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METHODOLOGY FOR ACCELERATING THE SURFACE CHECKING OF WOOD

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Summary

There is significant interest in developing preservatives that are better at preventing wood from checking. Currently, however, there is no accepted test methodology for accelerating the development of checks in wood samples so information on the effectiveness of treatments at restricting checking can be obtained more quickly. This paper describes the development of a new type of weatherometer (Accelerated Check Tester) and associated weathering cycles to accelerate the surface checking of wood. The device permits the testing of realistic-sized decking board samples that are oriented horizontally and restrained by fixings. It uses computer-controlled water spray and infra-red heating systems to expose samples over a 5 day period to wetting and drying cycles. Desiccated air is also blown across the surface of samples to further increase the effectiveness of the drying cycle. The Accelerated Check Tester operated continuously and trouble-free for 24 weeks during an experiment, which examined the effect of different weathering cycles on the checking of southern pine and western red cedar decking samples. Samples exposed in the Accelerated Check Tester developed large numbers of checks, some of which were quite big, particularly those in southern pine samples. Weathering cycles that increased the severity of drying by increasing drying time or temperature did not significantly increase checking. Similarly, the inclusion of a freezing step in the weathering cycle had little effect on checking. In contrast, samples subjected to a cycle that included exposure to ultraviolet light developed significantly more and larger checks than samples subjected to any of the other cycles. Checking was much more pronounced in southern pine samples than in western red cedar samples. The Accelerated Check Tester should be a very useful tool for obtaining information on factors that affect the checking of wood. Furthermore, it could also allow companies developing wood preservatives and associated water repellent additives to rapidly obtain information on the ability of treatments to restrict checking and so shorten the development time for new wood protection systems.

1. Introduction

The decking market is very important for companies manufacturing treated timber, and in North America alone this market exceeds 3-5 billion US dollars per year (Shook and Eastin 2001; Freedonia 2005). Such timber is used to build increasingly sophisticated decks that extend household living space into gardens. Consumers expect decks to look nice and maintain their appearance over time, but such expectations are difficult to meet because most wood preservatives do not prevent treated wood exposed outdoors from checking (Mackay 1973, Fowlie et al. 1990). To overcome this problem, there has been significant interest in developing preservatives that are better at preventing wood from checking (Jin et al. 1992, Connell et al. 1993, Cui and Zahora 2000, Christy et al. 2005). Currently, however, there is no accepted test methodology for assessing the checking of treated timber or accelerating the development of checks so information on the effectiveness of treatments at restricting checking can be obtained more quickly. To address these deficiencies we developed software for rapidly assessing the checking of treated timber (Christy et al. 2005), and embarked on research to develop ways of accelerating the surface checking of wood.

Methods for accelerating the weathering of materials rely on the use of devices (weatherometers) that expose the material to the factors that cause surface weathering such as solar radiation, water and heat (Arnold et al. 1991, Suits and Hsuan 2003). Weatherometers have been widely used to evaluate the ability of chemical treatments to restrict the weathering of wood (Feist 1977, Rowell et al. 1981, Feist and Williams 1991), but they cannot easily accommodate large dimension samples such as decking boards, and they do not permit horizontal orientation of samples. Furthermore, most of the weathering cycles that have been developed for weatherometers seek to maximize the surface degradation of materials rather than generate anisotropic distribution of stress in samples that causes the checking of wood. Consequently, a different approach is needed to accelerate surface checking of wood.

During previous research we observed that checking of treated wood was particularly severe at a test site in Canberra, Australia, where samples were exposed to frequent diurnal wetting and drying, high levels of solar radiation throughout the year, freezing temperatures in winter, and very high temperatures and low relative humidity in summer (Evans et al. 1997, 2000, 2003). In this environment, treated wood sometimes failed due to the development of large checks rather than as a result of biological deterioration. These observations provided a starting point for the development of a new type of weatherometer (Accelerated Check Tester, ACT) and associated weathering cycles designed to specifically accelerate the surface checking of wood. This paper describes the development of this weatherometer and an experiment which determined which elements of the weathering cycle were critical to accelerating the development of surface checks in decking samples.

2. Materials and Methods

2.1 Development of Accelerated Check Tester (ACT)

The initial design specifications for the Accelerated Check Tester called for a machine that would expose realistic-sized decking samples to wetting and drying cycles. Within this basic specification there were a number of other important requirements. Test samples were to be placed horizontally within the machine with their upper surfaces exposed to wetting and drying and their lower surfaces protected from drying. Such exposure would generate moisture gradients between the upper and lower parts of the decking samples leading to anisotropic stresses and strains that cause checking. Stresses that develop when wood is exposed to wetting and drying can be released by surface checking or warping. The latter is prevented from occurring to some extent in practice by fixings. There is some evidence that checking of decking samples is more severe when they are under restraint than when they are free to distort (Urban and Evans 2005). Therefore, we chose to restrain samples placed in the Accelerated Check Tester by screwing them to wooden supports. We also wanted to automate and place under control the different elements of the weathering cycle to make testing easier. The current version of the Accelerated Check Tester automates all aspects of the weathering cycle, except for exposure to UV light, and consists of three sections (Fig. 1); (1), Upper unit containing infra-red lamps; (2), Weathering chamber that houses the two wooden decking samples and spraying system; (3) Lower unit containing two linear actuators and the water supply system.

Figure 1: Accelerated Check Tester showing the three sections of the device and control system (right)

The upper part of the Accelerated Check Tester was originally part of an infra-red curing device for wood coatings. This part of the machine contains two 400 mm long quartz halogen infrared lamps arranged in parallel (USHIO America, Inc.; 220V/1850W) and also contains a digital temperature controller (Omron, E5CN) to set the time limits and range of operating temperatures for the drying (heating) cycles. The walls of the weathering chamber are made from 1 mm thick aluminum plate. The bottom of the chamber is made from 6 mm thick aluminum plate, and contains two openings measuring 155 x 472 mm to accommodate wooden decking samples (130 x 400 x 35 mm) and test boxes (see below). Small circulation fans (Xinruilian, RDM 8025S, 12V/0,11A (2x)) are attached to two subtended sides of the box, and blow air across the samples. These fans are connected by ribbed rubber tubes (internal diameter of 75 mm), each of which contains a polystyrene dish filled with approximately 60 g of silica-gel (W.A. Hammond Drierite Company LTD., ‘Drierite’, mesh size 8) to dry the air that is blown across the samples. Each tube also contains a baffle that can be used to control the flow of air across samples. Each decking sample sits in a box, measuring 155 x 420 mm, and made from 6 mm thick clear Perspex. Immediately above each of these boxes there is a stainless steel tray that collects overspray from the water spray system and diverts it to the bottom of the box. The boxes also contain two hardwood supports measuring 25 x 25 x 120 mm. The decking board samples are fixed to these supports using four brown, epoxy coated, self-cutting KIWIKI premium extra decking screws, 4.83 x 88.9 mm in size. The lower part of the weathering device supports the chamber and contains the automated water spray system. This system consists of two linear actuators (Techno-Isel ELS 2) connected to size-23 stepper motors (MS23C), placed parallel to the base of the chamber. Two water filters (Pentek series) with a network of hoses are positioned underneath the chamber and linked to solenoid valves (AZCAZ 8238 series). This system is connected to the actuator and then on to the sprayers. Each actuator is linked to a hook-shaped aluminium tube (Ø10 mm) which is connected to a fine spray nozzle (John Brooks Nozzle QVVA-SS). A micro-stepping motor driver (MD2S-P-R) stimulates the stepper motor and drives the actuator along its axis maintaining a constant speed when the nozzles spray the surface of samples with water. The water spray system and infra-red heating lamps are controlled using a Programmable Logic Controller (PLC) linked to a PC containing a TRiLOGI program (Fig. 1, right). The code for the program was designed to run on a T100MD+PLC (Triangle Research International, Inc). This system is able to control the drying cycle (temperature) and wetting cycle (volume of water applied to samples), and the timing and duration of these cycles. A separate UV curing machine (CC12 Conveyorized Curing System) is used to expose samples to ultraviolet radiation. A large flatbed scanner is used to obtain TIFF images of decking board samples. Quantification of checking can be done manually using wood samples or using the TIFF images and automated software, which we described previously (Christy et al. 2005).

2.2 Evaluation of Weathering Cycles

A factorial experiment was performed to examine the effect of different weathering cycles and wood species (southern pine v western red cedar) on checking of board samples. Each of the weathering cycles that was tested employed different combinations of heating temperature, duration of the drying stage, freezing and exposure to UV light (Table 1).

2.2.1 Experimental design

Four different boards for each species (8 boards in total) provided replication at the higher level within the experiment. One southern pine (*Pinus* sp.) board and one western red cedar (*Thuja plicata* D. Don) board were selected at random for the first replicate or experimental block. Each board was cut into six samples which were numbered sequentially from 1 to 6. Those samples were randomly allocated to one of six different weathering cycles. A pair of samples (one pine and one cedar) was randomly allocated to the two sample position within the Accelerated Check Tester and subjected to accelerated weathering. After these samples were weathered, samples from the second board were prepared and weathered. This process was repeated for boards 3 and board 4. The experiment involved four groups (blocks) of southern pine and western red cedar boards. Within these groups the individual boards represent the first experimental factor of interest namely species. Samples cut from these boards were allocated to the second experimental factor, weathering cycle. The resulting hierarchical (split-plot design) accounted for random variation between and within boards and that occurring as a result of the sequential nature of the experiment over 24 weeks. Analysis of variance (ANOVA) was performed to assess the effects of the experimental factors (wood species and weathering cycle) and random effects on checking of board samples. Statistical computation was performed using Genstat 5 (Lawes Agricultural Trust 1994, release v. 4.21). Before the final analysis, diagnostic checks were performed to see if data conformed to the assumptions of ANOVA, i.e., normality with constant variance. Results are presented graphically and a least significant difference bar on each graph can be used to estimate the significance of differences between individual means.

2.2.2 Preparation of decking samples

Four southern pine (*Pinus sp.*) decking boards measuring 2400 mm x 140 mm x 40 mm were obtained from CSI (now Viance) in North Carolina, USA. Four western red cedar decking boards measuring 3000 mm x 140 mm x 40 mm were purchased from Home Depot store in Richmond, Vancouver, Canada. All boards were flat sawn. Boards were stored in a constant climate room at 20 ± 1 °C and 65 ± 5 % relative humidity for 3 weeks and planed on all four sides using an edge planer (Martin T54) and a thickness planer (Martin T44). They were then crosscut using an Omga RN 600 radial arm saw. Twenty four decking samples for each species with a final size of 135 x 35 x 400 mm were produced. Each sample had a 3.175 mm diameter hole drilled in each corner, positioned 25 mm from its side and 40 mm from its ends. The specimens were then stored in a constant climate room (20^{o}C, 65% r.h.) for one week prior to accelerated weathering

2.2.3 Accelerated weathering cycles

Six different weathering cycles were tested. Each one involved different combinations of weathering factors. The first cycle acted as a standard. Cycles 2, 3 and 4 increased the severity of drying by either extending the drying time (cycle 2) or increasing drying temperature (cycle 3) or increasing both drying time and temperature (cycle 4). Cycles 5 and 6 were the same as cycle 1, but they omitted the freezing step (cycle 5) or exposed samples to UV light (cycle 6).

Table 1: Combinations of weathering factors used in the different weathering cycles

Cycle	Drying time	Wetting time	Drying temp. ^{o}C	Soaking	Freezing	UV
1	30 min	12 sec	73	yes	yes	no
2	60 min	12 sec	73	yes	yes	no
3	30 min	12 sec	80	yes	yes	no
4	60 min	12 sec	80	yes	yes	no
5	30 min	12 sec	73	yes	no	no
6	30 min	12 sec	73	yes	yes	yes

All the weathering cycles commenced by floating decking samples for 8 hours on distilled water at room temperature (20°C). Each sample was then weighed, placed in a Perspex box and fastened to wooden supports within each box using decking screws, as described above. These boxes containing the samples were reweighed, wrapped in plastic bags and put in a freezer at -20°C for 16 hours. Boards subjected to Cycle 5, which did not involve freezing, were simply put in a conditioning room for 16 hours. Perspex boxes were then reweighed and placed in the Accelerated Check Tester. They were then subjected to wetting and drying cycles. The surfaces of samples were sprayed with 12 g of filtered tap water every 30 or 60 minutes (Table 1). Heat generated by the device’s infrared lamps, and desiccated air blown across the samples was used to dry the surface of specimens in between wetting. After six hours of alternating wetting and drying, the Perspex boxes were taken out of the Accelerated Check Tester and weighed. Decking samples were removed from boxes and re-weighed. The moisture content of the unexposed, lower surface of decking board samples were measured using an electrical moisture meter (RDM[3], Delmhorst Instrument Co) to determine whether it was near the fiber saturation point. Then the upper exposed surfaces of the samples were scanned using a large flatbed scanner (Microteck ScanMaker i800). Digital images of samples showing surface checks were saved as tagged image format files (TIFF) within the software Adobe Photoshop (version CS, 8.0). Following scanning, boards subjected to Cycle 6 were exposed to UV light in a UV curing machine, as described above. All boards, irrespective of cycle type, were then freely floated on fresh, distilled water for 1.5 hours to recreate a moisture gradient between the upper and lower board surfaces. At the end of the soaking cycle the moisture content of the lower side of the boards was measured, the samples weighed, wrapped in plastic bags and put into the freezer or conditioning room for 16 h. On the last day of the cycle, samples were subjected to six hours of wetting and drying followed by scanning of the checked surfaces. Visible checks on the surface of samples were counted and their length and width were manually measured using a transparent Perspex ruler and an optical magnifying glass containing a calibrated graticule, respectively.

3. Results and Discussion

The Accelerated Check Tester operated continuously and trouble-free for 24 weeks during the experiment that examined the effect of cycle type on the checking of southern pine and western red cedar decking samples. An additional experiment is currently in progress to examine the degree to which the device accelerates checking compared to natural exposure. Preliminary results from this experiment suggest that the degree of acceleration is significant (20 to 30 fold). Furthermore, and most importantly, the checking in samples in the Accelerated Check Tester closely resembles that in samples exposed to natural weathering. All of the southern pine and western red cedar samples subjected to accelerated weathering here developed large numbers of checks, some of which were quite large, particularly in the southern pine samples.

There were significant effects of cycle type on the number ($p=0.020$) and total length ($p=0.005$) of checks that developed when samples were subjected to accelerated weathering. The effect of cycle type on total width of checks approached statistical significance ($p=0.067$). There were highly significant effects ($p<0.001$) of wood species on all check parameters, but no significant ($p>0.05$) cycle x species interactions. Figures 2 to 4 show the effects of the different cycles on check numbers, length and width, respectively. These results clearly show that boards subjected to cycle 6 checked more than boards exposed to the other cycles. Accordingly, the numbers of checks in samples subjected to cycle 6 were significantly ($p<0.05$) higher than those in samples subjected to the other cycles.

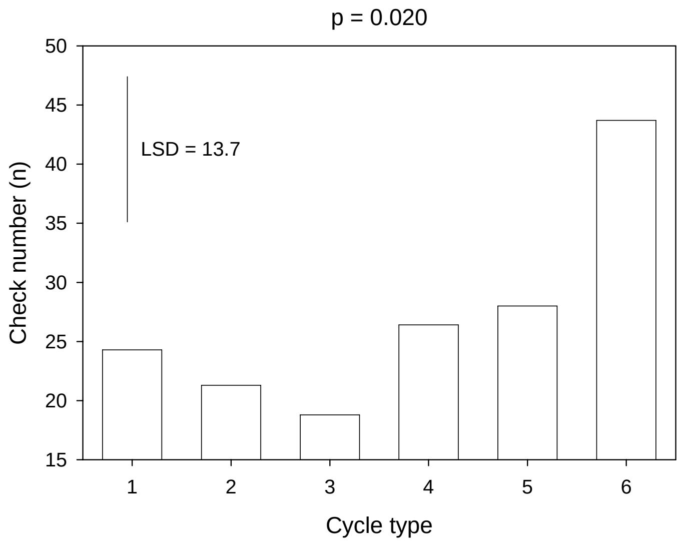

Figure 2: The effect of cycle type on the total number of checks in samples (averaged across species)

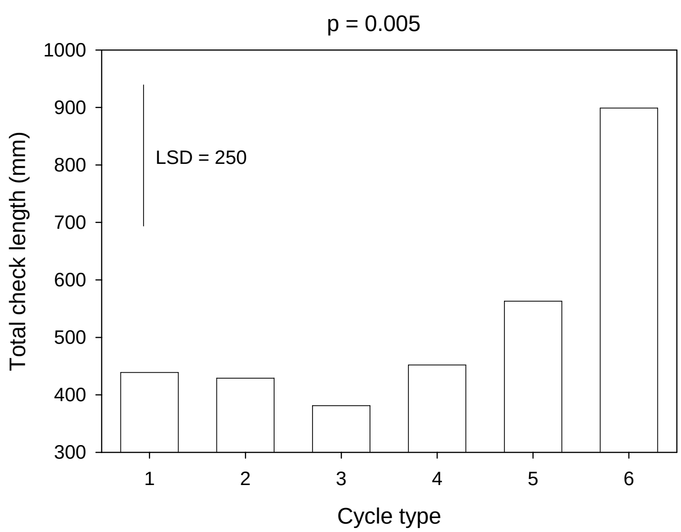

Figure 3: The effect of cycle type on total check length (averaged across species)

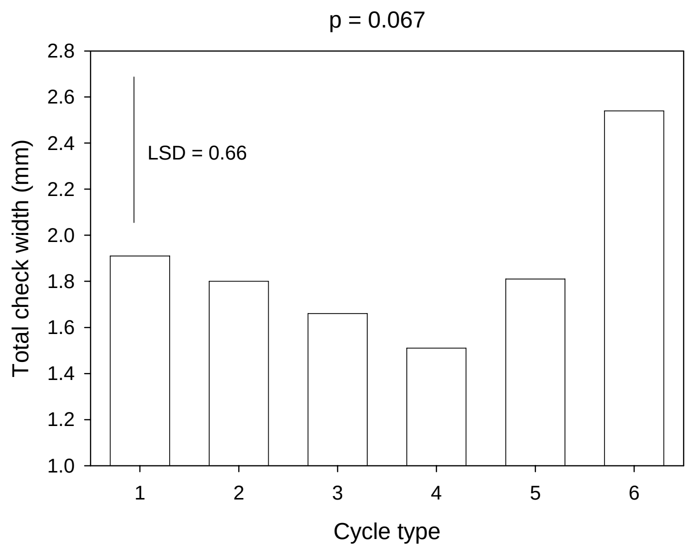

Figure 4: The effect of cycle type on total check width (averaged across species)

The total length and width of checks that formed at the surface of samples subjected to cycle 6 were also significantly ($p<0.05$) greater than those of checks in samples subjected to the other cycles. For example, the total length of checks in samples subjected to cycle 6 was almost double that of samples subjected to the other cycles. Cycle 6 was the only cycle that included UV exposure. UV radiation rapidly degrades the chemical components of wood, particularly lignin, (Kringstad and Lin 1970), and it was shown recently that exposure to ultraviolet light increases the tendency of wood to check when it is exposed outdoors (Evans et al. 2008). Results here accord with this observation and suggest that weathering devices designed to accelerate the surface checking of wood should certainly include lamps capable of exposing wood samples to UV radiation.

There were no significant differences ($p>0.05$) in the total numbers, length or width of checks in samples subjected to cycles 1, 2, 3, 4, and 5 (Figs 2-4). For example, the total numbers of checks that developed in samples subjected to cycle 1, which involved application of water spray at 30 minutes intervals and drying at 73 ºC was 24.3. The numbers of checks that developed when the drying interval was extended to 60 minutes (cycle 2) was 21.3. Furthermore, there was no significant increase in check numbers or their sizes when the drying temperature was increased to 80 ºC (cycles 3 and 4). These results indicate that the severity of the drying cycle did not significantly affect checking of wood samples.

A previous study of check formation in aspen (*Populus tremula* L.) and Norway spruce (*Picea abies* (L.) Karst.) used a weathering cycle based on a Norwegian Standard that included a freezing stage (Norwegian Standard 1985, Flæte et al. 2000). Our findings suggest that such a freezing stage may not be necessary. For example, cycles 1 and 5 were identical except the latter lacked a freezing stage, but there were no significant differences in check numbers or their sizes in samples subjected to these two cycles.

The total number of checks and their sizes were significantly ($p<0.05$) greater in southern pine samples than in western red cedar samples (Figures 5-7). For example, the length of the longest check in southern pine samples was four times larger than that of the longest check in western red cedar samples. Generally, checks in southern pine samples first developed at the centre of boards. These checks became visible on day 2 of the cycle and then became wider and longer with time during the weathering cycle. The check in the centre of boards was usually the largest check at the end of the cycle. Checks also developed in other areas of southern pine samples and became more prominent over the 5 day cycle. This pattern of checking in southern pine was not observed in Western red cedar samples, where the first visible check developed in different areas of the boards.

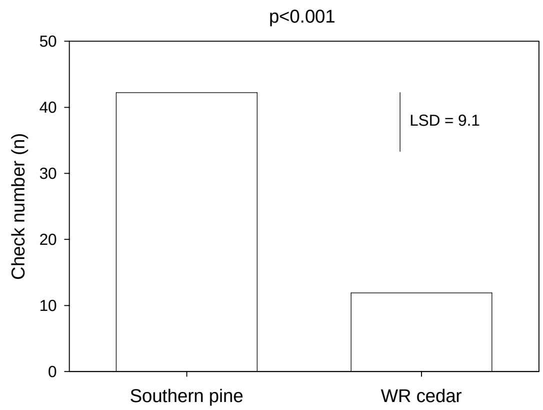

Figure 5: The effect of wood species on check number (averaged across cycle type)

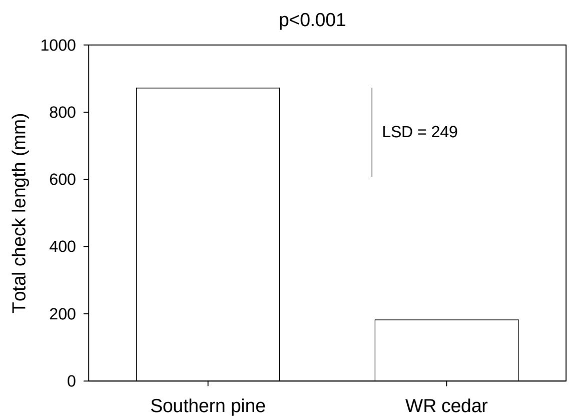

Figure 6: The effect of wood species on total check length (averaged across cycle type)

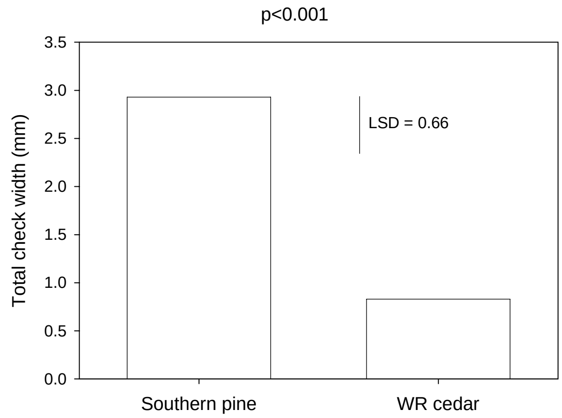

Figure 7: The effect of wood species on total check width (averaged across cycle type)

Clearly, Western red cedar is much less susceptible to checking than southern pine and this may account, in part, for its success in the decking market in western North America, even though western red cedar decking boards cost twice as much as treated pine boards. The difference in checking of these two species may be related to the lower overall shrinkage and higher dimensional stability of western red cedar compared to the southern pine. There have been very few studies of the susceptibility of different wood species to check when they are exposed outdoors. Flæte et al. (2000) commented on differences in the pattern of checking in aspen and Norway spruce, and Sandberg and Söderström (2006) examined the effect of growth ring orientation (radial v tangential) on the checking of Scots pine (*Pinus sylvestris* L.) and Norway spruce boards exposed outdoors. Yata (2001) examined the number and total length of checking in flat sawn hinoki (*Chamaecyparis obtusa* (Sieb. And Zucc.), sugi (*Cryptomeria japonica* (L.f.) Don), western hemlock (*Tsuga heterophylla* (Raf.) Sag.) and redwood (*Sequoia sempervirens* (D. Don) End.) exposed outdoors. Yata (2001) also examined the effect of growth ring orientation on the checking of western red cedar. Additional information on the factors that influence the surface checking of wood, however, would help the development wooden decking products that check less, and, hence, can compete more effectively with wood-plastic composites. The Accelerated Check tester that we have developed is a very useful tool for obtaining such information. It should also allow companies developing wood preservatives and associated water repellent additives to more rapidly obtain information on the ability of treatments to restrict checking and so shorten the development time for new wood preservatives. Further development of the machine and associated test cycle, however, are needed, based on findings here. Clearly, there is no need to include a freezing step in the test cycle, but it would be very desirable to incorporate UV lamps within the body of the machine to allow samples to be exposed to UV radiation in situ, rather than relying on an external device to irradiate specimens. A further limitation of the current device is that it can only test two samples at a time. Further work is in progress to rectify these deficiencies and develop a more advanced version of the Accelerated Check Tester that can be used to increase our understanding of the checking of wood, and help develop more effective preservative treatments for wood used outdoors.

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