–3594 cm\(^{-1}\) (800-2700 nm) with an average of 32 scans and a resolution 16 cm\(^{-1}\) in diffuse reflectance mode. The spectral data were obtained using the OPUS 6.5 software.

2.3. Determination of reference value

2.3.1. Determination of modulus of rupture. In determination of modulus of rupture of wood, the sample was analysed for modulus of rupture (MOR) by static bending test which is recorded at the rupture point of sawn timber *Hevea* wood with a Universal testing machine (Instron Engineering Co, High Wycombe, England). The timber sample was placed on a span of 37 cm to test compression load using a round head with a constant pressing force speed of 2.5 mm/min at the center of the length of the wood perpendicular to grain according to ASTM D143 [4].

2.3.2. Determination of moisture content. In determination of moisture content of wood, the sample was cut into 2.54 cm x 2.54 cm x 2.54 cm size of cubic at four scanned positions of sample. All samples were dried by hot air oven (FD240, BINDER, Tuttingen, Germany) at 103±2°C. Then the moisture content (%dry basis; %db) of wood was computed following ASTM D143 [4].

2.4. Data analysis

Reference data, such as moisture content and modulus of rupture, were examined to find the outlier by considering the standard score (Z-score). The samples with standard score greater than 3 or less than -3 were considered to be the outlier (Meier, 2014). After that, the mean values of the moisture content and the modulus of rupture were statistically tested for the difference between each grade of the dried sawn timber *Hevea* wood samples using one-way analysis of variance with SPSS v.11.5.

In building the predicting model, the sample data were arranged in ascending order and separated into two sets: a calibration set and a prediction set by ratio of 7:3 ensuring similar variance between the two sets. Partial least squares (PLS) regression models were developed for calibration model of modulus of rupture and moisture content using the Unscrambler v.9.8 (Camo, Oslo, Norway). The spectral pretreatments such as the first derivative (1D), second derivative (2D), multiplicative scatter correction (MSC) and standard normal variate (SNV) were applied to reduce the scattering effect from the spectra in order to improve the model performance.

By considering the performance, the best calibration model should have highest correlation of coefficient of calibration (R\(_c\)) and lowest root mean square error of calibration (RMSEC). Similarly, the best prediction model was obtained considering the prediction performance based on the correlation of coefficient of prediction (R\(_p\)) with highest value, lowest root means square error of prediction (RMSEP) and residual prediction deviation (RPD). The RPD was calculated from the ratio of the standard deviation (SD) of the prediction group to the standard error of prediction (SEP), which is used to compare the predictive accuracy of the equation [5].
3. Results and discussion

3.1. Properties of reference value

The moisture content and modulus of rupture of dried sawn timber *Hevea* wood was obtained as reference values for prediction. The moisture contents of each grade were found to be not significantly different at the 95% confidence level because the sawn timber companies dried the timber at oven in the same condition. In this study, the moisture content range was 5.73-12.57%db as Table 1. In case of modulus of rupture of dried sawn timber *Hevea* wood, it was found that the mean of modulus of rupture of AB, C and P the grade were significantly different at the 95% confidence level, with the mean of modulus of rupture ± standard deviation equaling 97.09 ± 15.74 MPa of AB grade, 72.54 ± 21.43 MPa C grade and 37.62 ± 22.66 MPa of P grade, respectively as shown in Table 1. The strength decreased with the lower quality of grades of timber as displayed in Table 1.

| Types of wood | Grades | Number of Samples | Min  | Max  | Mean±SD    |
|---------------|--------|------------------|------|------|------------|
| Moisture      | AB     | 92               | 5.73 | 12.57| 7.92±1.44  |
| Content       | C      | 92               | 7.68 | 11.98| 10.06±1.17 |
| (%dry basis)  | P      | 32               | 7.40 | 11.04| 8.89±0.80  |
|               | Total  | 216              | 5.73 | 12.57| 8.98±1.59  |

Different superscripts in the same column indicate that the values are significantly different (p < 0.05) by Duncan’s multiple range test.

3.2. Spectral characteristics

Figure 1 showed the domain peak at 8316 cm⁻¹(1203 nm) 6866 cm⁻¹(1457 nm of water) 6287 cm⁻¹(1591 nm of cellulose) 5215 cm⁻¹(1917 nm) 4752cm⁻¹(2104 nm) which were related with vibration bond of OH [6,7] and those at 7344 cm⁻¹(1362 nm) 5832 cm⁻¹(1715 nm of hemicellulose) [6] 4389 cm⁻¹(2278 nm) 4281 cm⁻¹(2336 nm) were related with vibration bond of CH.

| Parameters          | Data set     | Number of Samples | Min  | Max  | Mean±SD    |
|---------------------|--------------|------------------|------|------|------------|
| Moisture Content    | Calibration set | 147             | 5.73 | 12.57| 9.02±1.59  |
| (%dry basis)        | Prediction set | 69              | 6.17 | 11.69| 8.88±1.60  |
| Modulus of rupture  | Calibration set | 148             | 7.94 | 135.76| 78.04±28.74|
| (MPa)               | Prediction set | 66              | 10.07| 129.65| 78.55±25.72|

| Models                      | Pretreatment | LV | Calibration | Prediction |
|-----------------------------|--------------|----|-------------|------------|
|                             |              |    | R  | RMSEC | R  | RMSEP |
| Moisture content (% dry basis) | 2nd derivative | 4  | 0.94 | 0.53  | 0.89 | 0.70   |
| Modulus of rupture (MPa)     | Absorbance   | 9  | 0.85 | 15.11 | 0.78 | 17.11  |
3.3. Assessment of the moisture content and the modulus of rupture using PLS model

The highest accuracy of moisture content model assessed was based on the 2D spectra (Table 3), producing values of $R_p = 0.89$ and RMSEP = 0.70%db with four latent values (LV). The scatter plot displaying the relationship between the actual moisture content and the predicted moisture content of prediction model was shown in Figure 2a). The highest accuracy of the modulus of rupture model assessed was based on the absorbance of spectra as detailed in Table 3, producing values of $R_p = 0.78$ and RMSEP = 17.11 MPa with nine latent values. The scatter plot expressing the relationship between the actual modulus of rupture and the predicted modulus of rupture was shown in Figure 2b).

4. Conclusions

The prediction model of moisture content of sawn timber *Hevea* wood gave high accuracy with fair result based on the $R_p$ and RMSEP which indicated that the model could be applied for rough screening work. And the prediction performance of the model for the modulus of rupture of sawn timber *Hevea* wood indicated that the model could also be applied for rough screening work by the desktop near infrared spectrometer.

5. References

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