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IMAGE RECOGNITION AND ANALYSIS SYSTEM TO QUANTIFY CHECKING OF PRESERVATIVE TREATED WOOD

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Summary

Surface checking often disfigures the appearance of wood treated with water-borne preservatives and treatments designed to reduce such checking have been receiving increasing attention. Progress in this area has however been slowed by the lack of a method of rapidly and accurately quantifying checking at treated wood surfaces. A software package has therefore been developed which identifies, measures and records the dimensions and numbers of surface checks in scanned images of preservative treated wood specimens. The program uses grey-scale 600 dpi TIFF images of wood specimens and operates within the data acquisition, analysis and presentation software IGORPro (Wavemetrics). Procedures within the program analyse images sequentially pixel by pixel and one row at a time searching for brightness minima (dark areas) which satisfy criteria that are characteristic of checks. A black and white (b/w) image is then produced in which probable checks are shown black on a white background. Further procedures reduce noise in the b/w image eliminating artifacts (specks of dirt) and small checks that cannot be discerned by the naked eye. The final stage of the analysis rasters through the cleaned b/w image establishing which black pixels connect to each other and identifying and labeling checks and quantifying check positions, sizes and shape. These data are then presented in a spreadsheet. Using this package it has been possible to successfully quantify checking in a range of preservative treated wood specimens that have been subjected to natural weathering. This paper describes the principal features of the software package and presents preliminary data from analysis of treated and weathered specimens. The advantages of the system for quantifying checking in preservative treated wood as well as its limitations are discussed.

1. Introduction

Preservative treated wood is facing increasing competition from wood-plastic composites (WPCs) in above ground (decking and cladding) applications (Woodhams et al., 1984; Schut, 1999). One of the reasons for the success of WPCs is their perceived superiority over timber in terms of resistance to the physical effects of weathering, particularly surface checking and cracking (Muller, 1995). Despite the importance that surface checking exerts on consumer choice of treated cladding and decking there have been few studies of the checking of preservative treated wood in comparison to the large body of work on the resistance of treated wood to biological organisms.

Belford and Nicholson (1969) examined the effect of preservative treatment on the end grain checking of European beech (*Fagus sylvatica* L.), Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) and hemlock (*Tsuga heterophylla* (Raf.) Sarg.) boards exposed to artificial accelerated weathering. Photographs of the end grain of boards after 3 weeks exposure showed little difference in the number of end-grain checks and their sizes in chromated copper arsenate (CCA) treated boards compared to those in matched untreated boards (Belford and Nicholson, 1969). Mackay (1973) measured the length of checks formed in CCA treated boards and water treated controls after preservative treatment and redrying, and concluded that boards that were treated with CCA and then redried were more prone to check than control boards. Plackett et al., (1984) examined the ability of various preservative treatments to retard the physical deterioration of radiata pine (*Pinus radiata* D. Don) roofing shingles. A qualitative rating system, from 1 (no checking) to 5 (shingle split in two) was used to assess checking after 7 years exposure. They concluded that CCA treatment increased the tendency of shingles to split during exterior exposure, but the addition of wax to the CCA significantly enhanced resistance of CCA treated wood to checking. Fowlie et al., (1990) exposed CCA-treated and untreated southern yellow pine (*Pinus ponderosa* Dougl.) wafers to accelerated weathering and then used a qualitative rating system to compare the checking characteristics of the wafers. Their results, in contrast to the findings of Plackett et al., (1984), showed that, irrespective of exposure period, checking was more severe in the untreated wafers than in those treated with CCA (Fowlie et al., 1990). Zahora (1992) assessed the effect of a water-repellent additive on the physical deterioration (checking and cupping) of southern yellow pine boards treated with CCA and exposed to 1 years natural weathering. Checking was assessed by measuring the width of the 3 widest checks occurring in each board. Results clearly showed the beneficial effects of the addition of the water-repellent additive on the ability of CCA to protect wood from checking. Evans et al., (2000) measured the length and width of checks in radiata pine decking timber treated with CCA and CCA-wax and exposed to 1 years natural weathering and reached a similar conclusion. They also found that there was no significant difference in check number and sizes between CCA treated boards and untreated controls. Zahora (2000) used a similar technique to that first used by Belford and Nicholson (1969) to examine the ability of a wax additive to prevent surface checking of CCA-treated southern yellow pine boards exposed outdoors for 9 years. Photographs of the end grain of CCA and CCA-wax treated boards after exposure show deep checking and cracking in the former whereas the CCA-wax treated board showed only limited shallow checking on the exposed surface.

Notwithstanding these studies, routine assessment of surface checking of treated timber is generally not undertaken during the development and evaluation of new preservatives mainly one suspects because of the time and effort involved in manually measuring surface checks that develop when wood is weathered. Instead it is often assumed that assessment of the water repellency of the treated timber, for which established methodology is available (Rowell and Banks, 1985), will provide a reliable guide to the ability of treatments to protect wood from physical deterioration during weathering. However, while there is very strong evidence of a correlation between water repellency of wood and resistance to checking for wood treated with water borne preservative containing wax additives (Zahora and Rector 1990; Zahora, 1991; Cui and Zahora, 2000) there is little evidence that water repellency conferred by chromium in wood preservatives has any beneficial effect on checking. Indeed there is ample evidence to the contrary, for example the studies of Mackay, (1973) and Plackett et al., (1984) which showed that CCA treated wood was more prone to checking after drying and weathering, respectively. Accordingly a rapid, automated, method of directly measuring the checking of preservative treated wood is needed.

There are significant obstacles to the development of an automated check measurement system for wood despite rapid advances in image acquisition and analysis systems and the existence of automated crack recognition and measurement software for other materials (Lopez et al., 1998). In the case of wood, checks can be distinguished by the human eye because they are usually elongated, longitudinally orientated, objects that are darker than the surrounding wood and run parallel to the grain. There are however, other features on wood surfaces which possess similar characteristics most notably resin canals and bands of latewood. Check measurement software would need to differentiate checks from such objects and its output would need to correlate well with visual rating or manual measurement of surface checking. In addition it would be desirable for the system to use standard hardware for image acquisition and data processing.

This paper describes the principal features of a software package designed to identify, measure and record the dimensions and numbers of surface checks in preservative treated wood specimens. Preliminary data from analysis of checking in treated and weathered specimens is presented and the advantages of the system for quantifying checking in preservative treated wood as well as its limitations are discussed.

2. Methodology

Imaging of surface checking in weathered wood surfaces

After preliminary experimentation we decided to use a desk-top scanner in preference to a CCD camera to obtain images of weathered, preservative treated, wood surfaces because a scanner was able to digitally capture a larger surface area of weathered wood than a camera. The lack of portability of a desk-top scanner was not an important consideration in this work because we were interested in assessing checking in relatively small test specimens which could be brought to the scanner and imaged. A CCD camera by virtue of its greater portability would obviously be more suitable than a desk-top scanner for obtaining images of weathered wood surfaces in the field. Wood surfaces were scanned into an Apple iMac computer using Adobe Photoshop, at 600 d.p.i. resolution. The narrowest features of interest that could be captured reliably were about 4 pixels wide, which at this resolution equated to 0.17mm. A parabolic rather than a linear grayscale map was used, in which a scanned brightness of 50% was recorded as 75% in the image (i.e. 191 rather than 127 on a scale of 0 to 255). This had the effect of brightening the image, with enhancement of contrast for dark features such as checks. Images were archived on hard disk as TIFF (tagged image file format) files. TIFF is less compact than some image formats but has a number of advantages:

1. It is easily transferable between different applications and platforms.
2. Even very large TIFF files loaded reliably into IGORPro, the application used as a programming environment on the iMac. The same was not found to be true for PICT files.
3. Grayscale TIFF files can be loaded into IGORPro as two-dimensional data, whereas PICT files are assumed to contain three-colour information and take up three times as much space in RAM as the corresponding TIFF file.

At 600 d.p.i. resolution, a 256-step grayscale image of a 30 x 9 cm specimen surface with edges removed was typically 13.5 Mb in size. Figure 1 shows a small selected area (about 33 × 77 mm) of a backsawn southern yellow pine specimen treated with ACQ (H3) and subjected to 1 year of natural weathering. Some checks can be seen clearly as dark, elongated, longitudinally orientated, elements that are darker than the wood. Others, however, are difficult to resolve because they are thinner and lie within dark coloured latewood. Thin bands of latewood within areas of earlywood also resemble checks (Fig. 1). These features of the wood surface complicated the task of writing software to identify checks and meant that a number of criteria had to be used to identify checks and distinguish them from other features of similar appearance.

Computational Hardware and Programming Environment

The software that was written to identify and quantify checking on wood surfaces runs on a Macintosh iMac with a PowerPC G3 processor and 333 MHz clock speed. Minimum RAM required is approximately 60 Mb plus three times the size of the largest image file to be processed, which was 100 Mb for the work reported here. The data acquisition, analysis and presentation application IGORPro (WaveMetrics) was used as a development environment for the package. IGORPro includes an embedded high-level language (resembling Visual C) for writing user-defined functions. These are compiled and hence run at high speed. The IGOR language also allows programmers to construct windows and mouse-operated controls which can be used to provide an attractive, easy-to-use graphical user interface (GUI). The use of IGORPro as a programming environment provided many additional capabilities which have not been explicitly written into the check analysis package described here. These include the ability to zoom in or out of images, and also to load, save and copy any of the data used or generated by the package, perform calculations on it, or display it in graph or image form quite independently of the package. The numerical routines were written so as to be as fast as possible. Nevertheless, a 13 Mb image requires about 25 minutes of processor time at the current clock speed. Note that the package assumes that the user is searching for thin objects that are elongated in vertical direction or nearly so. It does not recognize highly oblique or horizontal objects. This can be an asset if there are pencil lines or writing on the specimen, since most such objects are ignored.

Identification of checking and analysis

Images of the type shown in Fig. 1 are loaded into IGORPro and the area of interest is selected (avoiding end seals, damaged areas of the specimen and pencil marks etc) and can be saved as a TIFF file. A data folder is created which shares the name of the selected area, and the image file placed within it. A procedure within the program uses the grayscale image to construct a black-and-white (b/w) image in which probable checks are shown black on a white background. This is achieved as follows:

1. The procedure works through the image sequentially, one horizontal row at a time
2. Each row undergoes 3-point smoothing to reduce noise
3. Then a search for brightness minima is conducted. The procedure looks for minima which satisfy the following criteria:

a) The steepest slopes in brightness on both sides should be steeper than a certain (user-adjustable) threshold
b) The darkest point in the traverse should be darker than a user-adjustable threshold
c) The depth/width ratio of the minimum should be steeper than an adjustable threshold

In practice, two sets of (b) and (c) are used, since depth/width was found to be less critical for extremely dark but broad checks than it was for narrow checks that may have less dark centres. To avoid triggering a false end-of-check signal if a small bridge or dirt particle is encountered in a check, the procedure does not look for the end of a check until the image brightness has partially returned to its start-of-check value. The fraction of check depth needed is again user-adjustable. Fig. 2 shows a typical brightness profile across the central portion of the scanned image shown in Fig. 1. Checks appear as steep minima in the profile.

Fig. 3 shows an enlarged region of the traverse in Fig. 2 including one broad check and two narrow ones. From Fig. 3 the need is apparent for two different depth/width thresholds if small checks are to be distinguished from the background noise. The broad check includes a particle of wood, which appears to break it into two checks. If the wood particle were less pale, parameter (b) above would prevent end-of-check from being triggered until the real end of the check was reached. In this case, the particle will be registered as an island in the check, which may be blacked over at a later stage in processing (see below).

Conversion of the grayscale image (Fig. 1) to a black-and-white (b/w) image (Fig. 4) containing probable checks is completed when a new image window shows the b/w, skeletonized, image. The “checks” on this can be compared with the original image, and the analysis, which we have termed binarization, repeated with new parameter settings if either too little or too much dark (check) structure has been captured. It was found to be better at this stage to miss some areas of real check (which can be reconstructed fairly accurately in the next stage) than to capture spurious "checks" such as very dark growth bands, resin pockets, dirt or writing on the specimen surface. Although the next stage of analysis can easily remove small amounts of such noise, removal of large amounts of noise is difficult without partial erasure of captured checks. All images are saved automatically as binary files, so that the clean-up of the image (see below) can be undone if necessary and the original raw b/w image restored.

The initial b/w (binarized) image (Fig. 4) should show all the visually important checks in the selected area. Although they should be reasonably complete, small spurious "bridges" and ragged check edges can be repaired in the next stage. The presence of major artifacts in the image implies that binarization should be repeated with a different set of parameter values. The next stage of analysis reduces noise in the b/w image as follows to produce an image (Fig. 5) that is free of background noise:

1. The procedure works through the b/w image one vertical column at a time.
2. Small, isolated, black blocks ($\leq$ 2 pixels) are whited out. This eliminates noisy background due to dust on the specimen surface.
3. Small white regions up to a certain (adjustable) size are then blacked out. This eliminates most spurious bridges and some real ones, and also smoothes ragged edges.
4. Small remnant black blocks up to a certain (adjustable) size are then removed. This further smoothes check edges and also eliminates large dirt particles and surface damage. Features such as resin pockets and very small checks are also removed at this stage.

The final stage of analysis rasters through the cleaned b/w image from bottom left to top right, and then down again, establishing which black pixels are connected to others. After the second percolation pass, every separate check in the image has a unique number, and every black pixel in that check is labeled with the check number. The second percolation pass ensures that Y-shaped and other branched checks are recognised as single objects. This procedure is relatively fast compared to the binarization and clean-up stages. While identifying each check, the procedure keeps a record of:

1. Vertical coordinates (in pixels) of its start and finish, and mean horizontal coordinate. These allow it to be identified in the original grayscale image
2. Length of check, in units chosen from a pull-down menu. Millimetres is the default. Inches or pixels are also available

3. Area of check (square mm, inches or pixels)
4. Width of check. Calculated as (area/length) × (shape function), where shape function = 1 for rectangular checks, 2 for rhomboid checks, and $4/\pi$(≈ 1.273) for ellipses. The default shape is rectangular, since this was found to give the closest fit to manually measured check widths (see below).
5. "Shape" (= length/width ratio) of check.

These data are then presented in a spreadsheet-like table that includes the name of the original TIFF file, the name of the selected area and its coordinates, the total number of checks, total length and area of checks, mean check spacing, and fraction of total area that is check. To avoid cluttering the table, objects below a threshold area and below a threshold shape (i.e. short, broad objects) are not included. These objects are re-coloured gray on the b/w image. The thresholds are adjustable on a pull-down menu. A typical minimum area would be 250 square pixels, which at 600 d.p.i corresponds to a check about 0.15 mm wide and 3 mm long. Such an object is just visible with difficulty by the naked eye. Total check numbers above this threshold have ranged from 0 to about 550 in 30 x 9 cm specimens analysed to date. Results can be saved on hard disk. A separate folder is created for each new selected area name, and all the tabulated data plus preset parameter data are saved as a set of arrays (Igor "waves") in there. Re-using the same selected area name will over-write older data. The results folder for each selected area name includes binary files for each image: grayscale, b/w, cleaned b/w and cleaned b/w with small "invalid" checks coloured grey. Each step of processing can be undone, and the previous image reloaded.

3. Results and Discussion

Application of the system to measure checking in treated wood specimens

The software described above has been used to assess checking in a suite of southern yellow pine specimens (30 x 9 cm) treated with commercially available wood preservatives (H3 level) and subjected to 1 year's natural weathering. Initially, in order to assess the accuracy of the software, a set of checks recorded by the program were re-located on the original specimen with the aid of the scanned image and the recorded coordinates, and were manually measured using a ruler and feeler gauge. Results for an ACQ treated specimen, a small area of which is shown in Fig.1, are given in Tables 1 and 2.

The correlation coefficient between the manual and automated check data are very close to 1 (Table 2), indicating that the automated and manual measurements correspond closely. Some of the closeness of fit is due to errors that counteract one another. The program has tendencies to truncate the ends of checks slightly, but also to merge some checks that are separated by narrow bridges. These errors nearly compensate to give a slope for the length regression that is slightly below 1, but with a 4 mm positive offset. For the width measurements, there is negligible offset, implying that the program estimates beginning and end of checks across the width correctly, without systematic addition or subtraction of columns of pixels at the edges. However, the slope of the regression line is significantly less than 1. This is because the manually measured widths were made at the visually widest part of the check, whereas the program calculates widths by dividing the measured area and length, assuming a rectangular shape. Use of an elliptical shape function would increase all program widths by 27.3%, and give a slope of 1.105. The best fit to the manually measured widths would use a shape function intermediate between rectangular and elliptical. For comparison of automated measurements with automated measurements, this adjustment is not necessary.

It would be desirable to have a simple, single parameter that estimated the surface quality of weathered specimens. This would presumably be related to the total check area. Preliminary indications are that there is in fact a trade-off between the total check area and the size of the largest check. If the first check in order of area is large, then there is a faster fall-off in size of other checks, and the total check area tends to be smaller. Presumably this effect is related to the large amount of stress relief afforded by a single large check. A parameter that is approximately constant for a given treatment and species is a linear combination of first check area and total check area. Both should probably be expressed as proportions of the total specimen area. The usefulness of the combined areas as a quality parameter can be seen from Fig. 6 in which data are plotted for southern yellow pine specimens (full-sized, 30 x 15 cm, and half-length 15 x 15 cm) treated to H3 level with a variety of wood preservatives and exposed outdoors in Canberra, Australia for 1 year.

The untreated specimens lie almost on a straight line connecting 12% total check area with 2.5% largest single check area. The linear trend is not so marked for the other treatments, but data points for each treatment lie in distinctive domains on the plot, between the origin and the "untreated" points. The majority of specimens treated with hydrophobic preservatives (CCA-wax, ACQ-wax and an experimental clear treatment) are in turn closer to the origin (indicating less total checking and a smaller first check) than those treated with CCA or ACQ. Specimens treated with ACQ-wax tended to have a smaller total check area than those treated with CCA-wax, but there was little difference between the two preservatives in terms of area of largest check.

Advantages and limitations of the developed software for quantifying checking in preservative treated wood

The most obvious advantage of our automated method of measuring checking in preservative treated wood is that it is far less tedious than measuring checks manually. Furthermore it is able to quantify the sizes of small checks that are usually ignored during manual assessment of checking. Preliminary results suggest that there is a good correlation between the sizes of checks measured manually and those quantified by the software program. In addition assessment of the ability of a range of preservatives to prevent checking produced results that correlate well with field data. The program is easy to use and requires inexpensive and readily available hardware and software.

The main constraints on the utility of the program at present are hardware limitations. Processing of images significantly larger than those examined here would require an extremely large amount of on-board RAM. For example, in the case of a very large wood specimen measuring 3 metres × 15 cm, which would produce 250 Mb images, 800 Mb of RAM would be required to process the image. It should be noted, however, that G4 iMac computers with this capacity are already available. Large images also require long processing times. In this study standard sized boards measuring 30 x 9 cm could be processed in 23 minutes but a large board (3 metres × 15 cm) would require 14 hours of processor time on a 333 MHz iMac. This still compares favorably with the time that would be required to measure such a board to the same level of completeness and accuracy by hand. In any case, processor clock speed of computers has increased by an order of magnitude in the last 10 years and should continue to do so. Small specimens can be analysed in minutes now. Real-time analysis of large batches of specimens that did not require a portable computer could be done using a parallel mini-supercomputer, since the array operations involved in image processing are ideally suited to being massively speeded up by a parallel computer architecture. The algorithm used at present has been written to operate as fast as possible. It therefore assumes that checks are nearly vertical in orientation. If it is necessary to identify and measure checks reliably in all orientations, including horizontal and strongly curved ones, then a more thorough algorithm is required. This would be likely to operate 4-10 times slower than the current one on a given machine, but the rate of improvement in computer hardware performance suggests that such an upgraded algorithm would run fast enough to be useful in a few years time.

4. Conclusions

The software package developed here was capable of recognizing and quantifying the dimensions and numbers of surface checks in scanned (gray-scale 600 dpi TIFF) images of preservative treated southern pine wood specimens. Checks could be differentiated from other features on wood surfaces such as bands of latewood and resin canals that superficially resemble checks. There was a close correlation between the dimensions of checks measured manually and those obtained using the system developed here. The system was able to rank a range of different preservative treatments in terms of their ability to reduce the checking of southern yellow pine specimens. In this regard a linear combination of the check area of the largest individual check and total check area expressed as a proportion of the total specimen area was useful in separating different treatments. The current system is a research tool suitable for the assessment of small test specimens treated with wood preservatives and water repellent finishes. It is envisaged that the system or higher-performance modifications of it could be practical for industrial quality assessment or control on small portable computers in the field or on larger fixed machines within very few years.

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5. Literature

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Tables

Table 1. A comparison of the manual and automated assessment of check length and width in a weathered ACQ specimen

Check ID#	Length (man.)	Length (auto.)	Width (man.)	Width (auto.)
26	200	196	0.94*	0.75
62	130	126	0.615	0.62
15	98	114	0.54	0.48
35	94	90	0.775	0.73
3	73	75	0.64	0.50
55	72	70	0.615	0.59
8	71	67	0.94*	0.79
114	56	45	0.94*	0.83
20	46	43	0.54	0.44
71	42	66	0.415	0.38
23	23	21	0.39	0.30
24	20	17	0.415	0.27
12	19	12	0.315	0.27
54	13	8	0.315	0.33
14	9.5	5.5	0.24	0.18

* Wider than 0.88 mm gauge but less than 1 mm

Table 2. Regression analysis of manually and automated check data

Regression parameter	Length	Width
Linear regression offset	4.04	-0.002
Linear regression slope	0.956	0.868
Correlation coefficient	0.985	0.970

Figure 1. Selected area from a weathered ACQ treated southern yellow pine specimen

Figure 2. Brightness profile along a line across Figure 1

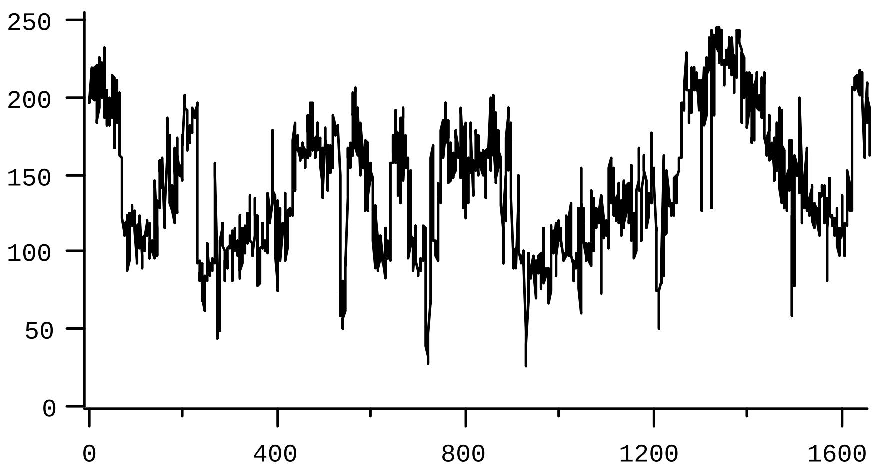

Figure 3. Enlarged area of the brightness profile shown in Figure 2

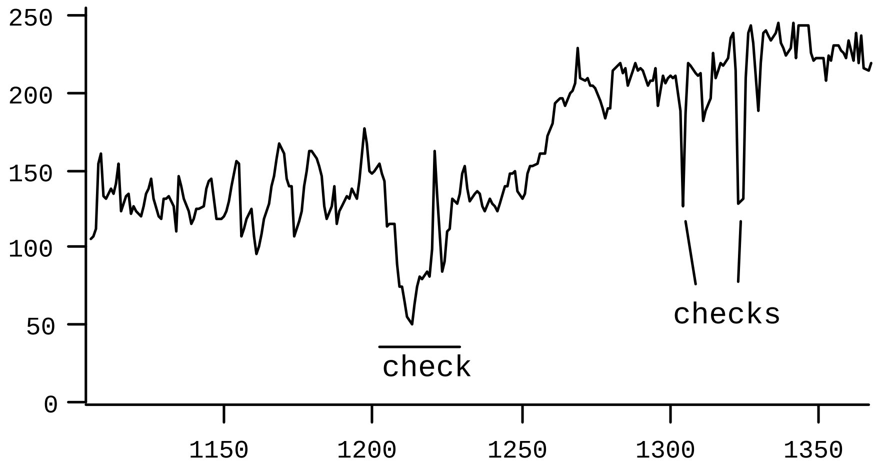

Figure 4. B/w (binarized) image from Fig. 1 showing some noise and incomplete capture of checks. Note insensitivity to surface dents and no capture of tongues of dark latewood

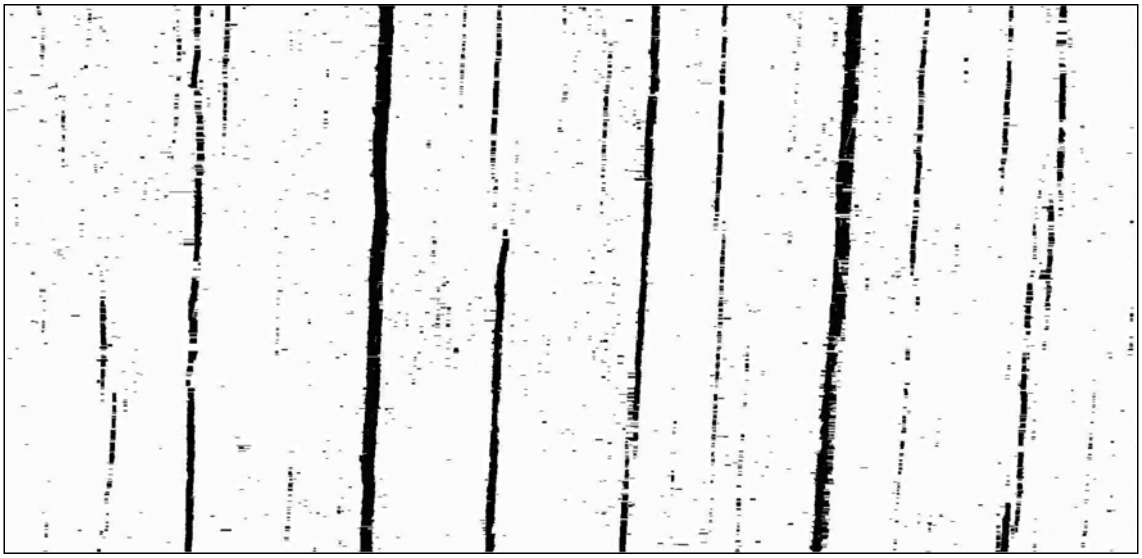

Figure 5. Cleaned image showing restored checks

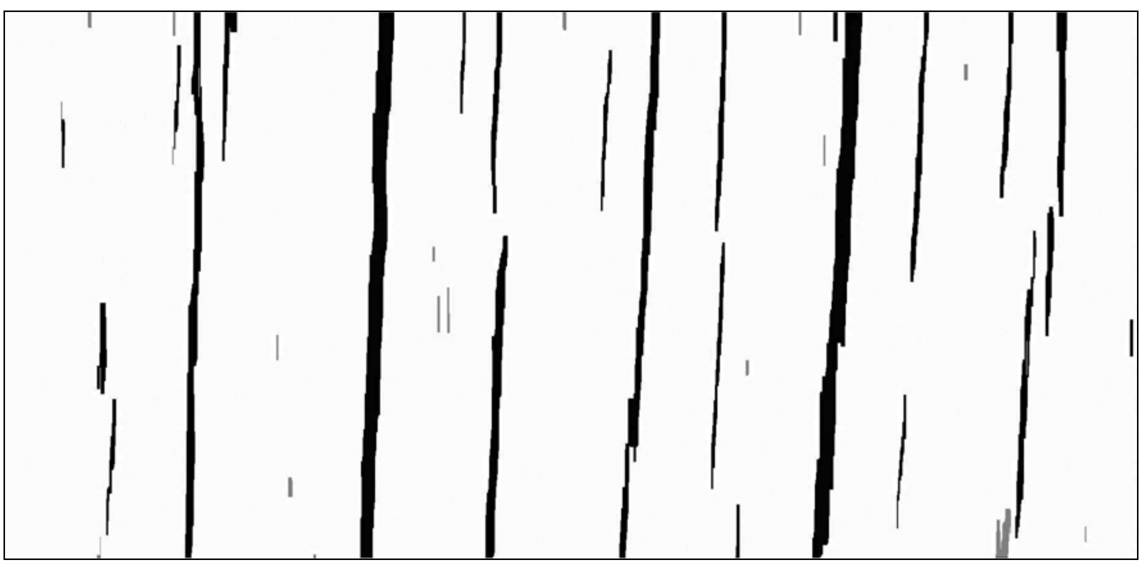

Figure 6. Total check area and area of largest check for southern yellow pine specimens treated with different wood preservatives and exposed outdoors for 1 year