Effect of strand geometrical distribution (SGD) in oriented strand composite (OSC) formation quality

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Abstract

The OSC industry is permanently in seek of new ways to improve their products increasing yields and reducing costs; and, at the same time, keeping acceptable quality standards. The use of mix of species and round year production causes high variability in the material to be processed by the mills. Changes in the mechanical properties of the stranding material bring changes in the geometrical distribution of the strands, unless major changes in the production set up take place. The objective of this study is to determine the effect of the different geometrical distributions in the formation quality of OSC mats using a constant forming set up. Using a fractional factorial design, aspen (*Populus grandidentata*) logs were submitted to frozen (-8°C); cold soaking (21°C) and hot soaking (70°C) conditioning. Strands were produced at the AEWC center facility of the University of Maine @ Orono. Sample strands were extracted from stranding and blending outcome material sources; and an image analysis procedure was implemented in order to perform individual strand measurements. Width, length, eccentricity and irregularity were measured using Euclidean and fractal geometries. Non-parametric statistical analysis was implemented using R language. OSC mats were formed using a home-made rotating disc based forming line. All the forming parameters were held constant except small adjustments to the landing speed in order to control board target density. Formation quality was evaluated by computing von Mises distribution parameters of the strand orientation angle distribution using image analysis. Horizontal density profile and bulk density using gravimetric methods were also determined. Significant differences in geometrical distribution response of frozen logs to the stranding process respect cold soaked and hot soaked were detected ($p<0.01$). Temperature treatment was found to have a significant effect on strand geometry ($p<0.01$ in all comparison tests). Noticeable differences were found in the dispersion factor of the orientation angle distribution of frozen (kf), cold soaked (kc), and hot soaked (kh) material ($1.1<kf<4.3$; $7.5<kh<9.8$ and $10.0<kc<19.9$). Significant differences were found in bulk density between mats formed using strand from cold soaked logs and mats formed using strands from frozen and hot soaked logs (p=0.002). Strand geometrical distribution affect the formation quality of OSC mats when the forming parameters are constant.

Keywords: Strand geometrical distribution, strand orientation distribution, image analysis, von Mises distribution, formation quality,

Introduction

Currently the most sensitive wood composites industry in the effectiveness of cost managing is oriented strand board (OSB) manufacturing. This sector has been affected by fluctuations of house markets and the reduction in the demand for new houses in the United States during 2007. Improvements either in the manufacturing process or the structural performance of OSB panels are necessary in order to optimize the costs/price relationship. Continuous increasing yields and costs reduction, maintaining acceptable quality standards, is imperative.

One of the most important areas in industrial cost control is energy. High oil prices and the potential tax on carbon emissions will increase considerably energy costs in the near future to all the industry. In OSB manufacturing, hot soaking is a traditional treatment applied to logs prior to stranding process in order to help reducing wood stiffness; which improves knifes lifespan and allows obtaining wider and smoother strands. However, hot soaking requires heating large amounts of water. Year round production generates different initial conditions of the logs in each season; in winter higher amounts of energy are necessary to rise wood temperature from freezing point to temperatures over 50°C. In summer, soaking is also recommended since high temperatures and low relative humidity originate high moisture content gradients in wood, which generates internal stresses affecting its properties.

The objective of this study was to determine the effect of log temperature on the formation quality of OSB mats using a constant forming set up by testing these three hypotheses.

Wood and temperature

The influence of temperature on wood properties has been reported since the early 1950's (Boller, 1954). Lignin and cellulosic glass-transition point determine the behavior of wood under different temperature conditions. At freezing temperatures the modulus of elasticity (MOE) increases; turning wood brittle and stiff due to the proximity of the cellulose and lignin glass transition point (Bodig, & Jayne, 1982; Wood Handbook, 1999). Conversely, high temperatures and moisture turn wood soft and plastic, reducing stiffness. Lignin and the amorphous cellulose turn more plastic allowing the wood to yield easily under load. Hot soaking, is a standard practice in wood industry used in order to soften the material increasing lifespan of cutting tools by reducing MOE temporarily (MacLean, 1954). The interaction of wood in different temperature conditioning with the stranding tool would produce different strand quality, in terms of its surface roughness; geometry and shape.

Measurements

Strand geometrical distribution (SGD) has been consistently reported as affecting strand alignment (Dai & Stainer, 1994; Gaimer, 1976; Gaimer, 1986; Nishimura et al., 2004). However, previous researches did not measure nor quantify strand irregularity; which has been reported as an important factor in the formation process (Painter et al., 2006); also the used methodologies have no practicality for on line applications. The use of digital image analysis (DIA) allowed the development of more accurate and fast methods of measuring objects and with large sample sizes. Nishimura (2004), Painter (2006) and Zombori (2001) applied DIA to perform measurements on strands and correlated size and shape to the bending properties of OSB boards.

Although Euclidean geometry can be applied to determine width, length, area and even eccentricity; it is necessary to apply a different method to quantify the irregularity of an object.

Fractal dimension (D) has been used in the wood industry to analyze complex geometries in the past (Lui & Furuno, 2001). There are several methods to determine D based on the ratio between the number of self similar entities (SSE) contained in a given domain and the scale or size of such SSE. In Eq. 1 D is computed as the limit slope of the log/log ratio when the size of the SSE tends to 0.

$$D = -\lim_{\delta \to 0}\left[\frac{\ln N(\delta)}{\ln \delta}\right] \qquad \text{Eq. 1}$$

where D is the fractal dimension
N is the number of SSE
d is the size of the SSE

Formation quality definitions

Mat formation has been characterized by measurements of mean orientation deviation and predictions of board properties has been presented in a series of reports by Barnes (2000;2001;2002). Shaler (1991) presented a method of measuring alignment based on the von Mises distribution for angular data. This two-parameter function distribution, equivalent to a normal distribution of linear data, considers cyclic or circular data and along with expressing the mean angle it also provides a dispersion index of the angular data with the following probability density function:

$$v(\theta;(\mu_0,\kappa)) = \frac{1}{2\pi I_0(k)} e^{\kappa\cos(\theta-\mu_0)} \qquad \text{Eq. 2}$$

where $I_0(\kappa) = \sum_{r=0}^{\infty} \frac{1}{r!^2}\left(\frac{\kappa}{2}\right)^{2r}$ is the Bessel series of order 0

μ is the mean angle parameter
κ is the concentration parameter

Another formation descriptor is the compaction ratio defined as the change in density experienced by a substance as a consequence of a process. This variable has been used to explain OSB panel permeability and it has been related to the strand geometry by Hood et al. (2005). It might be used to describe the quality of the packing of the mat. The expression to compute the compaction ratio is presented in the following equation:

$$C = 100 * \frac{\rho_b - \rho_m}{\rho_m} \% \qquad \text{Eq. 3}$$

Where ρ_b is the density of the board and
ρ_m is the bulk density of the mat

Methodology

Material

Populus tremuloides logs were cut and dimensioned to five feet long from selected trees. 54 logs had diameters ranging from 15 to 30 centimeters; the logs were randomly assigned and conditioned to different temperatures, namely: frozen (-6.6°C); cold soaking (21.1°C) and hot soaking (60°C).

Strands production
Logs were stranded using a Carmanah lab ring strander 12/48 with target geometry of 0.89x1.27x152.4 milimeters. The strands were screened; dried to 8% MC and blended with pMDI (4% weight basis) and wax (2%) in a lab scale spinning disc atomizer rotating drum blender. A one-pound sample was taken from the blended material which was used to characterize the forming material.

Strand geometrical characterization

Individual strand measurements were performed using DIA from a 1296x1016-pixel image. Fractal dimension was determined for every strand of the sample using dilation method. Maximum width, length, effective area were recorded and, additionally, strand eccentricity was measured. Since the contribution of each strand to the total value is highly dependant on its size, weighed values were computed rather than counts when determining geometrical distributions.

Mat Formation

Three OSB mats per treatment were formed using a custom-built rotating disc forming line. Free fall distance was 12 centimeters for the bottom layer. Target density was

700Kg/m^3. Every mat was formed in three layers by changing the forming conveyor advance direction. Bulk density measurements were performed after every pass. Digital images were acquired from the top surface of each mat with a 740x480 pixel camera.

Formation quality evaluation

The formation quality was evaluated by using compaction ratio and alignment through determining von Mises distribution parameters (μ, κ) on mat top, core and bottom surfaces from the acquired images.

Results and discussion

Strand Geometrical distributions

On Table 1 the mean and COV values for the five analyzed variables are presented. Significant differences on all the variables were observed for the different treatments. Although hot soaking treatment rendered significantly larger strands, in the case of the fractal dimension D, the highest value, which means the more regular strands, were observed on the cold soaking treatment. The least eccentric strands were obtained from frozen logs, this behavior may be attributed to the fact that narrower strands are less likely to be eccentric.

Table 1: Summary of geometrical dimensions for the three treatments

Treatment	Width [cm] Mean(COV%)	Length [cm] Mean(COV%)	Area [cm^2] Mean(COV%)	Eccentricity [%] Mean(COV%)	Fractal dimension D Mean(COV%)
Frozen n=7,086	1.56 (34.56)	10.68 (36.75)	2.07 (259.98)	0.99 (6.45)	1.89 (8.64)
Cold soaked n=3,745	1.87 (33.02)	11.95 (36.87)	2.68 (258.58)	0.98 (9.86)	1.90 (9.31)
Hot soaked n=1,835	2.62 (40.40)	12.92 (43.54)	6.62 (189.57)	0.97 (9.86)	1.89 (9.37)

The narrowest strands were produced from the frozen logs and specifically when the knife was hitting the central portion of the log. The production of individual strands using ring strander is affected by several factors. However, in the same conditions, the quality of the strand is affected by the cylindrical anisotropy of wood due to layered growth structure. In Figure 1 and Figure 2 the actual geometrical distributions are presented. As expected, wider and larger strands are obtained by hot soaking the log prior to the stranding process.

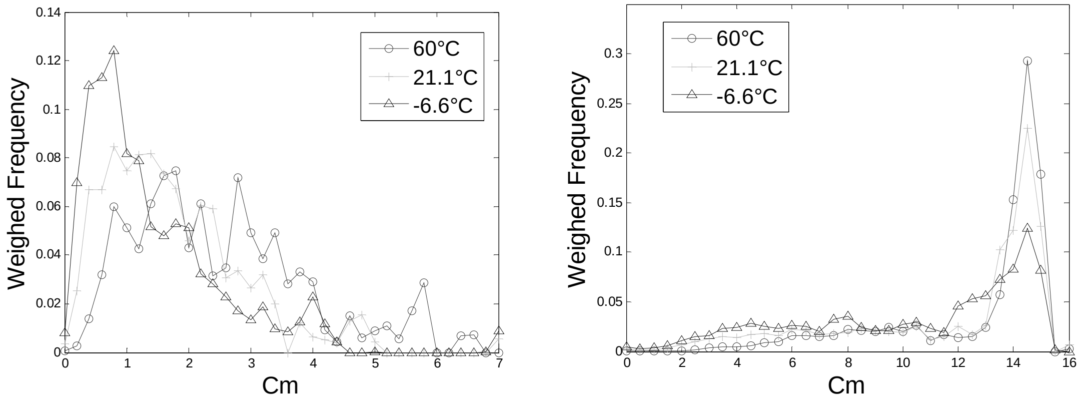

Figure 1: (1) Width and (2) Length distributions for the three treatments

On the other hand, smaller and narrower strands are produced from frozen logs; basically due to the increase in stiffness and brittleness of the wood. However, more irregularities are observed on hot soaked logs; this behavior may be attributed to the fact that, although large strands are obtained with the soaking process, those large strands are more likely to suffer breakage by interaction with the machinery during drying; blending and forming processes.

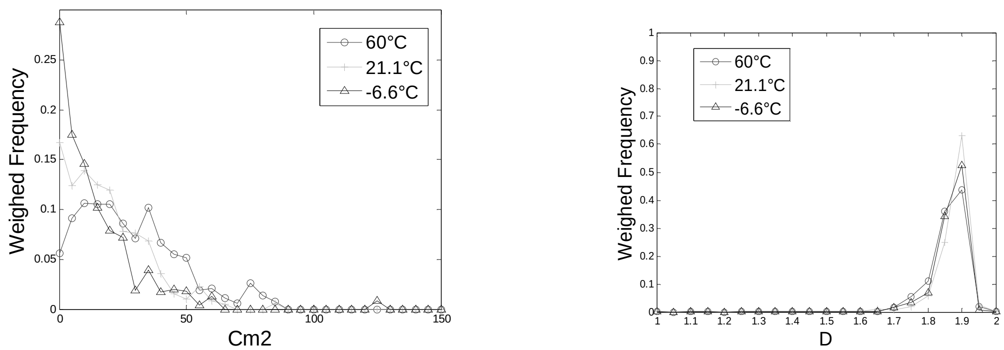

Figure 2: (1) Area and (2) Fractal dimension D distributions for the three treatments

Mat bulk density and compaction ratio

On Table 2 the measured bulk density using gravimetric methods and compaction ratio are presented. A significant effect of the treatment is observed on bulk density. Since stranding hot soaked wood produces larger strands voids are less likely to occur than with the smaller strands produced from frozen logs. Compaction ratio is significantly higher for the frozen treatment ($p<0.01$), however no significant difference exists between cold soaking and hot soaking treatments ($p=0.35$).

Table 2: Comparison on bulk density between the three treatments

Condition	Mean Bulk Density	CV	Mean Compaction ratio
	Kg/m3	%	%
Frozen	81.14	7.70	88.41
Cold soaked	85.33	13.15	87.56
Hot soaked	88.66	5.62	87.70

Alignment

Significant differences were observed on k between cold soaked/frozen and hot soaked treatments for the compression surface of the board (p=0.05). It is noticeable that there is not a significant difference in the alignment between frozen and cold soaking treatments (Figure 3). This result may be attributed to the fact that strands made out of frozen logs fit better in the used forming head than those produced from hot soaked logs. Strands wider than 50 millimeters are poorly aligned because they tend to fall freely flipped turned between the discs.

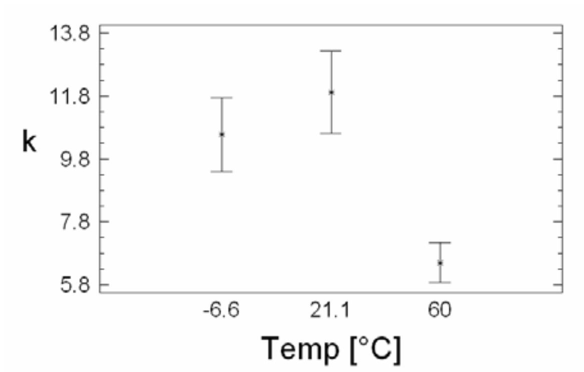

Figure 3: Concentration parameter k of the von Mises distribution measured from the mat top surface for the three treatments

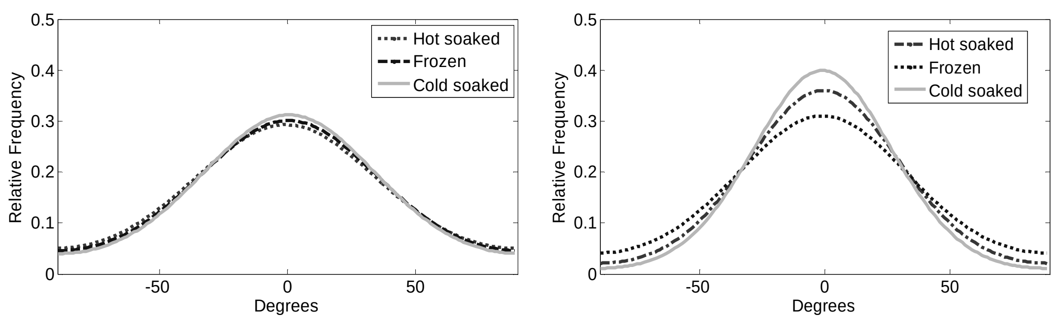

Figure 4: Von Mises PDF for the three treatments on bottom (1) and top (2) surfaces of the pressed board.

Significant differences were observed between the PDF of top and bottom surfaces of the boards; on the top layer more noticeable differences were detected between treatments; this may be associated to the reduced free fall distance to nearly 3 centimeters (Figure 4).

Core layers were randomly aligned in all the treatments. Randomness of the core layer surface was obtained due to the formation mechanism. In the forming line, small strands fall first therefore, since the uppermost layer is composed by those strands, the effectiveness of the alignment is importantly reduced (Figure 5).

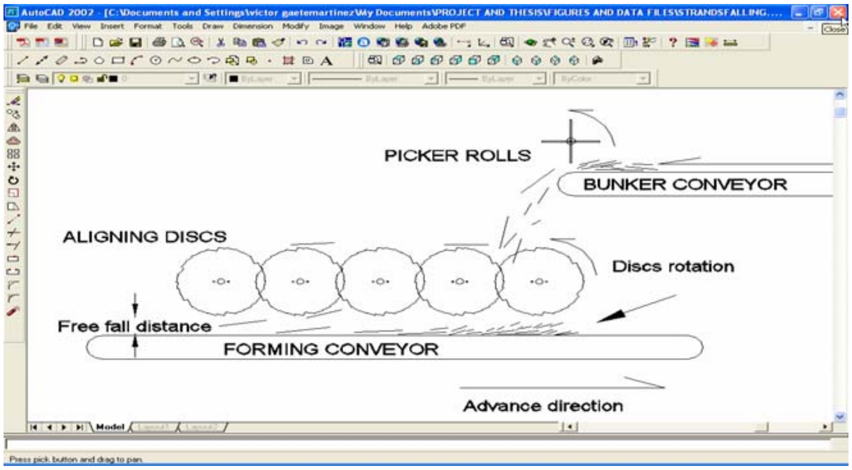

Figure 5: Diagram of longitudinal stratification of the strands (arrow) caused by the forming mechanism

Interactions

In Figure 6 non linear relationships between temperature and width and fractal dimension D are presented. It is apparent that an optimum temperature of about 20°C exists in order to obtain the most regular strands.
Figure 7 shows, the effect of width and the fractal dimension D on the concentration parameter k of the von Mises distribution for angular data. An optimum point for width is noticed in these regression curves; this may be explained by the suitability of such specific width to the used forming setup. On the other hand, more regular strands would render a better value of the angular dispersion. Strands with fewer singularities would interact more smoothly with others, increasing the effectiveness of the alignment.
The effect of the geometry on the compaction ratio is presented on Figure 8. Wider strands are associated to lower compaction ratio; which would reduce the chances of damaging the strands during the pressing. The lowest values of compaction ratio are obtained for more regular strands.

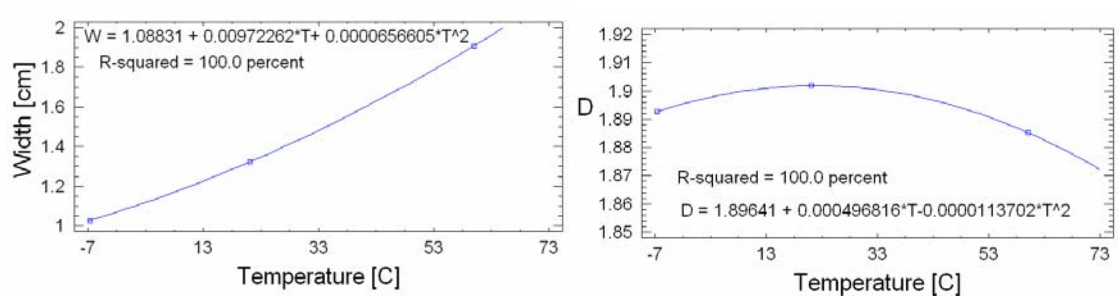

Figure 6: Effect of the temperature in strands geometry. (1) Temperature v/s width and (2) Temperature v/s Fractal dimension D.

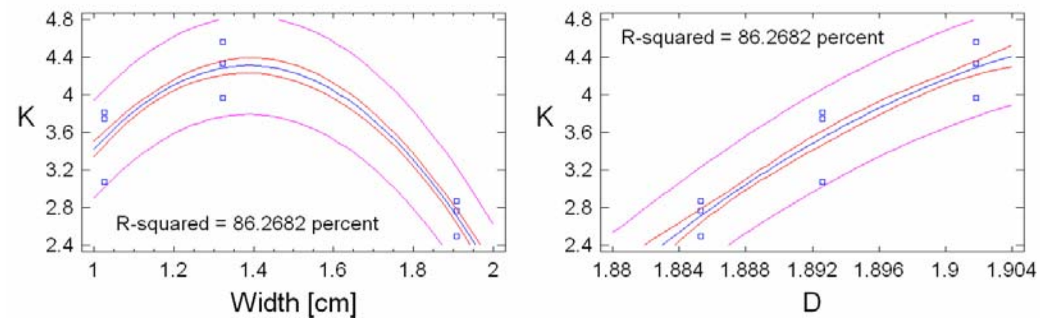

Figure 7: Effect of geometrical variables in the concentration parameter k of the von Mises distribution of the board bottom surface.

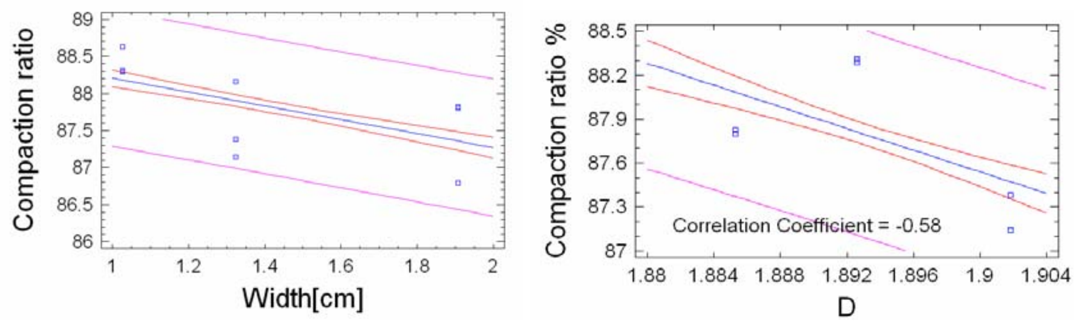

Figure 8: Regression analysis of geometrical variables versus compaction ratio

Conclusions

The results of the presented work confirm the effect of log temperature conditioning affecting OSB mat formation quality due to the effect on strand geometrical distributions.
Hot soaking does have a significant effect on the SGD, however large strands does not improve alignment on the mat surface, because larger strands are more prompt to suffer breakage during the blending and forming processes which produces more irregular strands. Indeed, strands produced from frozen logs are, in average, more regular than those produced from hot soaked logs. Big savings on energy costs might be achieved by reducing soaking temperatures. Knife sharpness lost due to the reduction on temperature and the subsequent energy used in maintenance should be evaluated though.
The presented methodology may be applied to on-line process control due to the degree of accuracy in the measurement; reduced processing time; and the potential large amount of data that can be processed. The use of fractal dimension as a geometrical descriptor of strand irregularity proved to be a suitable quantifying tool using digital image processing; which would facilitate its application on fast on-line processing systems.

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References

[1] Barnes, D. 2002. A model of the effect of strand angle and grain angle on the strength properties of oriented veneer and strand wood composites. Composites and Manufactured Products, Forest Products Journal. Vol. 52. No.4 pp. 39-47.
[2] Barnes, D. 2001. A model of the effect of strand length and strand thickness on the strength properties of oriented wood composites. Forest Products Journal 51(2) pp. 36-46.
[3] Barnes, D. 2000. An integrated model of the effect of processing parameters on the strength properties of oriented strand wood products. Forest Products Journal Vol. 50, NO 11/12. pp 33-42.
[4] Boller, 1954. Wood at low temperatures. Modern Packaging. 28(1): 153–157.
[5] Bodig, J.; Jayne, B.A. 1982. Mechanics of wood and wood composites. New York: Van Nostrand Reinhold Company.
[6] Dai, C.; P.R. Stainer, 1994. Spatial structure of wood composites in relation to processing and performance characteristics. Pt. II Modelling and simulation of a randomly-formed flake layer network. Wood Science and Technology. 28(2): 135-146.
[7] Gaimer, R. L. 1976. Flake alignment in particleboard as affected by machine variables and particle geometry. Ras. Paper 275. USDA – FPL, Madison, WI.
[8] Geimer, R. L. 1986. Mechanical Property Ratios-A measure of flake alignment. Research paper FLP 468. Forest Products Laboratory. USDA.
[9] Hood, J.P.; F.A. Kamke; J. Fuller. 2005. Permeability of oriented strand board mats. Forest Products Journal 55(12) pp 194-199.
[10] MacLean, J.D. 1954. Effect of heating in water on the strength properties of wood. American Wood-Preservers Association. 50: 253–281.
[11] Nishimura T., Jaymeen Amin, Martin P. Ansell. 2004."Image analysis and bending properties of model OSB panels as a function of strand distribution, shape and size". Wood Science and Technology, Vol. 38: pp. 297-309.
[12] Painter G., H. Budman, M. Pritzker. 2006. Prediction of oriented strand board properties from mat formation and compression operating conditions. Part 1. Horizontal density distribution and vertical density profile. Wood Science and Technology Vol. 40, pp 139-158.
[13] Shaler, S.M. 1991. Comparing two measures of flake alignment. Wood Science and Technology Vol. 26(1): 53-61.
[14] Liu, J., and T. Furuno. 2001. The fractal evaluation of wood texture by the triangular prism surface area method. Wood Fiber Science 33(2):213-222.
[15] Wood Handbook, Forest Products Laboratory, 1999.
[16] Zombori, Balazs G., Frederick A. Kambe and Layne T. Watson. 2001. Simulation of the mat formation process. Wood and Fiber Science, 33(4), 2001; pp. 564-579.