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Particleboard Surface-Roughness Classification System Modeling, Simulation, and Bench Testing

Particleboard panels are widely utilized as a raw material in the wood processing industry. It ends up as furniture, cabinets, and other industrial products. One of the problems particleboard mills face concerns the surface quality of their boards. As the demands of customers become more precise, very thin overlays are becoming more popular. Thus the problem of surface quality control and classification is clearly identified. In this paper, a particleboard surface-roughness classification system is modeled, simulated, and implemented. The particleboard model is based on the characterization of surface anomalies (pinholes, sander streaks, and grooves). Furthermore, an optical stylus surface-roughness measurement system is also modeled in order to determine whether it can be used to characterize a particleboard "on-ine." A classification algorithm is proposed to serve as an aid to the quality control operator. Simulation results are presented illustrating the change of surface roughness with increasing amounts of surface anomalies. A classification algorithm is used to sort the simulated panels into different classes. A trial bench test using 225 panels is made to determine the applicability of this system to the industrial context. [DOI: 10.1115/1.1954795]

Keywords: Particleboard, Surface Anomalies, Roughness Measurement, Modeling, Simulation, Classification, Quality Control, Wood Board Sanding

1 Introduction

Particleboard panels are widely utilized as a raw material in the wood processing industry. It ends up as furniture, cabinets, and other industrial products where finishing overlays are used, such as wood veneer, saturated papers, vinyl overlays, paint, and thin paper. Furthermore, as the demands of customers become more precise, very thin overlays are becoming more popular. As such, one of the problems particleboard mills face concerns the surface quality of their boards. This problem stems from the fact that as overlays becomes thinner, the surface anomalies in the underlying particleboard become increasingly apparent. Thus the problem of surface quality control and classification is clearly identified.

Particleboard surface quality is dependent on the presence and importance of surface anomalies, some of which can be characterized as visible to the naked eye of an operator, while others can be characterized as invisible or difficult to see by an operator. Some of the surface characteristics common to a large number of mills and visible by the naked eye are the following: resin stains, holes, broken corners, chatter lines, blows, pop flakes, etc. But some unwanted surface characteristics are very difficult to see without an outside aid (i.e., chalk marks); these include pinholes

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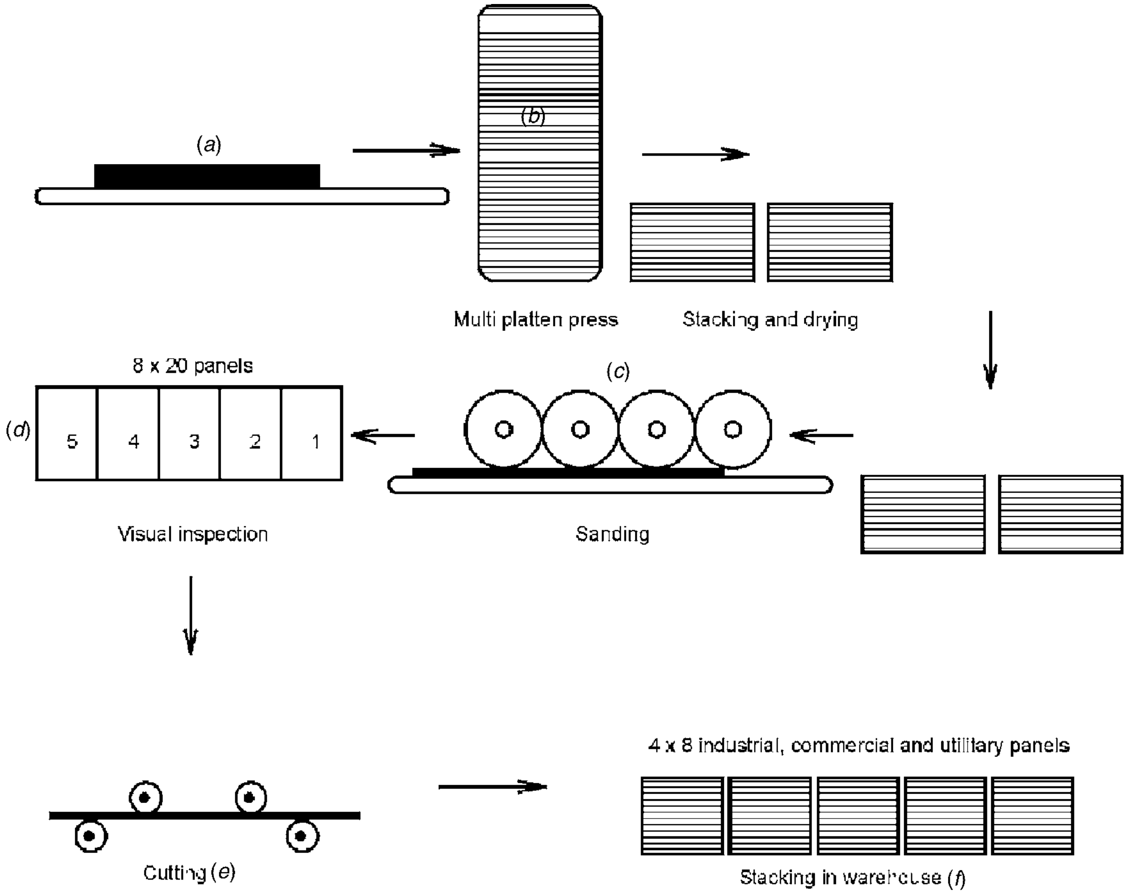


Fig. 1 Particleboard process

(pitting), sander streaks, and grooves. Typically, an operator grades the 8 ft × 20 ft board following specific company criteria based on the above-mentioned surface characteristics into three grades: industrial, commercial, or utility. The average speed of a typical production line is about 60 m/min, leaving the operator about 7 s to identify surface anomalies on the panel.

It should be noted that although some surface anomalies can be and are detectable using vision and image analysis systems, many of the smaller anomalies (pin holes, grooves, and sander streaks) are difficult to detect because of the particular characteristics of the particleboard. The objective of this study is to model and simulate a particleboard surface-roughness classification system and apply it to an industrial case.

2 Background

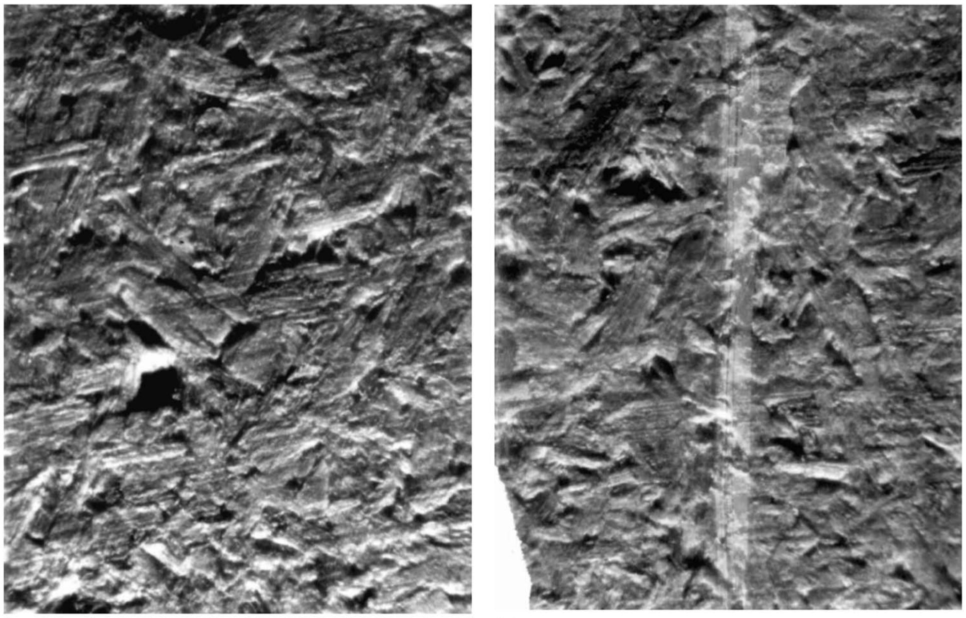
As shown in Fig. 1, the process used at this mill resembles that at most particleboard mills: the wood particles are glued together with a special resin (A) and then pressed at a high temperature and pressure in the multilevel press (B). The boards are then conditioned for a period of about 24 h to attain a specific humidity level. The 8 ft × 20 ft boards are then conveyed to the sanding station (C), graded by an operator (D), and then cut to a specific pattern (4 ft × 8 ft, 5 ft × 8 ft, or custom) (E). The stacked panels are then transported to the warehouse for shipping (F). During the time of this study, the statistics showed that about 95% of the panels were graded as industrial material; 3% were graded commercial; and 2% were graded utility. About 10% of the industrial panels were intended for laminating and painting applications.

3 Surface Anomaly Characterization

Two studies were conducted to characterize three different surface anomalies. The first of these studies characterized specific surfaces, such as pin holes, sander streaks, and grooves in terms of length, width, height, depth, and density, whereas the second study analyzed the surfaces of 1000 randomly picked 4 ft × 8 ft panels to try to find some correlation between different surface characteristics. These panels were collected in the stacking warehouse (point F in Fig. 1).

The samples used in the first study were limited to five pieces of 2 in. × 2 in. particleboard sections cut from panels that were collected and exhibited the target surface anomalies. These sample sections were then classified as 1, heavy pinholes; 2, medium pinholes; 3, grooves; 4, sander streaks; and 5, industrial category sample. The surface analysis was accomplished using both a microscope Olympus PMG3 and a binocular microscope Bausch & Lomb, and an Oplympus BHM microscope. Some pictures of the surface characteristics were taken with an integrated camera at different enlargements and are shown in Figs. 2–5. Different data were collected from each of the five samples, and an average was then calculated for all the specific characteristics.

As for the second study, a magnifying glass (5×) and a halogen light (500 W) were used and the results were recorded: the absence (0) or presence (1) of specific characteristics: pin holes, sander streaks, or grooves. The sampling was based on the actual grading statistics of this mill plant: 95% of the panels were classified as industrial material; 3% as commercial quality; and 2% as utility. The rejected panels were considered as recyclable and were not included in the grading statistics. The 926 panels of the industrial grade, 40 panels of commercial grade, and 40 utility



(*a*) (*b*)

Fig. 2 Industrial-quality sample

panels were analyzed on both sides (2012 panel surfaces), and the result of 0 or 1 (the absence or presence of surface defects) was recorded on charts. The thickness of the panels varied from 0.625 to 1 in.. The panels used for this study were chosen after sanding at the visual inspection station (D in Fig. 1) and followed throughout the remaining process to the stacking station. Each 4 ft × 8 ft panel was clearly identified in the production line (in the precut 8 ft × 20 ft panel), and the top or bottom side was also identified at the out load of the press. This identification was made to find a correlation between the production line and the surface characteristics. The characterization was based on data collected during two surveys. The amount of data recorded varies according to the surface characteristic: 86 readings for heavy pinholes 71 readings for medium pinholes 15 for the grooves, 13 for the sander streaks, and 20 for the industrial quality (or best quality) sample (Fig. 2).

3.1 Pinholes (Pitting). As identified by the representatives of the plant, the two samples (2 in. × 2 in.) used for this characterization were heavy and medium pinholes. On each of these samples, most of the pinholes were measured as described earlier in order to give an order of average size and concentration. The characterization is shown in these two categories and compared to a sample identified as industrial quality (Table 1).

3.2 Grooves. The sample used for this survey had a few

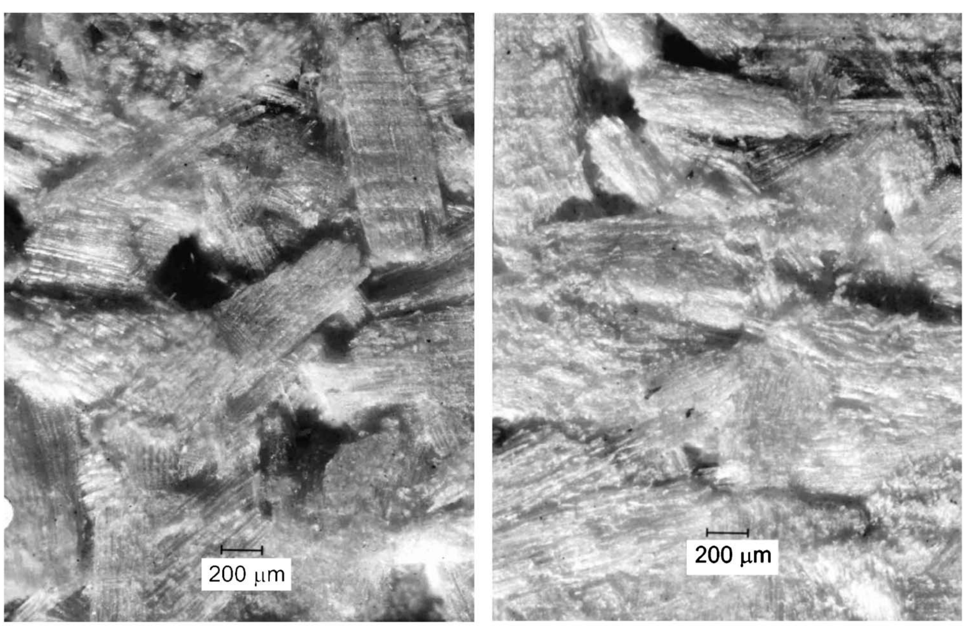


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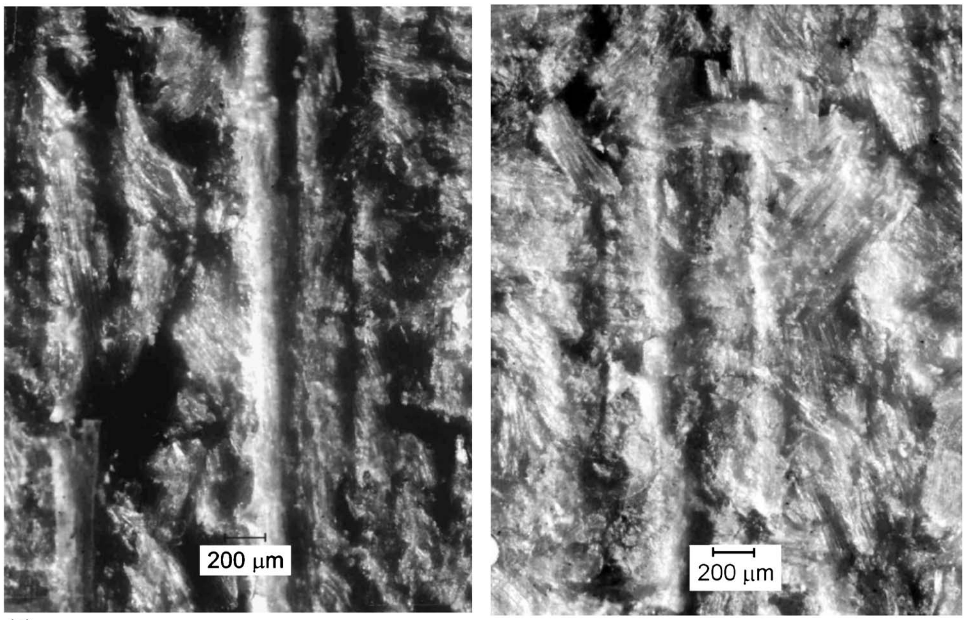
Fig. 3 Pinhole sample



(a) (b)

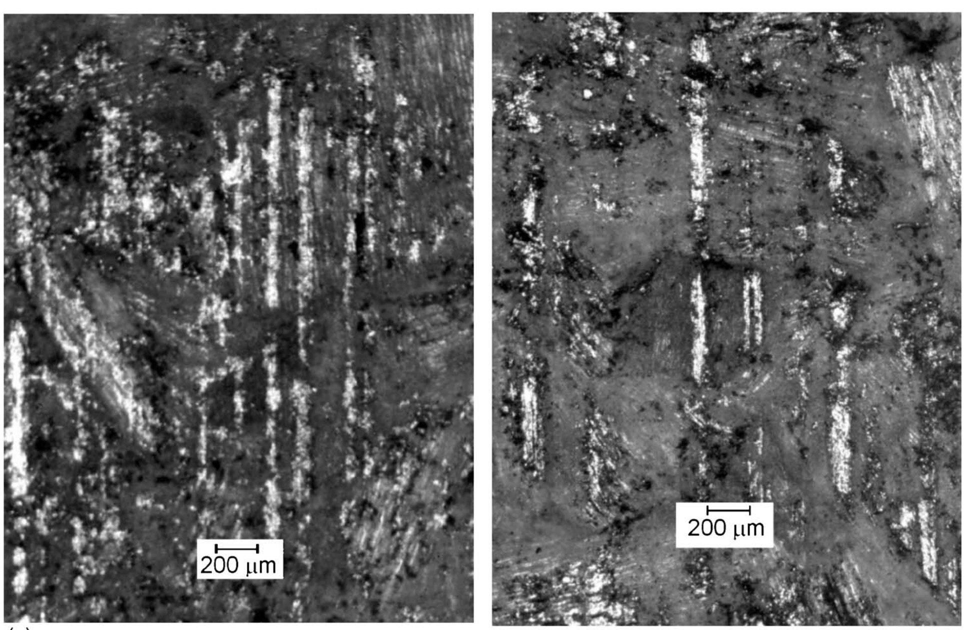
Fig. 4 Groove sample

grooves that were all oriented in the same direction of the production line. A groove is created when an unidentified scratching object (USO) is caught between the surface of the panel and the sanding belt thus creating a groove on the surface of the panel. The grooves seem to appear randomly, and based on the sample examined, the average depth was determined, as described earlier, in order to give an order of average size (Table 2).

3.3 Sander Streaks. A sander streak is created when part of the sanding belt wears out and no longer removes material from the board. A sander streak is made from wood that should have been removed from the surface of a board. A streak usually follows the direction of the production line and seem to appear gradually. The sample used for this survey had sander streaks that were no longer acceptable for industrial use (Table 3). On this sample, the sander streak dimensions were measured, as described earlier, in order to give an order of unacceptable limits and concentration.

3.4 Observations. Based on the sample analysis and the industrial survey of 1006 panels, the following observations were made:

1. Grooves and sander streaks are very difficult to tell apart. Grooves are considered a negative surface anomaly, as they can be characterized as a trough on the surface panel. Sander streaks are considered positive surface anomalies, as they



(a) (b)

Fig. 5 Sander streak sample

Table 1 Pinhole statistics

Surface characteristic	Depth (μm)		Density
	Average	Std deviation	
Heavy pinholes	177	60	2 pinholes/mm^2
Medium pinholes	111	40	1 pinhole/mm^2
Industrial quality	42	18	1 pinhole/0.25 mm^2

leave an unsanded mark or crest on the panel, which can be repaired.

2. No correlation was found in the occurrence or appearance of sander streaks and grooves in the 4 ft×8 ft panels and in their distribution on the surface of the boards. From a production point of view, this means that determining one of these anomalies does not indicate that the other occurs, as could be indicated if one were to assume that a sander streak occurs if a section of grit is lost on the sanding belt and that the grit could end up on another section of the sanding belt and causing a sander groove. This observation indicates that a random distribution can be used to predict these surface anomalies.
3. When a sander streak or a groove appears on the surface of a 4 ft×8 ft panel, it also appears on the next panel 95% of the time.
4. The results of the absence or presence of sander streaks and grooves did not vary with the thickness of the boards.
5. No 4 ft×8 ft panels in the production line were identified as having pinholes. These samples provided the opportunity to characterize the pinholes. However, no conclusion could be made on the possible correlation between other surface anomalies and pinholes.

4 Particleboard Surface-Roughness Simulator

The surface-roughness simulator (see Fig. 6) is defined in two parts: the first being a model of the surface, including the aforementioned surface anomalies (pinholes, sander streaks, and grooves), which are difficult to detect with the naked eye, whereas the second is a model of the optical roughness measurement system that was used. This simulator was developed using MATLAB.

Table 2 Grooves statistics

Surface characteristic	Depth (μm)		Density
	Average	Std deviation	
Grooves	19	7	not applicable

Table 3 Sander streaks statistics

Surface characteristic	Dimensions (μm)		Density
	Average	Std. deviation	
Height of sander streaks	20	8	3 sander streaks/mm^2
Width of the sander streaks	150		
Width between sander streaks	200		

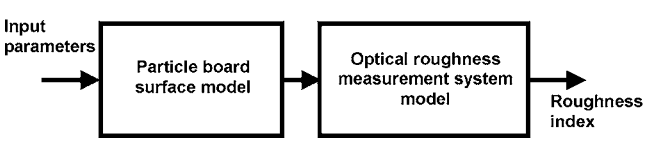


Fig. 6 Particleboard surface roughness simulator

4.1 Particleboard Surface Model.

4.1.1 Mathematical Definition of the Surface Anomalies. A mathematical model was developed for each type of surface characteristic. Each of the surface anomalies was characterized with different parameters that were defined with a known distribution. The following assumptions were made prior to the simulation:

1. Pinholes: Arbitrary data was used to characterize the number of pinholes on the surface of a particleboard panel.
2. Sander streaks and grooves: A uniform distribution with an exponential function was used to determine the maximum number of anomalies per board.
3. Distribution of the surface anomalies' dimensions were the pinholes represented as points; sander streaks and grooves were represented as straight lines.
4. The distribution of the orientation of the surface anomalies on a panel was given a constant value: pinholes had orientation, and sander streaks and grooves were oriented on the principal axis of the panels.
5. No specific distribution was found concerning the localization of the surface anomalies on the panel, which again indicate that a uniform distribution can be used to indicate the localization of surface anomalies.

4.1.2 Development of the Panel Surface Model. Based on the above assumptions, a panel surface model was developed that generated two surfaces for each panel, the upper (Fig. 7) and lower faces of an 8 ft×20 ft feet with anomalies.

4.2 Optic Stylus Model. The surface anomalies studied (pinholes, sander streaks, and grooves) pose a particular detection problem. However, the following studies were used as a foundation for this work. Cielo and Lamontagne [1] used an optic receiver to obtain a profile. To do so, they compared the results of profiles produced by a diamond end stylus with an optic receiver at low scan speeds (<1 cm/min). The conclusions of this study showed that an optic receiver could, in fact, be used as a statistical quality control system.

Orech et al. [2] proposed the use of lasers for the electro-optical testing of wood surfaces, an optical profilometer to measure the relative height of the wood surface was developed by Lemaster and Taylor [3]. Lemaster and Beall [4], Lemaster and DeVries [5], and Lemaster and Dornfeld [6] also used an optical profilometer to measure the surface roughness of wood.

Hiziroglu and Suchsland [7] used a mechanical profilometer to study particleboard surface roughness. Three indexes were calculated based on the average signal value. The conclusions of this study showed that these indexes were significant for different classes of particleboard panels.

Gauthier and Dufour [8] used a laser receiver with triangulation to determine the surface quality of particleboard panels. Different scanning speeds were used to determine the limits of this application: 3.95–48.2 cm/s at a frequency of 1 kHz. The study concluded that the resolution was better at a lower speed and the scanning speed had to be very well controlled to get significant results.

The system to be developed and modeled had to be able to measure the surface roughness of the particleboard panels or, preferably, its roughness index. The proposed system consisted of an optical receiver that had a trajectory perpendicular to the movement of the panel on-line.

The signal received had two principal components: $S_d(t)$ and $S_b(t)$, which were, respectively, the signal containing only the anomalies and the signal from the noise. The two principal sources of noise were, first, electromagnetic (caused by electrical machinery), and second, mechanical (caused by the displacement of the panel on the conveyor)

$$S_s(t) = S_d(t) + S_b(t) \tag{1}$$

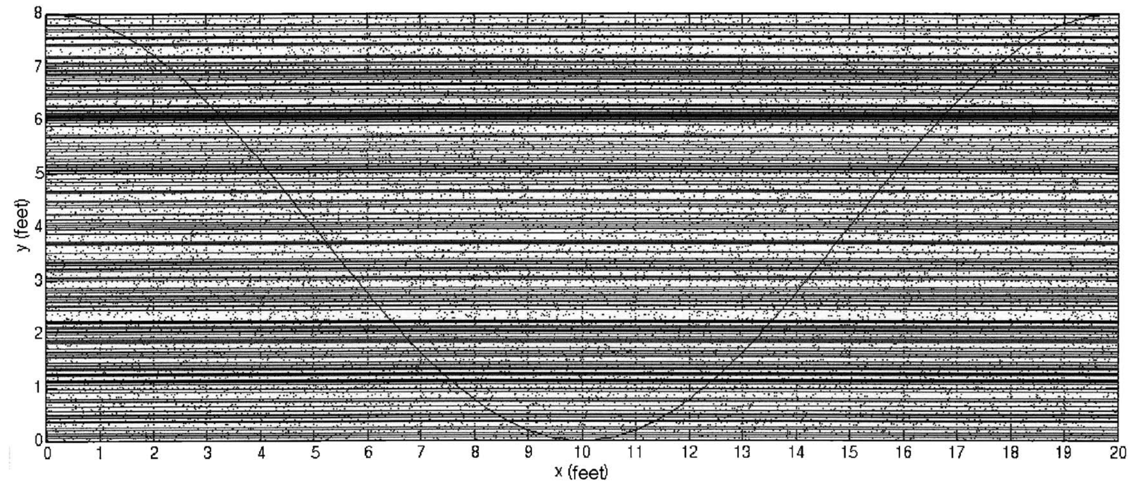


Fig. 7 Particleboard with surface anomalies

4.2.1 Optical Receiver's Trajectory. The curved line on the panel in Fig. 7, as well as in Fig. 8, is the optical receiver's trajectory. The optical receiver's trajectory (x, y) is calculated following these equations:

$$x = vt \tag{2}$$

$$y = \frac{W}{2}\left[\cos\left(\frac{2\pi n}{T}t\right) + 1\right] \tag{3}$$

$$T = \frac{L}{v} \tag{4}$$

where

v = on-line speed of the panel (ft/s)
t = time (s)
T = inspection time (s)
L = length of the panel (ft)
W = width of the panel (ft)
n = number of lateral scans (Fig. 8)

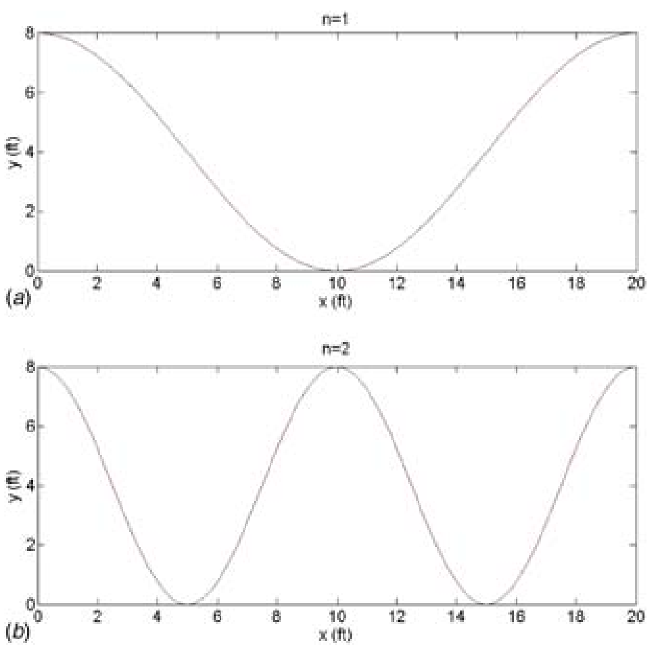


Fig. 8 Receiver's trajectory $(x, y\text{: ft})$

4.2.2 Calculation of Receiver's Sampling Frequency. For a straight-line trajectory at constant speed, the space d_f between two acquisition intervals (Fig. 9) is constant and can be calculated as follows:

$$d_f = \frac{s}{fT}k \tag{5}$$

where

k = unit conversion factor$=0.3048\times 10^6$ (μm/ft)
s = length of the beam trajectory (ft)
T = total time of inspection (s)
f = sampling frequency (Hz)

The width of the scanning inspection path d is also uniform

$$d = \sqrt{4r^2 - d_f^{(2)}} \quad \text{for } 0 < d_f < 2r \tag{6}$$

where

d = width of the scanning path (μm)
r = beam radius (μm)
d_f = distance between two acquisition intervals (μm)

The sampling frequency can be determined by selecting a d_f value that maximizes the width of path d, between 0 and $2r$.

$$f = \frac{s}{d_f T}k \tag{7}$$

In our case, the beam's movement speed will not be constant because of the type of trajectory expressed by the following equations:

$$y = \frac{W}{2}\left[\cos\left(\frac{2\pi n}{L}x\right) + 1\right] \tag{8}$$

$$x = vt \tag{9}$$

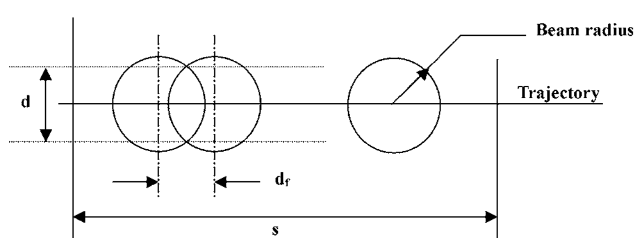


Fig. 9 Straight-line receiver's trajectory

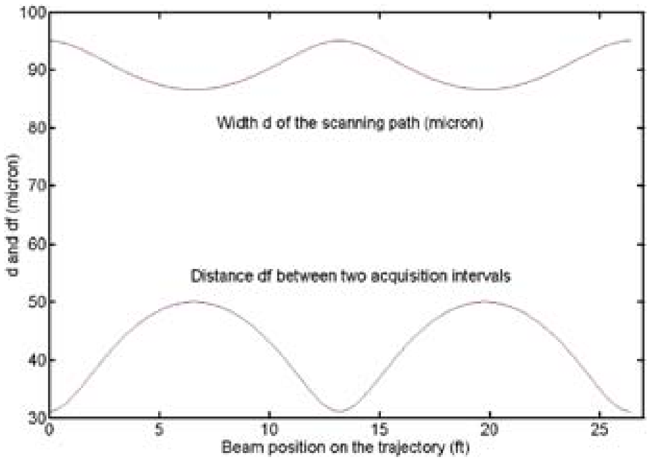


Fig. 10 Variation of *d* and d_f

$$s(x) = \int_{x=0}^{x=L} \sqrt{1 + \frac{W^2\pi^2 n^2}{L^2}\sin^2\left(\frac{2\pi nx}{L}\right)}dx \quad (10)$$

$$\frac{ds(x)}{dx} = \sqrt{1 + \frac{W^2\pi^2 n^2}{L^2}\sin^2\left(\frac{2\pi nx}{L}\right)} \quad (11)$$

By examination, $d_f(x)$ is at a maximum at $x=L/4n$

The minimum frequency f can be obtained for a continuous scanning path by taking $d_{f\max}<2r$.

$$f_{\min} = \frac{k}{d_{f\max}}\frac{4nv}{L}s\left(x = \frac{L}{4n}\right) \quad (12)$$

Figure 10 shows the variation of d and d_f with $L=20$ ft, $W=8$ ft, $v=10$ ft/s, $n=1$, $r=50$ μm and $d_{f\max}=r$.

4.2.3 Surface Roughness Indexes. Particleboard surface roughness can be quantified using different indexes. Hiziroglu and Suchsland [7] used three indices: R_a, R_z, and $R_{\max}$;

$$R_a = \frac{1}{L_s}\int_{x=0}^{x=L_s} S dx \quad (13)$$

where S is the output signal of the laser and L_s is the length of the signal;

$$R_z = \frac{1}{n}\sum_{x=1}^{x=n}(R_{\max})_x \quad (14)$$

where $R_{\max}$ is the maximum amplitude peak to peak of the signal, $(R_{\max})_x$ is the maximum amplitude peak to peak of the signal over x, and n is the number of intervals. The results of this study showed that the indices R_a and R_z are significantly different for the different classes of panels.

Table 4 Simulation parameters

Radius of the laser beam	50 μm
Frequency of the periodic noise	50 Hz
Production speed of the panels	10 ft/s ($\approx$3 m/s)
Sampling frequency of the laser	80,531 Hz
Average amplitude of the mechanical noise	2 μm
Average amplitude of the white noise	5 μm
Number of passes n	1

A derived form of the index R_a was used

$$P_s = \frac{1}{T}\int_0^T S_s^2(t)dt \quad (15)$$

$$P_b = \frac{1}{T}\int_0^T S_b^2(t)dt \quad (16)$$

where P_s is the index of the signal $S_s(t)$, P_b is the index of the signal $S_s(t)$ coming from a panel without any surface anomalies, and T is the duration of the signal. In a real case, the index P_b cannot be determined directly. Instead, the signal obtained from the inspection of a reference panel or panels with nearly no surface anomalies is used to determine P_b. These reference panels can be determined by the industrial representative. With this baseline, a roughness index Q_{sb} can be determined,

$$Q_{sb} + \frac{P_s}{P_b} \quad (17)$$

where Q_{sb} is the real roughness index (obtained with simulation).

5 Simulation Results

Initially, five panels at different pinhole densities were simulated where the initial parameters can be found in Table 4. Two roughness indices (Q_{sb}, R_z) are determined, with only Q_{sb} being illustrated in the results shown in the table.

The Q_{sb} indices calculated for the different pinhole densities are found in Table 5, with the averages presented in Fig. 11. The Q_{sb} indexes calculated for the different grooves and sander streaks densities are found in Table 6, with the averages presented in Fig. 12.

The results show that the roughness indices increased predictability with concentrations of grooves and sander streaks. This observation leads to the use of the index Q_{sb} to calculate indices for the future classification of particleboard as a function of particleboard roughness.

6 Surface Roughness Classification

The particleboard surface-roughness classification scheme can be defined as a function of one or both of the surface-roughness

Table 5 Roughness index for panels with pinholes

	Q_{sb} indexes at different pinhole densities (ph/m^2)					
Panels	1.0×10^6	0.5×10^6	1.0×10^5	1.0×10^4	1.0×10^3	1.0×10^2
1	19.5791	10.3827	2.9100	1.1904	1.0296	1.0035
2	19.1814	10.4187	2.9900	1.1976	1.0073	1.0019
3	19.2403	10.2783	2.9300	1.1936	1.0232	1.0033
4	19.6411	10.2659	2.9600	1.2288	1.0174	1.0029
5	19.7286	10.4493	2.8700	1.2171	1.0115	1.0017
Average	19.4741	10.3590	2.9310	1.2055	1.0178	1.0027

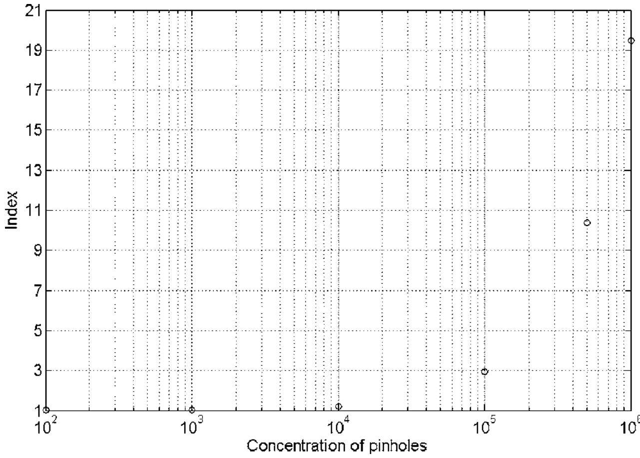


Fig. 11 Average roughness index for panels with pinholes

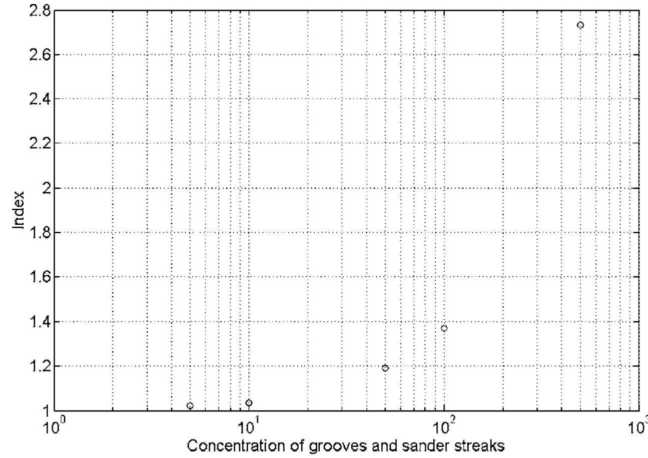


Fig. 12 Average roughness index for panels with grooves and sander streaks

indices determined above. Using the particleboard simulator, it was possible to test such a classification scheme before completing a trial test on selected particleboard panels from industry.

6.1 Simulated Particleboard Classifaction. At present, panels are classified using a visual control. An inadequate classification because of undetected surface anomalies is possible. To verify this hypothesis, an additional 150 panels with grooves and sander streaks were generated and randomly classified into three classes (20% utility, 40% commercial, and 40% industrial). The roughness indices Q_{sb} and R_z were determined and used to reclassify the panels as compared to the first classification. Different classification criteria were used to classify the panels into three categories, depending on the percentage of utility, commercial, or industrial panels.

The following criterion was used where the average index of all panels is μ and the standard deviation is σ:

Industrial: index $< \mu$

Commercial: $\mu-\sigma \leq$ index $\leq \mu+\sigma$

Utility index: $> \mu+\sigma$

The initial classification was made using this criterion and was distributed following the results of the Q_{sb} and R_z indices (Table 7). For example, of all the panels visually classified as industrial, only 56.67% of the panels were also classified as industrial using the roughness index Q_{sb}, and only 53.33% of these panels were classified industrial using the R_z index.

The panels were then reclassified using the following hypothesis. Even if the surface roughness permits the panel to be classified as industrial, if the visual control classifies it as commercial, it could not be upgraded to the next class, but stays in its original class, commercial. Also, if a visual control classifies a panel as industrial, but the surface roughness is poor, the panel is downgraded to a lower class (Table 8).

6.2 Trial Bench-Test Classification. An experiment was conducted to verify the effect of the classification scheme. During this experiment, 225 panels collected in the stacking warehouse (point F of Fig. 1) were scanned with the laser beam using a bench test. Every scan was reproduced three times along the length of the panel and along its diagonal, using three different scan speeds: 1.71, 1.96, and 2.45 m/s. Only the peak-trough index R_z was used in this bench-test campaign with two classification criteria (Table 9). The results obtained at different scanning speeds are shown as percentages in Tables 10 and 11.

7 Discussion

The results in Tables 10 and 11 show that the criteria used are crucial to the classification: the limits of the different classes of classification have to be set using trial and error. The results also show that a roughness index can be used to classify the particleboard panels in different known classes.

At this point, two questions can be raised:

i. What are the limitations of this system?
ii. Where would such a system be installed in a typical particleboard production process?

7.1 Limitations. Before addressing this question, it is important to underline what is being measured. This system cannot be used to determine where a pinhole, sander streak, or groove is located. The reason behind this impossibility is based on two characteristics: the nature of particleboards' surfaces and the dimensions of the targeted anomalies as compared to the diameter of the laser stylus beam.

Particleboards, as shown in Figs. 2–5, are composed of sawdust

Table 6 Roughness index for panels with grooves and sander streaks

Panels	Q_{sb} indexes at different grooves and sander streaks densities (ph/m^2)				
	5 g st/m^2	10 g st/m^2	50 g st/m^2	100 g st/m^2	500 g st/m^2
1	1.0160	1.0326	1.1891	1.3575	2.7284
2	1.0275	1.0422	1.1715	1.3569	2.7839
3	1.0203	1.0303	1.1623	1.4020	2.7739
4	1.0155	1.0394	1.2141	1.3785	2.7414
5	1.0307	1.0312	1.2195	1.3540	2.6256
Average	1.0220	1.0351	1.1913	1.3698	2.7307

Table 7 First classification

	Visual classification (%)					
	Industrial		Commercial		utility	
	Q_{sb}	R_z	Q_{sb}	R_z	Q_{sb}	R_z
Industrial	56.67	53.33	50.00	46.67	50.00	53.33
Commercial	40.00	41.67	46.67	50.00	50.00	40.00
Utility	3.33	5.00	3.33	3.33	0.00	6.67

flakes glued and pressed together. As such, a laser stylus scanning a section of particleboard void of any anomalies would, nevertheless, generate a lot of noise.

The laser stylus used produced a beam diameter of 100 μm, while the sizes of the targeted anomalies measured up to 200 μm (Tables 1–3). Thus, a laser stylus scanning such anomalies of comparable size would essentially produce noise. Increasing the occurrence of such anomalies would increase the noise generated.

Based on these two characteristics, the system measures noise and transposes that noise into a surface-roughness index. Out of this noise, no effort was made to localize a particular pin hole, sander streak, or groove. As the occurrences of the targeted surface anomalies increase, it was expected that the noise level and, thus, the surface roughness index also increase. The results show that this is the case.

If the surface anomalies, especially pinholes, are found to be concentrated in particular zones, it is possible to miss these zones with this system.

Furthermore, these results were obtained using panels from a single company where the quality of raw material used in the production of the particleboards was considered relatively constant. However, where the quality of raw materials used in the production of particleboards would not be constant, this system based on relating laser stylus noise to surface roughness would be expected to have limited utility.

7.2 Installation. The ideal position of such a laser stylus system for the measurement of panel surfaces in the production line would be at the output of the sanding station (point C in fig. 1). The surface index (Q_{sb}, R_z) determined here could feed the visual inspection accomplished at point D (Fig. 13) in order to appropriately class the panel.

Table 8 New classification

	Visual classification (%)					
	Industrial		Commercial		Utility	
	Q_{sb}	R_z	Q_{sb}	R_z	Q_{sb}	R_z
Industrial	56.67	53.33	0.00	0.00	0.00	0.00
Commercial	40.00	41.67	96.67	97.67	0.00	0.00
Utility	3.33	5.00	3.33	3.33	100.00	100.00

8 Conclusion

The initial objective of this study was to model and simulate a particleboard surface-roughness classification system and apply it to an industrial situation. To this end, surface anomalies on the particleboard panels, in particular, pinholes, sander streaks, and grooves, were characterized. Following the analysis of the anomalies found on ~1000 panels, it was possible to conclude that the anomalies (pinholes, sander streaks, and grooves) do affect the roughness of the panels. As the sander streaks and grooves are along the axis of the movement of the panels, the effect on roughness can be given by analyzing the profile perpendicular to the movement of the panels.

Models, using this data, were then developed to generate surface anomalies on the particleboards, to simulate the optical measurement system (including the noise) as well as its trajectory and to describe the roughness of the surface panels according to the readings taken. Furthermore, the determination of a roughness index was the first step toward the development of a classification algorithm. By integrating this index, based on the roughness measurement, with the procedure of classification based on the appearance, it was possible to formulate a procedure for the use of the classification algorithm.

A particleboard surface-roughness simulator was developed using the MATLAB environment to check and test various processes, thereby reducing the cost of prototyping. With use of the rough-

Table 9 Classification criteria

	Industrial	Commercial	Utility
Criterion 1	index $< \mu - \sigma$	$\mu - \sigma \leqslant$ index $\leqslant \mu + \sigma$	index $> \mu + \sigma$
Criterion 2	index $< \mu$	$\mu \leqslant$ index $\leqslant \mu + 2\sigma$	index $> \mu + 2\sigma$

Table 10 Classification with criterion 1

Classification using the R_z index	Visual classification								
	Industrial			Commercial			Utility		
With criterion 1 (ms)	1.71	1.96	2.45	1.71	1.96	2.45	1.71	1.96	2.45
Industrial	13.04	11.11	9.88	0.74	2.96	1.48	4.17	4.17	7.64
Commercial	50.93	50.62	51.85	97.04	92.59	94.07	90.97	91.66	89.58
Utility	36.02	38.27	38.27	2.22	4.45	4.44	4.86	4.17	2.78

Table 11 Classification with criterion 2

Classification using the R_z index	Visual classification								
	Industrial			Commercial			Utility		
With criterion 2 (m/s)	1.71	1.96	2.45	1.71	1.96	2.45	1.71	1.96	2.45
Industrial	37.89	32.72	32.10	70.37	72.59	73.33	67.36	70.83	72.22
Commercial	57.14	64.81	66.05	28.15	26.67	25.93	32.64	29.17	27.78
Utility	4.97	2.47	1.85	1.48	0.74	0.74	0.00	0.00	0.00

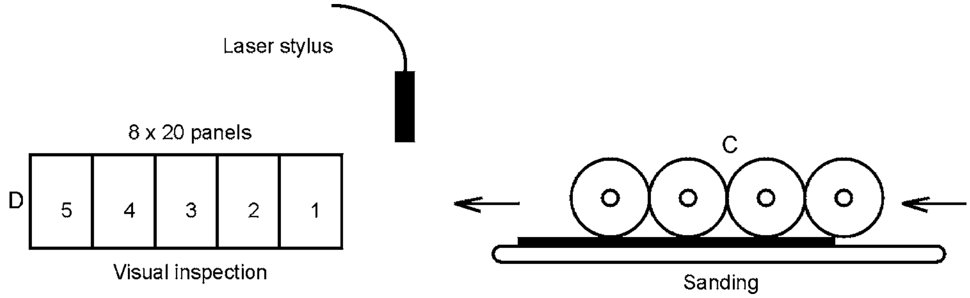


Fig. 13 Location of the laser stylus system in the particleboard production process

ness index from an optical measurement of the surface panels and establishment of the classification criteria, it was possible to classify particleboard panels according to roughness. By generating simulated panels according to time and thus generating an increasingly significant number of anomalies, it was possible to establish a control chart for the simulated case. The quality control system simulator of the particleboard panels was used to check the applicability of the measurement system, calculation of roughness indexes, and classification procedures.

The result of this development made possible the measurement of the surface panel roughness and to classify the panels according to their roughness as shown in the laboratory tests. Moreover, this system can be complementary to the grading systems, based on visual appearance.

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