

DETERMINATION OF PARALLAM®¹ MACROPOROSITY BY TWO OPTICAL TECHNIQUES

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ABSTRACT

The macroporosity of Parallam®, a structural wood-based product based on parallel strand lumber technology, was investigated using two imaging techniques. A video camera and a line scan camera were used to capture the images of thin Parallam® squares viewed in transmitted light. Quantification of macro-void areas in the images recorded was performed using an image analysis system. Total macro-void areas determined for fifty Parallam® squares ranged from 2.90% to 3.90% as determined using the video camera and from 1.29% to 2.24% as determined using the line scan camera. The relative merits of the two imaging systems are discussed.

Keywords: Wood composites, Parallam®, macroporosity, scanner, video camera, image analysis.

INTRODUCTION

Image analysis systems involving computer software programs that perform numerical calculations and manipulations of images captured by a video camera have numerous applications in the wood science field (McMillin 1982). Computer-aided vision systems have been used successfully to determine the amount of wood failure on plywood shear specimens (Miller et al. 1973; McMillin 1984). A similar system was also found adequate to measure veneer roughness at real time production speeds (Faust 1987). A computer-aided vision system

has also been used to develop an analytical method for characterizing the dimension and shape of cracks created by nailing in wood (Lau and Tardiff 1990). A recently developed tree ring measurement system is based on a line scan camera rather than a conventional video camera (Guay et al. 1992). Higher resolution than with a conventional video camera is claimed when scanning large-diameter wood discs. Quantitative wood anatomy studies have also been performed using image analysis systems (Ilic and Hillis 1983; Peachey and Osbourne 1990).

Parallam® is a registered trademark of MacMillan Bloedel Limited for parallel strand lumber. Parallam® beams have been developed over the last 20 years and have the high-

¹ The use of company names or products does not constitute endorsement by the authors.

est allowable design stresses of any wood-based beams available in the market today. Parallam® beams are made from long strands of wood veneer peeled from Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] or southern pine (*Pinus* spp.). The veneer strands, up to 2.4 m in length, are coated in phenolic adhesive and randomly distributed in a mat with their long axis parallel to the long axis of the finished product. The mat is fed on a rotary belt into a continuous press where they are cured using microwave energy. Parallam® emerges as a billet that can be factory cut and trimmed to standard lengths of over 20 m.

As in any composite material produced from comminuted wood particles, macro-voids are formed in the Parallam® mat during its lay-up as a result of the random nature of the strand deposition. While many of these macro-voids are eliminated upon pressing, a certain proportion remain in the finished product. These remaining macro-voids can contribute both positive and negative attributes to the composite's properties. If they are extensive, they may lead to a reduction in the mechanical strength properties of the material. Their presence may also have a beneficial effect by increasing the permeability of the material to liquid preservatives. This is because the flow of liquids through the interconnected micro-voids volume (i.e., lumens, pits) is extremely slow and when refractory wood species are used in Parallam® manufacturing, impregnation characteristics of the composite will be drastically affected. Furthermore, the presence of macro-voids will increase the internal composite surface available for gas adsorption during in-service fumigation with organic fungicides. Large internal surface areas may also result in higher equilibrium moisture contents due to larger amounts and rates of water adsorption from the environment, thus resulting in reduced material strength and larger time-dependent deflections under static loads.

The objective of this study was to measure macro-void areas in Parallam® using two imaging systems: a video camera and a line scan camera.



FIG. 1. Experimental Parallam® square (cross section of block). Scale bar = 2 cm.

METHODOLOGY

Material

A rough-sawn Parallam® block made from Douglas-fir measuring 21.5 cm × 27.5 cm × 35.5 cm was used. This block was trimmed to 12.7 cm × 12.7 cm in cross section and 25.2 cm along the long axis of the strands. Fifty squares 3 mm in thickness were then sawn using a saw kerf of 1.5 mm and finally trimmed to produce the 10.2 cm experimental squares (Fig. 1). Each specimen was measured and weighed.

Video camera

A Javelin JE3462HR color video camera was used with a Truevision Targa-plus frame-grabber installed on an IBM-486 compatible computer. When the Parallam® squares were placed on a light table, macro-voids were apparent by light shining through the squares while areas of solid wood prevented the transmission of light (Fig. 2a). The image captured by the video camera was saved as a TIFF file (tagged image file format) by the image analysis software package. A PostScript file of the TIFF file was produced using external software

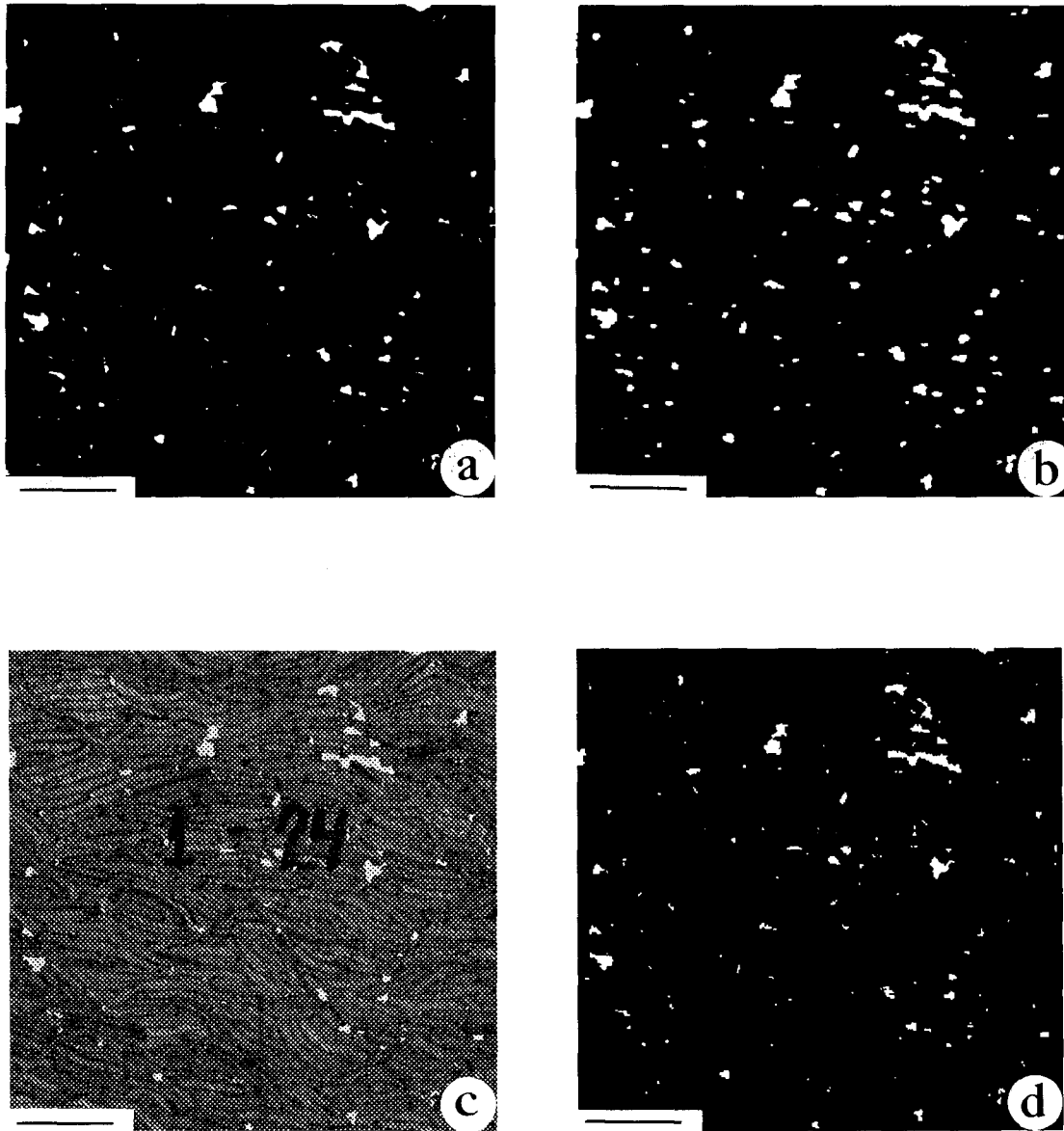


FIG. 2. Parallam® square (a) on light table and (b) image captured by video camera and regenerated using threshold gray shade of 65. Parallam® square (c) image captured by scanner and (d) image regenerated using threshold gray shade of 140. Scale bar = 2 cm.

(CorelDraw) from which a hard copy of the image captured could be printed.

Scanner

A Hewlett Packard ScanJet Plus scanner was used with HP Scanning Gallery Plus 5.0 software. This scanner (or line scan camera) uses

a charge-coupled device (CCD) array to capture images. A light is directed to the image, and the array of CCD elements detects how much light is reflected from each point of the image. The macro-void area of the Parallam® squares could not be determined by direct scanning of the squares since the dark glue-

lines present would have been recognized as macro-voids by the scanner. Thus, transmitted light was used again as four 250-watt photographic light bulbs illuminated the squares from above. A thin sheet of frosted white plastic was placed over each square to keep it flat in contact with the glass plate of the scanner and to help to diffuse the light from the bulbs. If no such diffusion effect was employed, "hot-spots" corresponding to the elements in the light bulbs were evident; and a short-term memory-lag effect was left in the CCD array by the bright lights, which produced erroneous readings. The scan of each square was saved as a TIFF file, which could then be imported into the image analysis software. Once again a PostScript file was produced from this TIFF file to print a hard copy of the image captured by the scanner.

Image analysis

The image analysis software package used was JAVA®, produced by Jandel Scientific Ltd. The image analysis software recognizes one of 256 gray shades for each pixel in an image (0 = black, 255 = white). With the image in this digital form, a wide range of image processing and computational operations can be performed. In order to calculate the percentage macro-void area of each square, it was necessary to determine threshold values for both the video camera and scanner images. Gray shades above the threshold value were assigned as macro-voids, and gray shades below the threshold value were assigned as wood. The software package aided in the choice of this threshold value by allowing pixels above an operator-selected gray shade to be colored one monochrome color, pixels below another operator-selected gray shade to be colored another monochrome color, and those pixels of gray shades between the two selected levels to be colored a third monochrome color. These monochrome colors could then be superimposed against the black and white image on the video monitor (only the image on the monitor was affected by this operation, not the image data file). The histogram data for the num-

ber of pixels having each gray shade were imported into a spreadsheet software package, where the percentage of macro-voids for each of the experimental squares was calculated as the proportion of pixels in the area of interest in the image corresponding to the square having a gray shade above the threshold value.

RESULTS AND DISCUSSION

Typical histograms showing the pixel frequency for the gray shades in the images of a square captured using the video camera and the scanner are shown in Fig. 3. The histogram for the image captured by the video camera shows three distinct regions. From gray shades of 0 to approximately 65, there is a large peak representing the solid wood in the squares where light was not transmitted. The single line at a gray shade of 255 represents the white light shining through the macro-voids in the square. The gray shades between these two regions (from approximately 65 to 254) represent the edges of the macro-voids. The zoom facility of the image analysis software aided in the choice of a gray shade of 65 as the threshold value between macro-void and solid wood. The histogram for the image captured by the scanner shows a different profile. Here one peak of gray shades up to approximately 140 represents the solid wood where light was not transmitted, and the second peak above gray shades of approximately 140 represents the areas where light was transmitted through the macro-voids in the squares. The edges of the macro-voids were sharper in the image captured by the scanner than in the image captured by the video camera. This sharpness was reflected in the bimodal distribution of the intensity histogram, which aided in the selection of the threshold value. The threshold gray shades chosen for each of the imaging techniques cannot be compared directly because of the different imaging principles and different lighting systems used.

The image of the square captured with the video camera and then regenerated using the threshold value of 65 is shown in Fig. 2b. In this figure all pixels of gray shade 65 and below

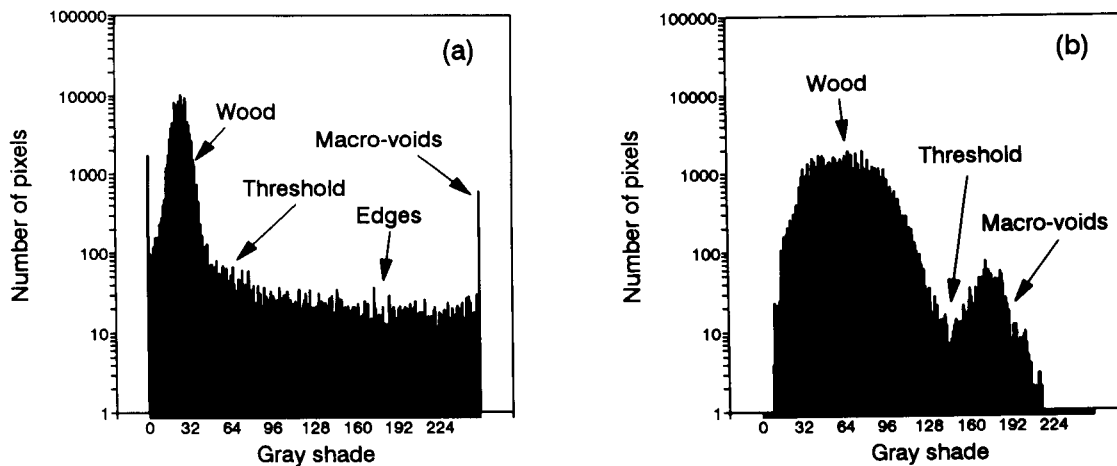


FIG. 3. Histograms showing frequency of pixels for each gray shade in image captured by (a) video camera and (b) scanner.

are converted to a gray shade of 0 (black), and those pixels of gray shades above 65 are converted to a gray shade of 255 (white). There is good agreement between this image and the photograph of the square (Fig. 2a). Figure 2c shows the image captured by the scanner in 256 gray shades, and Fig. 2d represents the image of the macro-voids determined using the threshold value of 140.

After a suitable calibration had been performed, the image analysis software was able to count and quantify the macro-void areas in the images. The software calculated the number of pixels in a defined area of interest of known dimension (the image of the square). One pixel represented 0.08 mm² for the video camera and 0.12 mm² for the scanner. The percentage total macro-void areas of the 50 squares as determined by the two different methods are compared in Table 1. The video camera consistently produced values for the total macro-void areas almost twice those val-

ues determined by the scanner. There was a good correlation between the two sets of values ($r^2 = 0.83$). A comparison of the distribution of the sizes of the macro-voids determined for a randomly selected square is presented in Table 2. More than half of the macro-voids determined by the scanner were less than 0.40 mm² in area (three pixels or less), while the video camera determined just less than one quarter of the macro-voids to be 0.40 mm² or less (five pixels or less) in area. More than one third of the individual macro-void areas determined by the scanner were of only one pixel in area. On visual examination of the square on the light table, it was apparent that some pixels of gray shades greater than 140 were being detected by the scanner in areas of the square where no macro-voids were present. Such spurious macro-voids were not detected by the video camera. With the video camera, transmitted light alone was used in determining the macro-void areas, and wood—whether light or dark in color in normal lighting conditions—appeared dark to the video camera. With the scanner, both transmitted light from the light bulbs above the squares and reflected light from the scanner's light tube were used in determining the macro-voids areas. Thus it would appear that small specks of wood reflected sufficient light from the scanner's light

TABLE 1. Percentage macro-void areas determined for fifty *Parallam* squares using a video camera and a line scan camera.

Camera	Average	Standard deviation	Minimum	Maximum
Video	2.90	0.28	2.35	3.45
Line scan	1.66	0.23	1.29	2.24

TABLE 2. Distribution of macro-void areas determined for one Parallam square by a video camera and a line scan camera.

Macro-void area (mm ²)	Number of macro-voids determined	
	Video camera	Line scan camera
0.00–0.19	13	52
0.20–0.39	17	37
0.40–0.59	10	16
0.60–0.79	13	2
0.80–0.99	13	2
1.00–1.19	11	2
1.20–1.39	3	2
1.40–1.59	8	3
1.60–1.79	2	2
1.80–1.99	7	1
2.00–2.99	10	11
3.00–3.99	10	1
4.00–4.99	4	2
5.00–5.99	3	0
6.00–6.99	2	2
7.00–7.99	0	1
8.00–8.99	3	2
≤9.00	4	2
Total	133	140

tube to register as a macro-void according to the threshold value selected. The situation might have been improved by the use of a more intensive source of transmitted light; but if the light source was too intense, then problems with the CCD array already mentioned became apparent. Alternatively, the scanner could be run while disabling its light tube.

As was expected, there was an inverse relationship between the densities of the Parallam® squares and their macro-void areas as determined by either technique. A plot of the total macro-void areas of the squares determined using the video camera in sequence along the longitudinal axis of the Parallam® block showed that the distribution of the macro-voids was not random (Fig. 4). A gradual rise and fall in the values of the total macro-void areas of the squares are observed along the length of the Parallam® block. The long axis of the macro-voids is oriented parallel to the longitudinal axis of the strands and thus to the longitudinal axis of the block. An individual macro-void runs through the thickness of more than one square; and as more or

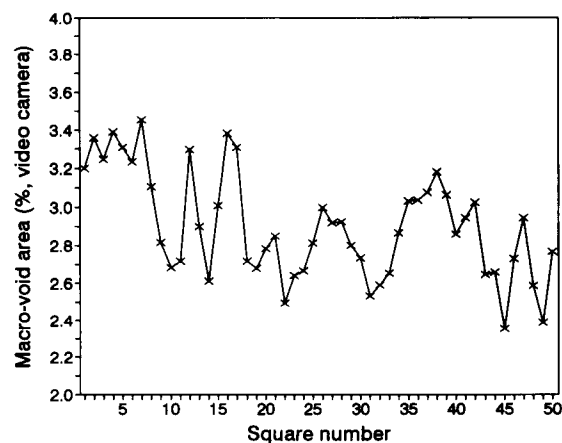


FIG. 4. Variation along the length of a block of Parallam® of macro-void area determined using the video camera.

fewer macro-voids are introduced into the adjacent squares, the effect will be for a gradual change in the total macro-void areas along the length of the block. The length of the Parallam® block represented by the 50 squares was 22.4 cm. It should be recognized that these results were determined from only one block of Parallam® and may not be directly applicable to the whole population of Parallam® material.

Although the potential resolution of the scanner was greater than that of the video camera, the number of pixels on the video monitor used with the image analysis system limited the resolution setting of the scanner that could be used. If the scanner was used at a setting of 300 or 150 dots per inch, the number of pixels in the scanner image of the Parallam® square exceeded the capacity of the video monitor, and thus only a portion of the image scanned appeared on the video monitor. Only at the 75 lines per inch setting was the full image of the square within the capacity of the video monitor. When the image of a Parallam® square captured by the video camera was viewed at maximum size on the video monitor, there was a resolution of 94 pixels per inch. If it had been possible to use the higher levels of precision possible with the scanner, the problem of the detection of spurious macro-

voids discussed earlier would have most likely increased.

The video camera is more flexible in that the distance the camera is away from the object can be varied because of the focussing capability of the lens, whereas the object to be scanned must be placed directly on the glass plate of the scanner. The video camera also employs a lens aperture that permits the amount of light entering the camera to be controlled in an alternative way to simply lowering the intensity of the light illuminating the object. However, this increased flexibility leads to a correspondingly increased sensitivity to the experimental parameters. The fact that the distance from the image to the detecting device was less with the scanner may have contributed to the appearance of fewer edges to the macro-voids in the scanner images.

From a visual inspection of the squares placed on the light table, it could be seen that a few very small areas of light that were visible through the square when placed on the light table were not included in the macro-voids determined in the images captured by either the video camera or the scanner. One reason for this may have been that the tiny holes were smaller than the resolution limit of the image analysis system. If the image of a small hole was shared between two or more pixels, its contribution may not have been sufficient to raise the gray shade for any one of the pixels over the threshold value.

Although the larger of the macro-voids can be followed along the longitudinal axis of the Parallam[®] because of their distinctive shapes, this is not possible for the smaller macro-voids. It is not possible to be certain which small macro-void in one square corresponds to which macro-void in an adjacent square. The bit-maps of the images of sequential squares could be combined to build up a three-dimensional model of the larger macro-voids along the long axis of the Parallam[®] block. Such a three-dimensional model could be useful in future studies such as modelling gaseous or liquid flow through the material. These techniques provide relatively cheap alternatives to X-ray

instrumentation designed to produce three-dimensional profiles of wood-based materials. However, such X-ray instrumentation does not necessitate the destruction of the gross nature of the sample as is the case of these two techniques and is less time consuming.

CONCLUSIONS

Macro-voids in Parallam[®] squares were successfully determined using transmitted light and a video camera or a line scan camera to capture the images of the squares. The areas of the macro-voids in each square could then be quantified using an image analysis system. The images of the Parallam[®] squares captured with the video camera gave consistently higher values for the total area of the macro-voids. The video camera was felt to be the better imaging device since the problem of spurious macro-voids resulting due to reflected light was eliminated. Both techniques indicated that the majority of the macro-voids were towards the lower end of the detection limit of the techniques. These techniques could be used as a first step in developing a three-dimensional model of Parallam[®].

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