SURFACE CHARACTERIZATION OF PARTICLEBOARD PANELS MANUFACTURED FROM EASTERN REDCEDAR USING A MULTI-SENSOR APPROACH

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SUMMARY

Multi-sensor systems are becoming more popular and well accepted in characterization of different properties of materials. Application of such techniques can be employed to represent properties of engineered materials more precisely. The objective of this work was to evaluate and characterize surface of the experimental particleboard panels manufactured from Eastern redcedar (*Juniperus virginiana* L.) which is an invasive species creating a significant ecological problem. Single- and three-layer panel specimens were manufactured from raw material using 9% urea formaldehyde, or a combination of 15% modified corn starch and 2% urea formaldehyde adhesive.
Chemical characteristics of the samples were determined employing FT-NIR spectroscopy. Colour measurements of the specimens were also carried out on VIS-NIR hyperspectral camera to evaluate uniformity of the colour pattern within the surface of each sample. Surface roughness of the panels was evaluated using a 3D equipment and such data was combined with surface wettability properties of the specimens. Multivariate statistical analysis was used to evaluate overall test results. Based on the findings in this work it appears that multi-sensor evaluation of such samples can be considered an efficient and effective method to objectively determine the different properties of the panels. While the methods employed in this work are prototype, they have a great potential to be utilized and applied at industrial scale.

INTRODUCTION

Wood-based panels such as particleboard are commodity products manufactured in large quantities, and have rapidly gained popularity for various applications including furniture productions, structural and construction applications. Particleboards vary in appearance and properties depending on the wood species, resin type and manufacturing parameters. Panels are made usually from small particles of wood such as flakes, shavings, sawdust as well as from other non-wood lignocellulosic materials including flax shives, hemp shives, and bagasse.
Eastern redcedar (*Juniperus virginiana* L.) is a widely distributed invasive species in several states in the USA including Oklahoma, Arkansas, Missouri, and Texas. The area covered by Eastern redcedar in Oklahoma was estimated to be 6.3 million hectares in 2013 (Hiziroglu 2009). The use of this species for the particleboard production was previously investigated in past studies (Hiziroglu et al. 2002, Kard et al. 2007, Bufalino et al. 2012). Currently there is no or little information on the use of a multi-sensor approach to evaluate the properties of particleboard. Therefore the goal of this work was to use a multi-sensor strategy for comprehensive characterization of laboratory manufactured particleboards in order to evaluate and compare their characteristics and performance so that they can be used more efficiently.

MATERIALS AND METHODS

Panels manufacture

Single- and three-layer particleboard panels were manufactured from raw material using 9% urea formaldehyde, or a combination of 15% modified corn starch and 2% urea formaldehyde adhesive. Following samples were prepared: type A – single-layer samples with 9% UF, type B- three-layer samples with 9% UF and type C – three-layer samples with combination of 15% starch and 2 % UF. All mats were compressed in a laboratory press using a pressure of 5MPa, at a temperature of 165ºC for 5min, and 10min in the case of modified corn starch bonded samples. Experimental samples were measured by means of standard instruments and prototype scanners developed at CNR-IVALSA for the purpose of surface characterization.

Colour measurement of the samples

A prototype of the hyperspectral system has been developed for this research as illustrated in Figure 1. The optical system consisted of spectrograph (Specim V10) ❶, high sensitivity CCD camera (Hamamatsu ORCA-5) ❷ and telecentric lenses (Computar TEC-55) ❸. The light source ❹ was a halogen bulb emitting light that covers the whole spectral band of the spectrograph. The movement of the hyperspectral system over the measured sample was performed by means of the laboratory CNC machine ❺. The sample ❼ was placed on the machine table, then the optical system mechanically connected with the light source was moved over the measured surface. The computer ❻ controlled the motion, triggered the camera and collected data. The data, in a form of the 12-bit gray images, were stored on the hard disk and were post-processed on the external server. Custom software has been developed for both the hyperspectral data acquisition and processing steps.

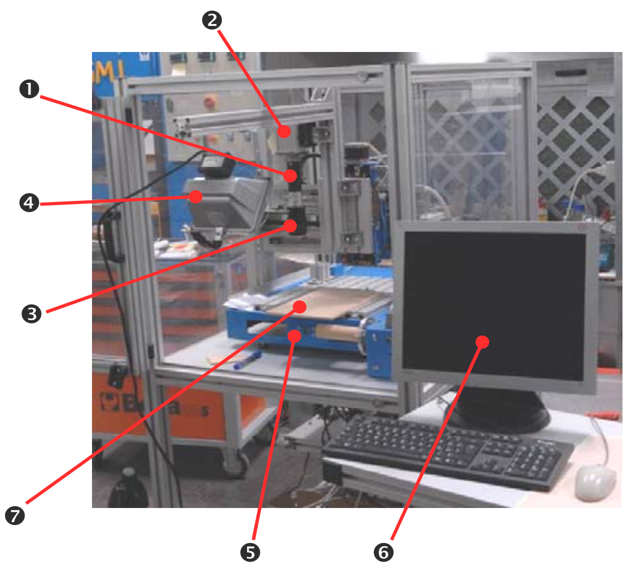

Figure 1: Experimental set-up for hyperspectral imaging of panel samples

Surface roughness measurement of the samples

Measurement of the surface roughness of the specimens was performed by means of the laser displacement sensor Keyence LK-G32 installed on the laboratory CNC machine as shown in Figure 2. The surface of panel was scanned as a raster assuming the spatial resolution of 0.04mm within both axes of the horizontal plane. 128 sample points were measured in both directions and the overall scanned surface was 5x5 mm^2. The raw surface map was processed with an open-source software tool Gwyddion (http://gwyddion.net/) and included surface flattening, mean correction and computation of roughness indicators. The arithmetic mean

(S_a), the root mean squared average (S_q), the skewness (Sk) and the kurtosis (Ku) were selected here for the surface roughness description.

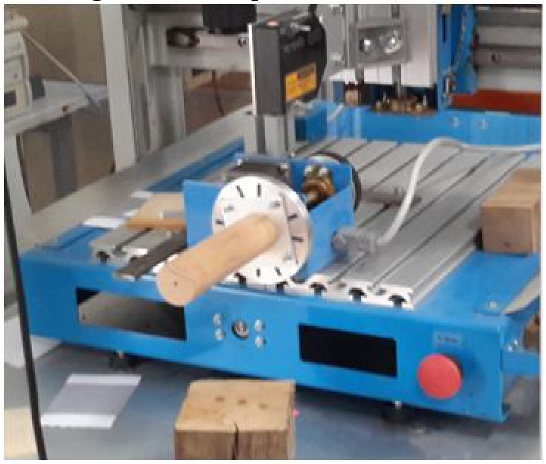

Figure 2: Surface roughness scanner with Laser Displacement Sensor

Wettability evaluation of the samples

A prototype experimental device has been used for measurement of the contact angles as illustrated in Figure 3. The device is capable of observing the drop of liquid on the surface from three perspectives. Each direction is monitored with a CMOS camera, macro-zoom optics and diffuse light illuminator. The drop is injected on the surface by means of the robotized pipette. The robot is capable of supplying a drop of a given volume and the pipette is removed from the field of view of the camera immediately after drop delivery to the surface. Dedicated software for controlling of the scanner functionalities, visualizing the drop appearance on the sample surface, and image data acquisition has been developed in LabView v.12 software package (National Instruments).

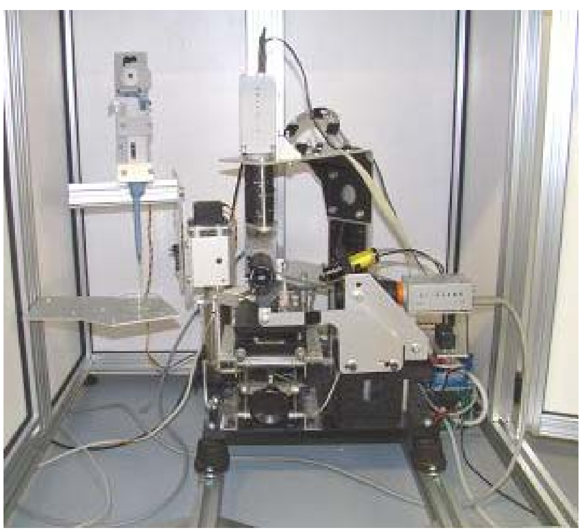

Figure 3: Surface wettability scanner used for this experiments

FT-NIR spectroscopy

A Fourier transform near infrared spectrometer, VECTOR 22-N (Bruker Optics GmbH, Ettlingen, Germany), equipped with the fibre-optic probe as illustrated in Figure 4 was used for spectra collection from the samples. The spectral range measured was between 4000cm^{-1} and 12000cm^{-1}. The spectral resolution of the spectrometer was set to 8cm^{-1}. The spectral wave number interval was 3.85 cm^{-1} with zero-filling = 2. Each spectrum has been computed as an average of 32 successive scans in order to minimize the measurement error. FT-NIR measurements were performed in an air-conditioned laboratory (20°C, 65% RH), five times on each sample. OPUS 7.0 (Bruker Optics GmBH), software was used for spectra collection, pre-processing and data mining.

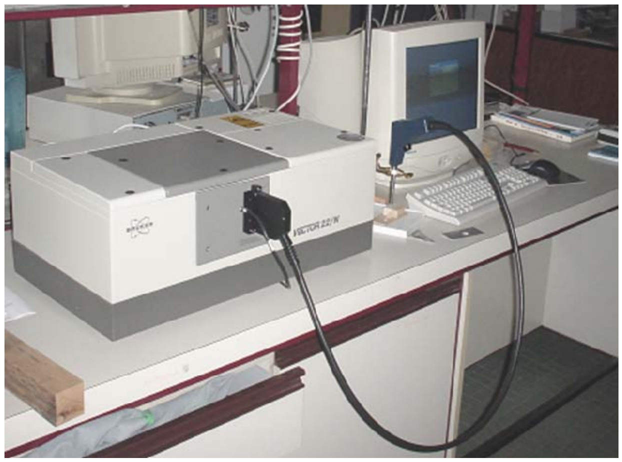

Figure 4: Fourier transform near infrared spectrometer used for panels characterization

RESULTS AND DISCUSSION

Colour measurements by hyperspectral imaging

The ability to analyse spatially resolved spectral information observed from the particle board surface is a main advantage of hyperspectral imaging. CIE Lab colour coordinates, even if possessing important limitations, are considered as most suitable indicators characterizing colour properties. It is clear that the colour pattern of the particleboard surface is very complex as the composite includes various types of particles. An example of the colour maps as measured on the investigated type A sample is presented in Figure 5. A clear variation of the lightness (L*), and colour components (a* and b*) over the panel surface is noticeable. Consequently, it can be concluded that the average measurement of CIE Lab colour as usually performed with various colour/spectrometers is far from the real representation of the colour variability. In fact when plotting the CIE Lab maps (as measured on the three different particleboard types) in the form of histogram, different component distributions can be observed. Figure 6 presents the distribution curves for L*, a* and b* showing how the distribution varies depending on the panel type. Moreover, several peaks can be identified in the histogram, indicating the "average colour" being a superposition of various components or particles, each of varying properties.

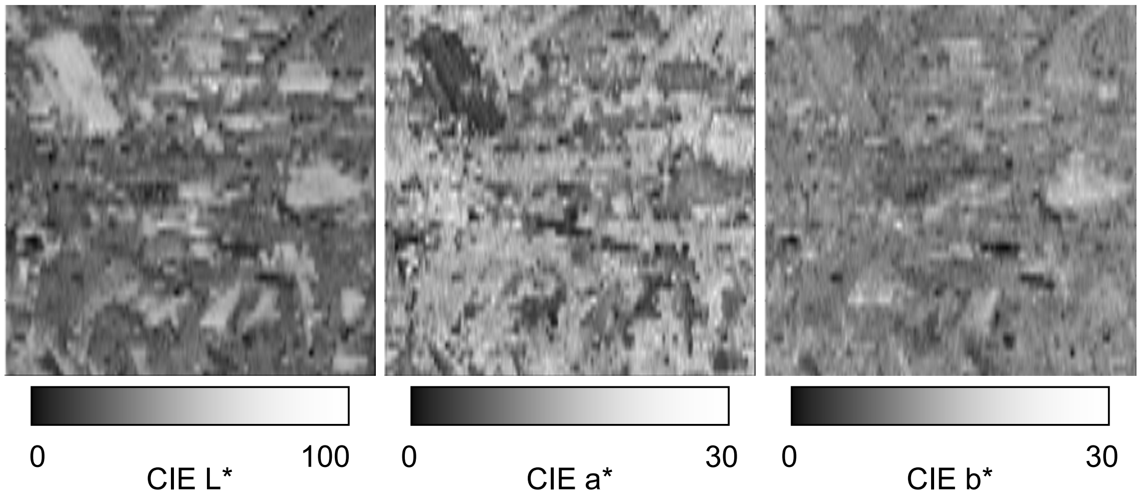

Figure 5: CIE Lab colour maps for L^*, a^* and b^* components as measured on the surface of particle board panels with hyperspectral imaging

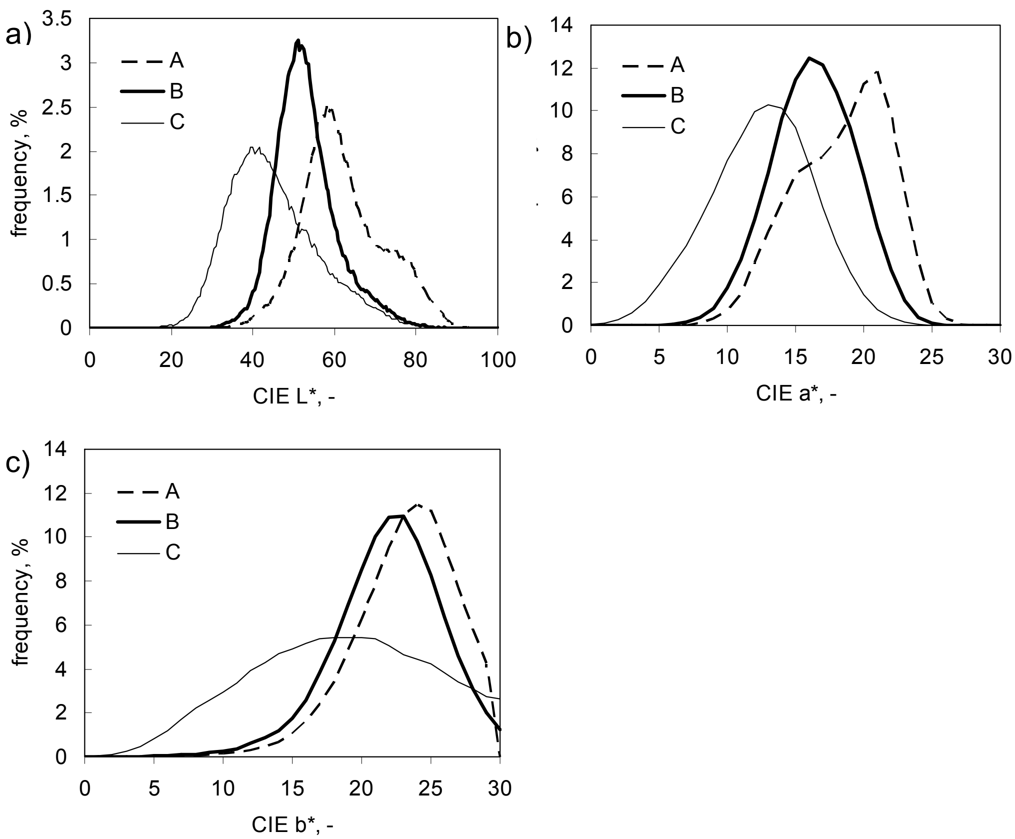

Figure 6: CIE Lab colour histograms for the tested samples of type A, type B and type C particleboard; CIE L^* (a), CIE a^* (b) and CIE b^* (c)

Surface roughness of the samples

The smoothness of the particleboard surface is an important issue, especially when the panels are used as a substrate for thin overlays such as laminated papers. The surface roughness evaluation using the profilometers, such as stylus type, present important limitations, including requiring direct contact with the surface, slow running speed and only partial representation of the surface. The alternative method proposed in this research is based on the 3D surface roughness evaluation. The resulting topography maps as observed from experimental samples are presented in Figure 7. A clear difference in surface topography can be noticed, with the surface of sample A (single-layer) being the most rough. It was confirmed by means of the roughness parameters, where S_a and S_q were significantly higher than the same parameters measured on samples B and C. In contrast, the topography of surface A was in general more platykurtic and only moderately (negatively) skewed (Figure 8).

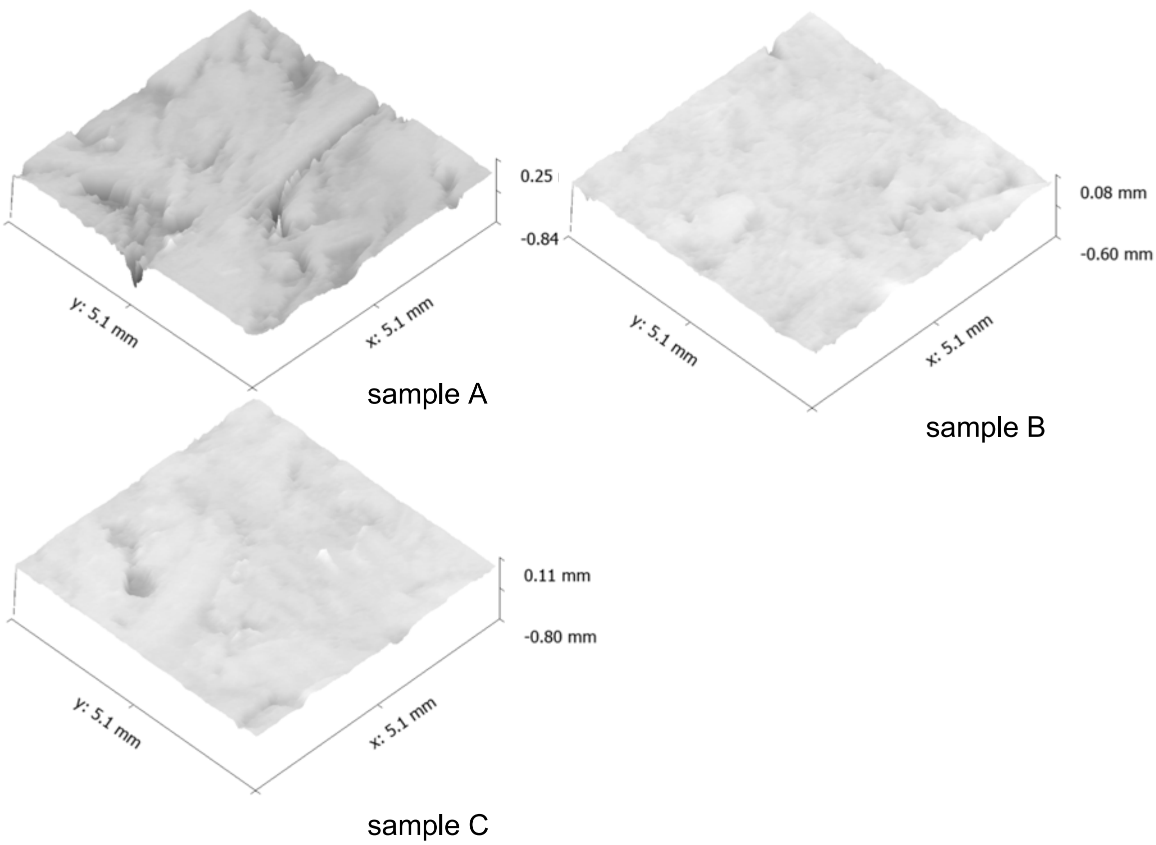

Figure 7: 3D surface roughness maps of particleboard panels type A, B and C

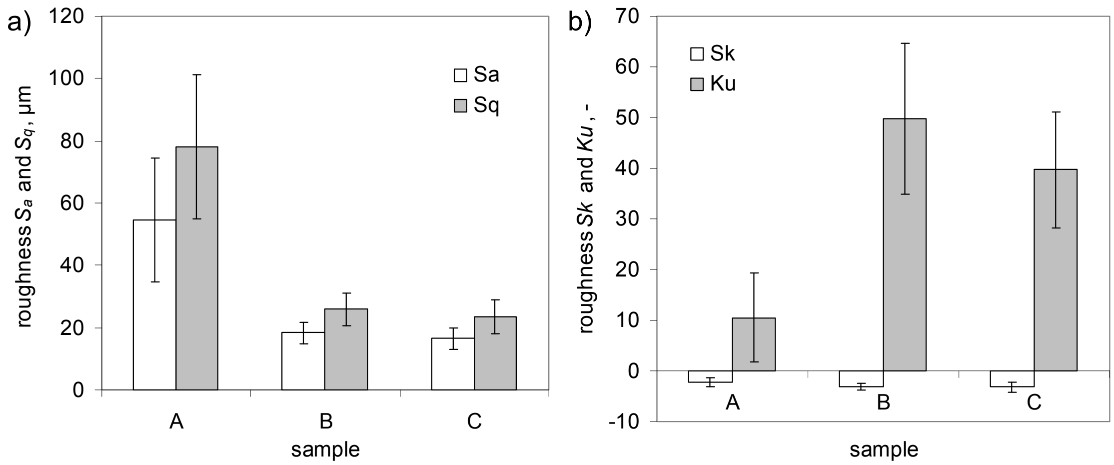

Figure 8: Surface roughness indicators as measured on experimental samples; S_a, S_q (a) and Sk, Ku (b)

Wettability of the samples

Hydrophobic properties of the wood-based panels are of the greatest importance when considering gluing and/or surface finishing. Measurement of the sessile drop contact angle is one of the most commonly used methods for estimating of wetting properties of composite type samples. Two contact angles along and perpendicular to the fiber direction are computed simultaneously with the instrument utilised for this research. The initial 15 seconds of the particleboards surface wetting with the water drop are presented in Figure 9. The most hydrophobic surface was of panel C, where the contact angle was highest. It was also noticed that the drop spread was smallest on the surface of same panel C as the contact angle was constant in time. The most hydrophilic surface was determined for panel type -B, especially after considering the 15 seconds wetting time. The drop on the surface of panel type -B showed the greatest degree of spreading indicating a relatively dynamic interaction between panel surface and water. The value of contact angle measured on the surface of panel A samples was relatively stable after initial drop delivery, with its value stabilising within 5 seconds of the test start. It was also noticed that the variability of results, measured as the spread of the contact angle curves, was relatively low for samples of panel C. In contrast, the contact angle spread noticed for panel types -A and -B was high, indicating substantial unevenness of physical-chemical properties of surface of the samples.

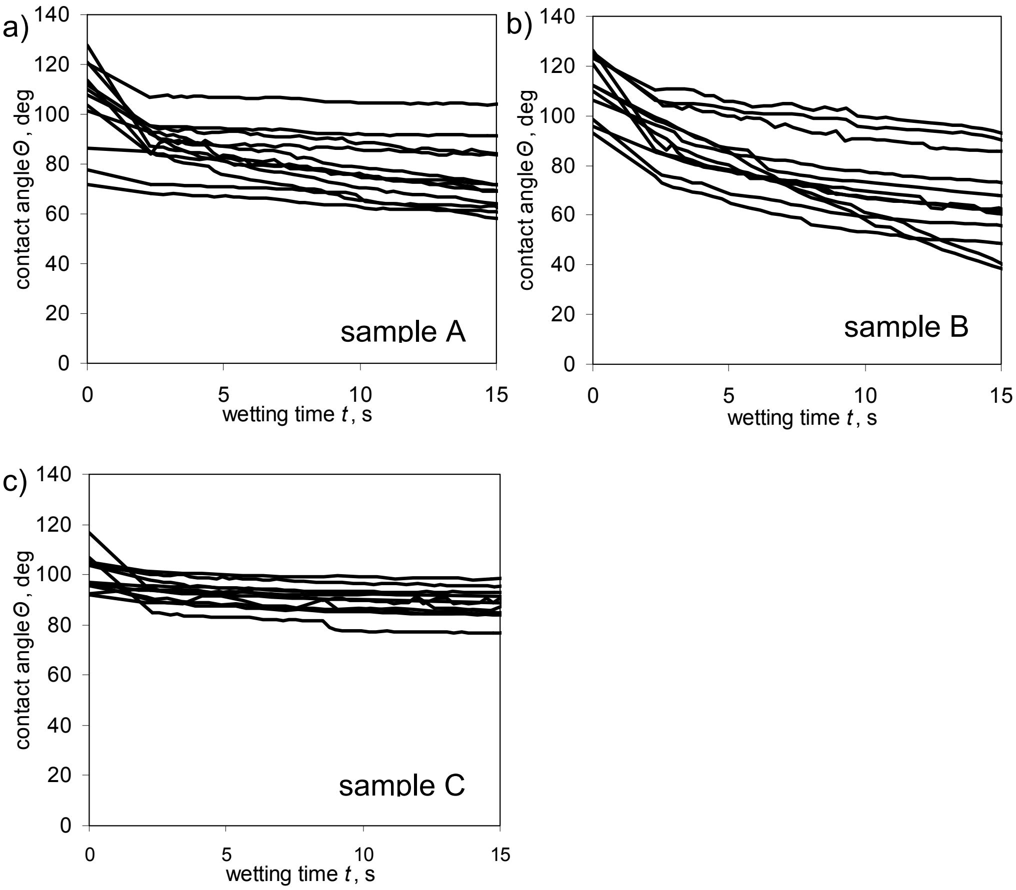

Figure 9: Dynamic contact angle of distilled water droplet placed on the particleboard panels of various types.

FT-NIR spectroscopy

Near infrared spectroscopy allows characterization of samples according to their chemical-physical properties. It was determined in this research that it is possible to classify various particleboard panels by means of the spectra from the sample surface. Principle Components Analysis (PCA) was applied to the series of NIR spectra and three data clusters were generated. Three principle components were identified, and in particular principal component PC2 was efficient in differentiation between sample sets (Figure 10). The classification of samples may be also implemented as an identity test, where selectivity S is an indicator of the similarity (Sandak et al. 2015). The selectivity as computed for the experimental samples within this test (Table 1) indicated that sample sets A and B are overlapping, whereas sample set C was nearly perfectly separated. The interpretation of the chemometric model is possible, assuming analysis of PCA loadings as presented in Figure 11 and spectral band assignment as summarized in Table 2. The list of functional groups most influencing PC2 loading includes: -CH of carbohydrates: holocellulose, cellulose and hemicelulose, -CH groups of lignin, -OH groups of semi-crystalline cellulose as well as -CH groups of aliphatic chains.

It has to be mentioned that the list of functional groups as listed in Table 2 is extracted from literature, but relevant only for the solid unmodified wood. Conversely, the experimental samples are composites possessing important quantities of polymers different than lignin, cellulose and hemicellulose.

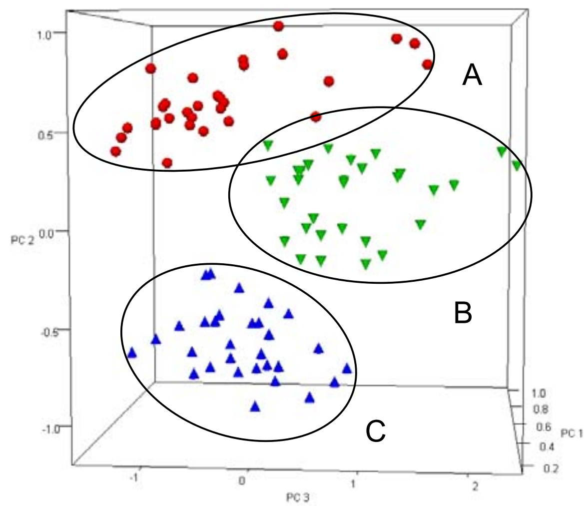

Figure 10: Principle Components Analysis of NIR spectra measured on experimental panels and clustering of samples according to the type

Table 1: Selectivity index of panel samples of various compositions

	A	B	C
A	x	0.65	1.55
B	0.65	x	0.95
C	1.55	0.95	x

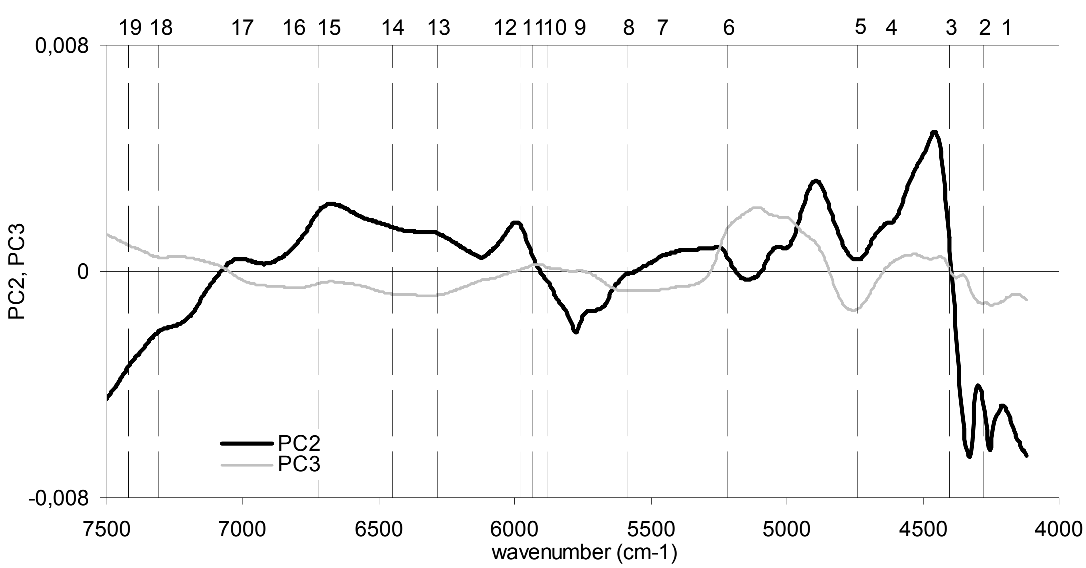

Figure 11: PCA model loadings for 2nd and 3rd components and spectral feature assignments

Table 2: Band assignment and NIR spectra interpretation (according to Schwanninger et al. 2011)

nr	band assignment	wavenumber (cm^{-1})
1	C–H deformation holocellulose	4198
2	C–H stretching + C–H deformation cellulose	4280
3	$C–H_2$ stretching + $C–H_2$ deformation cellulose	4404
4	O–H stretching + C–H deformation cellulose	4620
5	O–H stretching + C–H deformation cellulose	4740
6	O–H stretching + O–H deformation water	5219
7	O–H + C–H stretching semi and crystalline cellulose	5464
8	C–H stretching semi and crystalline cellulose	5587
9	C–H stretching hemicellulose	5800
10	C–H stretching aliphatic	5883
11	C–H stretching aromatic lignin	5935
12	C–H stretching aromatic lignin	5980
13	O–H stretching crystalline cellulose	6287
14	O–H stretching crystalline cellulose	6450
15	O–H stretching semi-crystalline cellulose	6722
16	O–H stretching amorous and crystalline cellulose	6785
17	O–H stretching amorpous cellulose	7008
18	C–H stretching aliphatic	7309
19	C–H stretching aliphatic	7418

CONCLUSIONS

Several unconventional measurement techniques have been applied here for characterization of the particleboard surface properties:

- Colour uniformity and pattern were carried out with VIS-NIR hyperspectral camera
- Chemical characteristics of the samples were determined employing FT-NIR spectroscopy.
- Surface roughness was evaluated in 3D with laser displacement sensor
- Surface wettability was assessed by a prototype sessile drop scanner

Single- and three-layer specimens manufactured from Eastern redcedar (*Juniperus virginiana* L.) using 9% urea formaldehyde, or combination of 15% modified corn starch and 2% urea formaldehyde adhesive were observed and compared.

Panels of type A (single layer with 9% UF) were clearly rougher, type B (three-layer with 9% UF) were the most hydrophilic, especially after considering the 15 seconds wetting time. Panels of type C (three-layer with 15% starch and 2 % UF) have the most hydrophobic surface and were easily identified by FT-NIR.

Based on the results presented within this paper, it can be concluded that multi-sensor evaluation of such samples can be considered an efficient and effective method to determine objectively different properties of the panels made in this study. It has been demonstrated that while the methods employed in this work are in prototype stage, they have a great potential to be utilized and applied at industrial scale.

ACKNOWLEDGEMENT

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