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Sawmilling

Issue No. 41 January 2008

DO STABILITY GROOVES IN WEATHERBOARDS REDUCE CUPPING IN SERVICE??

John Turner, Bernard Dawson, Damien Sellier, Mark Kimberley, and Jonathan Harrington

Readers may recall an article in a previous Wood Processing Newsletter (No. 37 December 2005) concerning rusticated weatherboards and problems encountered when they were wetted by severe weather conditions before a topcoat could be applied. The article discussed issues around the primer and the dimension and alignment of the weather groove in the profile. While investigating this issue, questions arose about the effectiveness of another groove required in rusticated and vertical shiplap weatherboards (as specified in the NZ standard profile: NZS 3617:1979), namely the stability or warp groove.

New Zealand first developed standard profiles for weatherboards and flooring in the late 1940s (NZS 495:1948). "*The general adoption of standard profiles will lead to substantial economies in production costs, and correspondingly increased production, by permitting longer, and therefore more economic production runs, due to a reduction in the number of different settings of cutter heads required to produce an unduly diversified range of profiles.*" The profiles did not contain any grooving for protection against either water ingress or warp (cupping). This standard was revised in 1979 to incorporate current fixing and weathering features. Weather grooves and warp grooves appear for the first time in this standard. Unfortunately the background documentation as to why or what evidence was produced to recommend such grooves in this standard has apparently been destroyed (Standards New Zealand pers. comm.).

Typically one or two warp grooves are machined into the unexposed side of the weatherboard and may have dimensions of the order of 5 × 5 mm (Fig. 1).

It appears, therefore, that there are some questions about warp grooves. Why were they introduced? What is their purpose? How do they function? What evidence was their introduction into the New Zealand standard based on? Trying to answer these questions has proved about as fruitless as a dog chasing its own tail. In addition to seeking information from NZ Standards and Building Research Association New Zealand, we contacted wood technologists in other countries to see if they could relate their own national experiences with warp grooves.

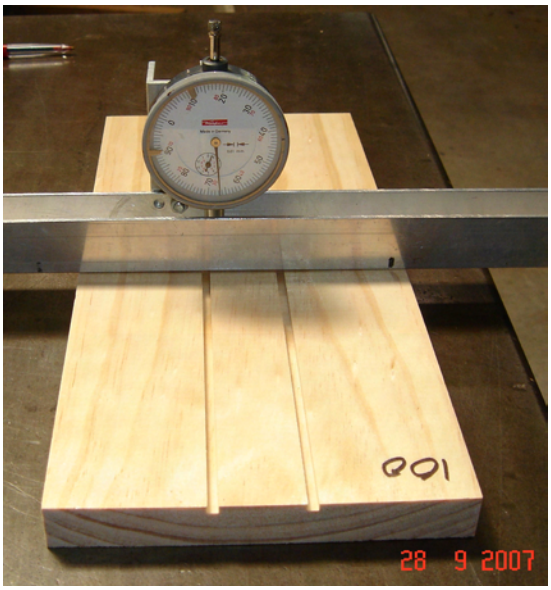

Figure 1. Warp grooves, in pith-side-up board, and cupping measurement set-up

In the UK, TRADA floor specialist Peter Kaczmar had also considered warp groves in flooring and commented: "*The grooves can take the form of a shallow channel approximately 1 mm in depth, ranging from a few millimetres to greater than 1 cm in width. Alternatively, they can be little more than saw cuts a few millimetres in depth, or can take the form of V-profiled slots cut into the back of the board. Most commonly they occur either as channels or slots throughout, but can also occur in combination. The point is that they have been machined into the backs of solid wood flooring components in order to relieve stresses in the wood, although the manner in which they do so does not always stand up to technical scrutiny.*"

In France, according to Frederic Simon (CTBA): "*Grooves are indeed employed at the back of external cladding but to my knowledge they are not regulated by any standards, neither in France nor in Europe. Grooving is primarily considered as 'a good*

practice' by the manufacturers, although more of an automatism than a really justified design.

Talking with colleagues, it seems that [grooving] is recommended here, not in the context of dimensional stability, but for the purpose of decreasing board stiffness so that it increases the ease of implementation and potentially reduces the loads transmitted to the frame. Finally, it also seems that depending on the species and conditions back grooves may induce greater board deformations."

In the USA, Jerry Winandy at the Forest Products Laboratory, Madison, Wisconsin, states: "*Back grooves on building cladding (i.e., siding, weatherboards, etc.) and on horizontal outdoor decking (usually hi-density, decay-resistant, tropical hardwoods) have been occasionally used in US and Canada. However, their use has usually been acknowledged as a proprietary marketing tool. We know of no US/Canadian standards that require back grooves, which probably reflects the consensus technical opinion in North America"* (That they have no technical function).

Having drawn a blank in finding out compelling evidence for or against warp groves in any country, we decided to model the ingress of water into boards and look at cupping as a response to changing moisture gradients in the boards and then test the modelling results by carrying out experiments by wetting samples of real wood boards.

A 2D numerical model based on the Finite Element Method (FEM) was developed to model the dimensional movement of boards in response to moisture gradients as a function of grain and density. Heat and water transfers were modelled with the equations of diffusion for steady-state flow. Results show that grooving has little, if any, influence on board cupping (Fig. 2 and 3). In fact, the grooves may actually slightly increase the cup, as their presence causes a local decrease of the cross-section and consequently the bending stiffness. Results are not definitive in the sense that physics behind the model could be developed more rigorously (transient diffusion, creep) to describe more thoroughly the influence of grooves. However, in its first iteration, the model does not bring evidence for any significant role of grooves on stability, and this is consistent with experimental findings.

In order to confirm these modelling results, we carried out experiments by wetting a selection of grooved and non-grooved boards. Commonly in New Zealand, weatherboards are made from solid and/or fingerjointed, predominantly flat-sawn, lengths of radiata pine. Thus for our wetting trials one experiment used fingerjointed lengths and the other used non-fingerjointed lengths. The design for the trial required division of these lengths into groups representing pith side up/down with grooves/no grooves. Boards were grouped in a random manner and wetted by laying the non-grooved face down on

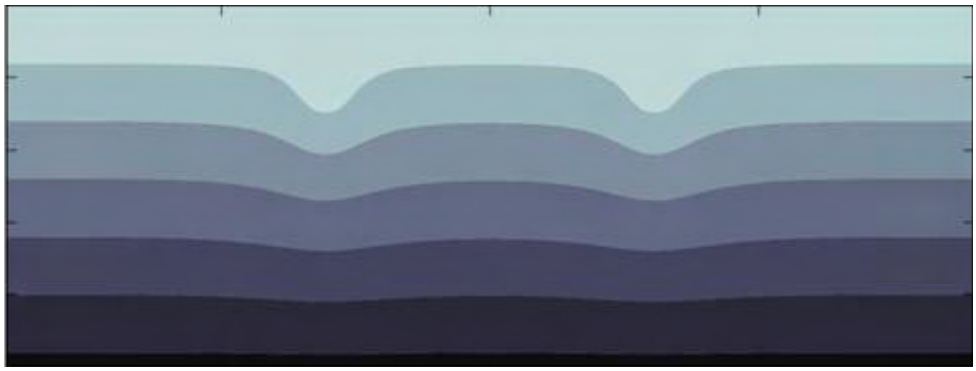

Figure 2. Example of moisture montent gradient calculated within a board with two grooves on the top. The darker the blue, the higher is the MC.

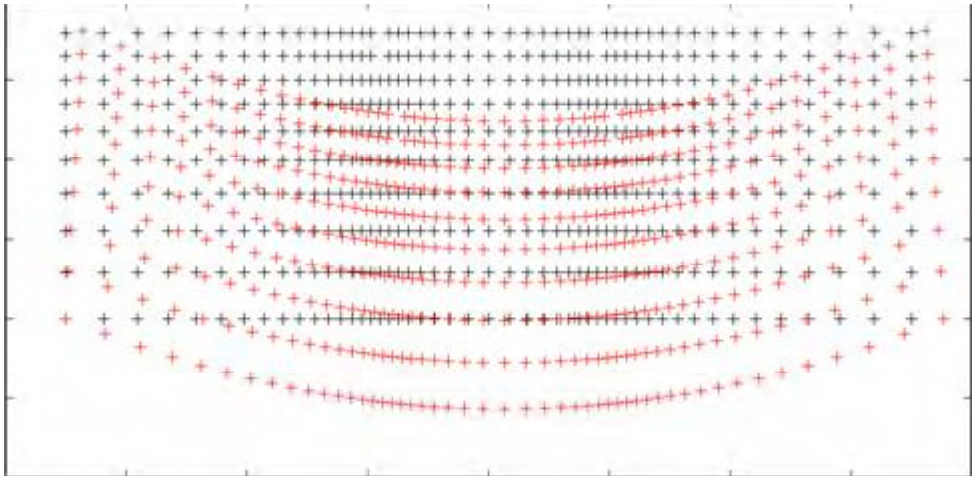

Figure 3. Shape of a board section with two grooves on the top before (in black) and after (in red) wetting of the section bottom.

a water-soaked carpet for one hour (Fig. 4). Moisture content, weight, and cup measurements were recorded before and after wetting on the carpet.

Figure 4. Wetting of boards on soaked carpet.

Statistical analysis of our data confirmed that:

- Cupping was dependent on the amount of water uptake and resulting water gradient between the two faces (note that an extended soaking period relieves cupping as the water gradient reduces between the board faces)
- Cupping was independent of the presence of grooves and the board orientation

From anecdotal responses to questioning about the effectiveness of putting warp grooves in weatherboards, we have established by both modelling and verification with physical testing, that for radiata pine warp grooves do not reduce cupping of boards.

To those of our readers who may remember, or wish to offer an opinion on why warp grooves were recommended for certain of our NZ cladding profiles, the authors would appreciate your comments.

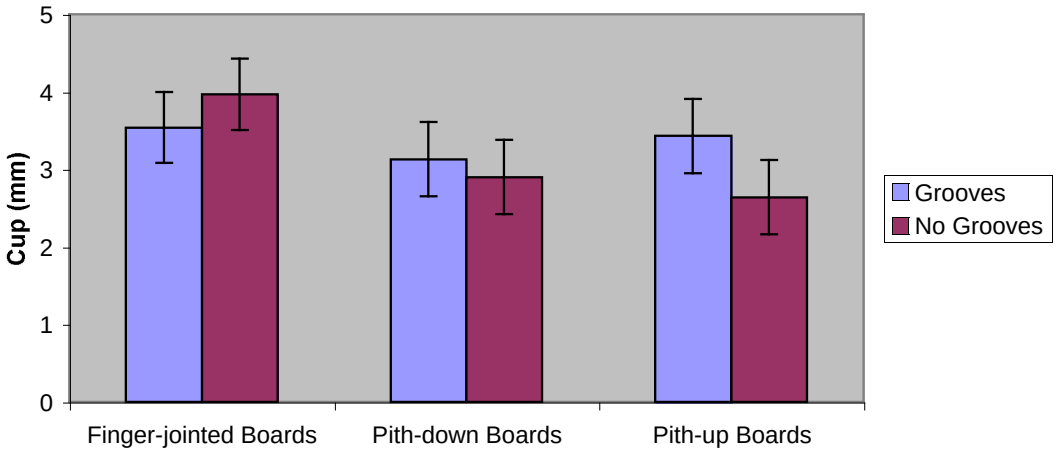

Figure 5. Mean cup (mm) for three types of radiata pine board with and without grooves.Error bars show 95% confidence intervals

ANATOMICAL EXPLANATION FOR GRAIN RAISING IN MACHINED RADIATA BOARDS

Adya Singh, Bernard Dawson, John Turner and Catherine Rickard

Machining of radiata pine wood and problems encountered with the final product due to poor or incorrect knife maintenance have been described in previous Wood Processing Newsletter articles (see No.26, 1999 and No.30, 2001). Recently we had an enquiry from a weatherboard manufacturer about a defect on the painted surfaces of radiata pine weatherboards which appeared as prominent ridges on the surface. The “ridges” were immediately recognisable as the result of raised latewood grain on the flatsawn surface.

Such grain raising is considered a machining defect and is usually caused by running dull knives and or knives with insufficient clearance angle, as occurs with heavy jointing of the knives. Such knives tend to "pound" the wood resulting in compression of the wood surface, particularly the thin earlywood cells under surface latewood bands. Raised grain occurs when compressed earlywood cells recover their shape and volume over time, pushing up latewood tissues overlying them, and the problem can become more severe if the surfaced wood encounters high humidity conditions.

The grain raising phenomenon has not been fully investigated at the anatomical level and therefore an understanding of this problem based on cellular micro-mechanics is lacking. We carried out a detailed microscopic examination of the defect in the painted surfaces of these weatherboards to determine whether the ridges were in fact linked to the condition known as raised grain and to gain a better understanding of the anatomical basis for this defect.

Of the various microscopic methods available — light microscopy (LM), confocal laser scanning microscopy (CLSM), and scanning electron microscopy (SEM) — SEM was the most useful because considerably thicker samples than those suitable for LM and CLSM could be used and this helped to retain the rather stiff, fragile, paint coating intact. Additionally, low magnification viewing with SEM was particularly useful, as sharply defined images from relatively large areas of wood sections could be produced, which was not possible with LM or CLSM.

For SEM work, regions of boards showing imperfections on the painted face as ridged areas (Fig. 1) were dissected out. These pieces were sub-divided into smaller blocks of a dimension suitable

Figure 1. Photograph of raised grain

for obtaining transverse sections. Blocks were briefly soaked (2–5 seconds) in water at one end and then immediately cut transversely into 1- to 2-mm-thick sections using a razor blade. The sections were air-dried, mounted on carbon discs applied to metal stubs, coated with chromium in a vacuum evaporator, and then examined with a field emission scanning electron microscope (FE-SEM) at a low voltage (3 kV) to avoid electron beam related damages that can occur at high voltages.

The SEM micrographs revealed that the raised wood grain occurred where the latewood (summer wood) interfaced with the earlywood (spring wood), corresponding to an abrupt change in wood density (Fig. 2). The raised grain region is where there was most severe compression (crushing) of earlywood cells underlying the tapered part of the latewood band, judging by the presence of large masses of compressed cells (Fig. 2 & 3). The extremity of the taper in the latewood band of this region was only a few cell layers thick, giving the earlywood in this region less physical protection from the compressive forces arising during planing; in other regions the latewood band overlaying the earlywood was thicker.

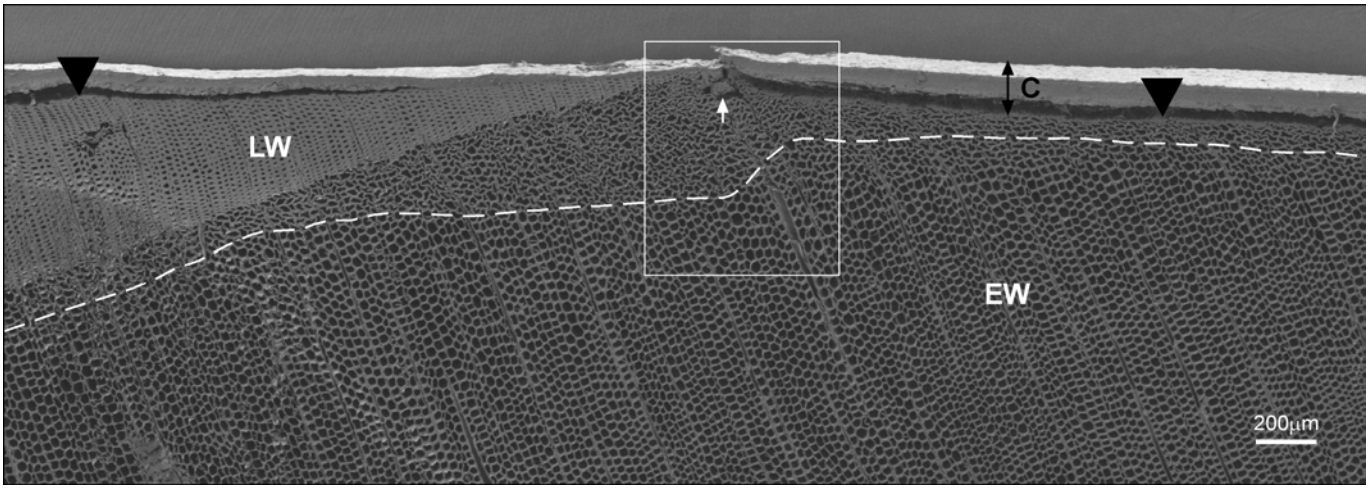

Figure 2. SEM micrograph of a section cut across a ridge. The arrow points to a region where tapered latewood contacts earlywood and the grain is maximally raised. The wood is cracked at this point. The stippled line defines depths to which earlywood is compressed in various regions. The boxed region is shown at higher magnification in Fig. 3. The coating has separated from the wood in places (arrowheads) during sectioning. C coating; EW earlywood; LW latewood. Scale bar = 200 µm.

Figure 3, a higher magnification view of the boxed region in Fig. 2, shows more clearly the morphological features of deformed cells (e.g., cell wall deformation, direction and extent of cell compression). Earlywood cells are deformed from the compressive forces generated during machining and the cell volume is reduced, particularly in the earlywood cells underlying the tapered part of the latewood band, where the depth to which cells are compressed is also greatest. The coating overlying the protrusion is considerably thinner than in other areas and is ruptured at the point of contact between earlywood and latewood regions (Fig. 2, 3, & 4), indicating that the coating of this region is vulnerable to weathering mechanical stresses.

Raised grain is caused by volume recovery, over time, of compressed earlywood cells pushing up the latewood band. The volume recovery is a function of the moisture uptake by the compressed cells. The boards examined had been exposed to exterior atmospheric moisture and this had been sufficient to produce discernible raised grain on the painted surface; the "height" of the raised grain on

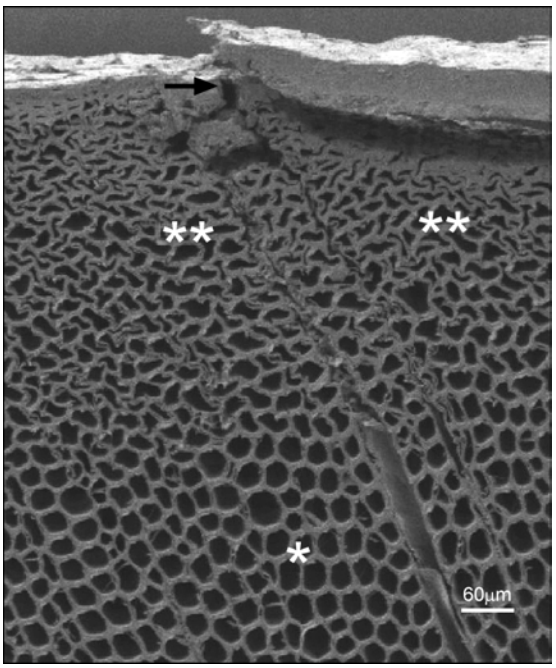

Figure 3. Higher magnification SEM micrograph of the boxed region in Fig. 2 providing a comparison of the appearances of compressed (paired asterisks) and uncompressed (single asterisk) cells. The arrow indicates a region where the paint film and the underlying wood tissues have developed cracks. Scale bar = 60 µm.

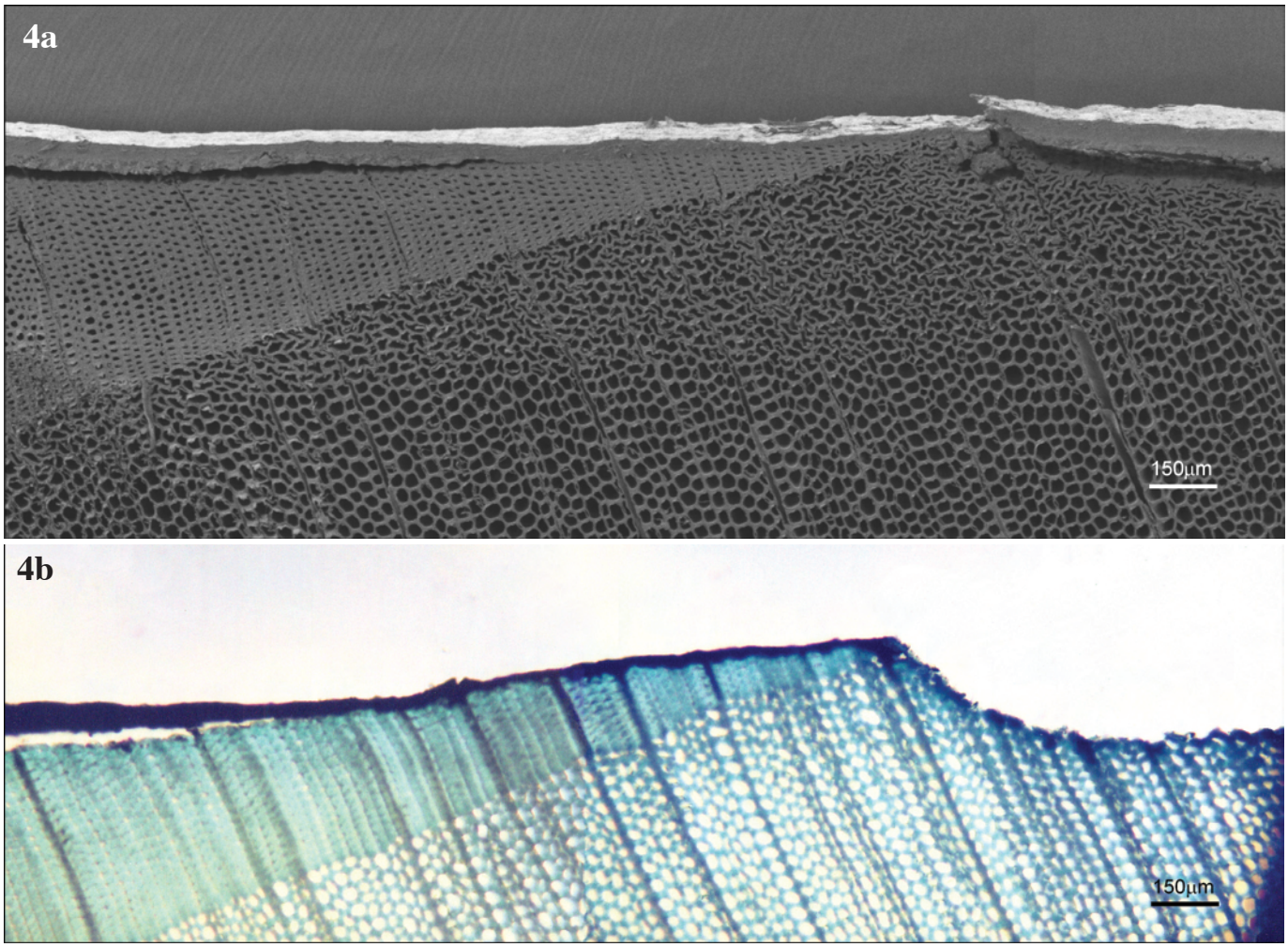

Figure 4. SEM and light micrographs of sections cut across ridges: (a) exposed to atmospheric moisture; (b) water-soaked sample (note coating to the right of raised grain peak has been removed). Scale bar for (a) and)(b) = 150 µm.

the painted surface in this image was measured as 140 μm (Fig. 4a). The peak to trough maximum for a profileometer scan of the paint surface also showed that the deviation in height on a typical raised grain feature was 140 μm (Fig. 5). Raised grain shows more clearly on a light coloured painted surface than on unpainted wood due to the uniformity of the paint surface. When sections had been soaked in water for over an hour prior to LM examination, the corresponding raised grain height was 188 μm and the light micrograph in Fig. 4b shows almost full volume and shape recovery of earlywood cells that had once been compressed during machining (compare with earlywood cells in Fig. 2).

A greater understanding of the phenomenon of raised grain has been gained from microscopy by providing an anatomical visualisation. It has also highlighted the potential effect of raised grain on surface coatings — besides the aesthetically unacceptable surface appearance, the thinning of surface coatings over the raised areas has created an area of vulnerability which is susceptible to mechanically induced paint delamination/failure during weathering processes.

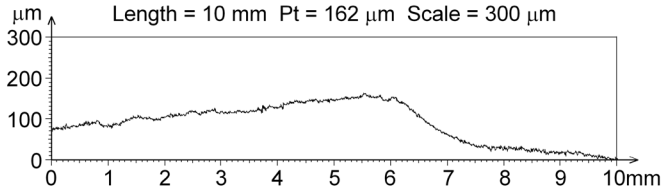

Figure 5. Profileometer scan of surface showed deviation in height of painted surface on a typical raised grain feature

RESIN BLEED FROM RADIATA PINE WEATHERBOARDS

Bernard Dawson and John Turner

In the last Wood Processing Newsletter (No.40, June 2007) we discussed the formation of resin streaks plus some of the issues around resin in radiata pine and the problems associated with resinous timber. This newsletter article, from a collaboration between Scion and the NZ Pine Manufacturers Association, covers the effects of kiln drying temperature on resin bleed using radiant heat to simulate temperature changes of a product in service.

Green wood was selected from the green chains of a number of mills based on two resinous features — namely resinous latewood, and resin streaks. Boards were kiln dried in the Scion research kilns using five temperature schedules:

40ºC (wet bulb/dry bulb: 40/30 and steaming 45/45)

70ºC (70/60 and 75/75)

90ºC (90/60 and 100/100)

120ºC (120/70 and 100/100)

170ºC (170/100 and 100/100).

After kiln-drying, boards were assessed for resin features. One surface was selected and machined to provide a clean surface for radiant heating in order to determine propensity for resin bleed.

An infrared radiant lamp was used to heat the surfaces. An infrared "gun", calibrated against thermometer and thermocouples, was used to measure surface temperature. It was determined that samples hung vertically were better for resin bleed assessment than with heating down on to the top surface because any bleed tended to run down under gravity, providing more visible evidence of bleed. The rate of temperature rise of the board surface on radiant heating and the equilibrium temperature reached were assessed as a function of distance from the heater, and a temperature of around 60–70°C was decided on as providing sufficient heat to accelerate resin bleed from boards.

During these "test" trials it was noted that beads of resin bleeding would occur with in half-an-hour of heating at the selected surface temperature and then only increase slightly with further extended heating (4–8 h). The heater was turned off overnight and on again in the morning and bleeding continued to increase. Over a 6-day period, with 8 hours heating and 16 hours with no heating, the bleed continued to move. This suggested that a cooling down between heating periods appeared to produce a pumping action to push the resin out of the board. Based on this, the heating regime used was heating for 3 hours, cooling for 1 or 2 days with a final heating for another 3 hours.

Six boards from each kiln-drying schedule were chosen for radiant heating. Of the six boards, three were mainly resinous latewood and three mainly resin streaked. In many boards, examples of both features occurred on the same board. Boards were rated for resin bleed during the exposure to radiant heat. Because it was not possible to "match" boards, rating was on the basis of intensity of bleed and not on area of bleed. Intensity was subjectively assessed as light, medium, or heavy by comparison with "calibration boards" (Fig. 1, 2, 3).

When the resin bleed ratings for each board in each kiln-drying temperature group were added together

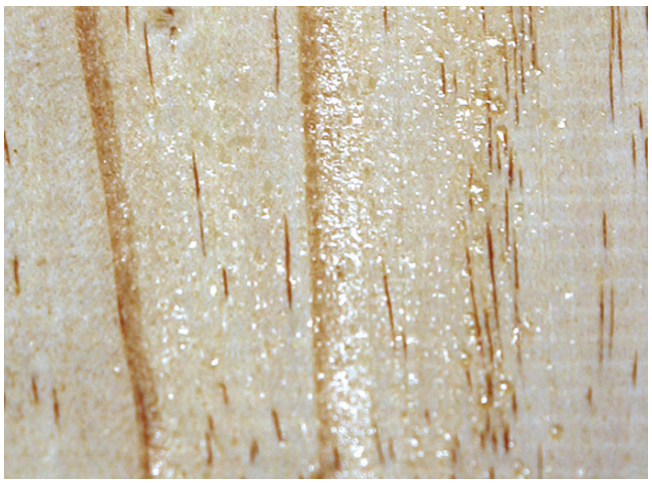

Figure 1. Light resin bleed

Figure 2. Medium resin bleed

Figure 3. Heavy resin bleed

and the aggregate scores were plotted against the kiln-drying temperature, there was a linear relationship showing that resin bleed decreased with kiln-drying temperature (Fig. 4), 69% of the variation in resin bleed being attributable to the kiln-drying temperature. It is clear that at all temperatures, even 170°C, resin bleeding can be significant. As kiln-drying temperature increases, there is a more effective removal of volatile compounds in the resin as well as greater oxidation of remaining resin and this is likely to be the cause of the inverse relationship between kiln-drying temperature and resin bleed. However, it is clear that residual resin in boards is still mobilised by radiant heating at about 65°C. Thus from a practical view point, drying at conventional temperatures, and even at raised temperatures of 170°C, will not eliminate the potential for the resinous features (resinous latewood and resin streaks) to bleed when subjected to radiant heat (i.e., solar heat).

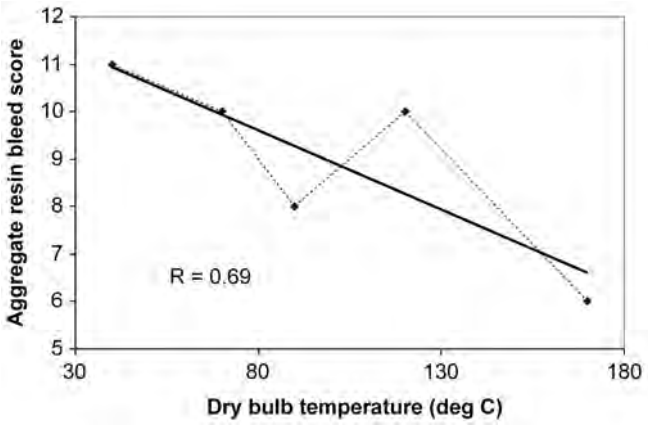

Figure 4. Aggregated resin bleeding from all boards (n = 6) at each kiln drying temperature.

The highest rating of 3 for resin bleeding was scored only by resin streaks. Resin streaks, by their size, are likely to have the largest reservoir of resin and are thus more likely to produce greater bleeding. Radiant heat induced resin bleed from streaks, resinous latewood, and resin canals.

Wood Drying

Issue No. 41 January 2008

VISITOR FROM ITALY TO THE WOOD DRYING LAB

Last November, Silvia Ferrari, a PhD student from the University of Padova in Italy, arrived to work at Scion to improve her knowledge of high-temperature drying. She will be staying at Scion for 5 months, not only to study HT drying but also to share her ideas about the stress phenomena of wood which she is studying for her PhD thesis.

Silvia's PhD project is to develop a sensor for measuring the stresses which develop in wood during the drying process. Knowing this, will lead to better adjustment of the kiln parameters to improve the final quality of the material.

In Italy the most common way to dry wood is by conventional drying, also called low-temperature drying, because the maximum value of the air temperature is about 70°C. This method is particularly suitable for the species dried in Italy which are difficult and slow to dry, especially the hardwoods.

Common species dried are European oak, beech, cherry, and African species including iroko, doussie, and niangon. These species are used for furniture and flooring.

Nevertheless, one of the Italian projects for the new year involves introducing new techniques in the field of wood drying with the aim of optimising energy consumption, the drying period, and the quality of the final dried material. This project will test high-temperature drying for her local species; hence Silvia's choice to come to New Zealand and to Scion to learn about drying research and HT drying in particular.

WOOD CORE TEMPERATURE BEHAVIOUR DURING DRYING

Rosie Sargent and Steve Riley

Recently there has been renewed interest in the core temperature of lumber boards during drying and steaming. Heat treatment standards specify that the centre of the board being treated must be above a certain temperature for a certain period of time. There is a commonly held belief that the internal temperature of a board will be at, or below, the WB (wet bulb temperature) until all free water has been removed, i.e., the wood is dried below the fsp — fibre saturation point (moisture content 25–30%). If this was the case, then when the WB is below the desired core temperature, as in a 90/60 schedule, long drying times would be needed to ensure the core is heated sufficiently.

The wet bulb temperature of an air-water mixture is defined as "*the dynamic equilibrium temperature attained by a water surface when the rate of heat transfer to the surface by convection equals the rate of mass transfer away from the surface*". So the heat being transferred to the water surface from the surroundings equals the amount of energy used to evaporate water on the surface. During drying the timber is not in equilibrium, and the water in the centre of the board is not able to evaporate until it reaches the surface. If the drying rate is limited by the rate at which the water can be transported to the surface, it is quite likely that more energy can be transferred to the board from the surrounding air than is taken away from the board by evaporation. The system is not in equilibrium, and the centre of the board is warmer than it would be if the moisture there was free to evaporate, i.e., above the WB temperature.

In experiments drying single boards of 100 × 40-mm radiata pine at Scion, the internal temperature will often go above the WB temperature quite early in the drying process. This behaviour is confirmed by different measurement techniques. Figure 1 shows core temperatures for a 90/60 (DB/WB) schedule, using three methods — small T-type thermocouples, fibre optic sensors (which have a thermal conductivity over a thousand times less than T-type thermocouples), and a two-dimensional heat

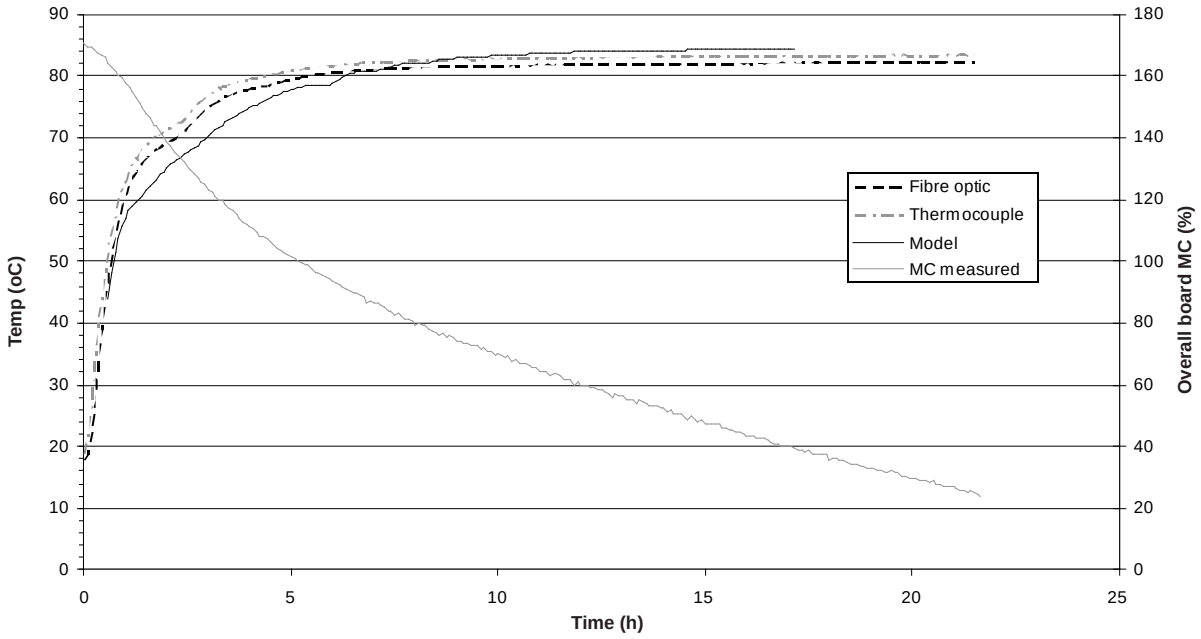

Figure 1. Measured and model-predicted core temperatures and measured overall moisture content for a single board dried at 90/60

and mass transfer model. Initially it was thought that heat conducting down thermocouple wires would make the temperature measured by the thermocouples artificially high. These results do show a slightly lower measured temperature for the fibre optic sensors than for the thermocouple measurements. The model tends to under-predict the temperature rise by both these methods. The fact is, the core temperature has risen above the WB long before the average moisture content has reached 30% (let alone the core). Figure 1 shows that the centre of the board in a 90/60 schedule will get above 74°C in less than 3 hours, while the board moisture content is still >120% (well above fibre saturation). Similar behaviour was found in all schedules measured. With HT (high temperature) schedules, often the cores will stay close to 100°C and then begin rising towards the DB as MC drops below fsp. Even so, they are still over the WB in the earlier stage of drying.

Thus even if your WB is below the core temperature limit, you may meet the phyto-sanitary standard. Since our model simulations conservatively estimate core temperature and have been rigorously tested they are accepted by phyto-sanitary authorities. A model simulation for each schedule and size combination is usually more cost-effective than measurement or installing probes.

NEW EXPORT REGULATIONS FOR KILN OPERATIONS

Ian Simpson and Steve Riley

All wood processors exporting timber from New Zealand must now comply with new requirements with the aim of aligning forestry and horticulture phyto-sanitation processes. At our recent Multiclient Drying meeting we invited Stephen Mansfield of Independent Verification Services (IVS), an independent verification agency, to inform us on this as it affects most people involved in wood drying. It is thus appropriate to summarise his presentation in this newsletter.

When exporting timber in the past, in order to meet kiln sterilisation requirements of the importing country, a company's kiln operator just had to sign and date charge sheets and the company just had to keep a record of such sheets. There was no mention of any QA system, involving particular procedures, training, or reference to equipment calibration.

In 2006 MAF Biosecurity NZ introduced new requirements with the aim of aligning forestry and horticulture phyto-sanitation processes. These were supposed to be in place by September 2007. The requirement put emphasis on the company's Quality Management systems. Kiln drying was seen as another treatment operation, i.e., heat treatment, and as such had to meet certain technical requirements.

Unfortunately heat treatments required by importing countries are not all the same; thus the kiln manager needs to be familiar with the particular importing

country's specification for condition of entry.
Examples of our key importing countries are:

Australia – Core temperature 74°C for a time which depends on thickness;

USA timber – Core temperature 71.4°C for 75 min (or as per dry-kiln operators' manual)?

ISPM 15 – Core temperature 56°C for 30 min?

The important message is that the process requires

- Verifiable procedures, i.e., documented procedures must be in place;
- Routine calibration of temperature sensors (at least annually);
- All records maintained in an orderly system.

Procedures require verification to the new Biosecurity NZ standards. This includes:

Documented organisation procedures;

Documented treatment procedures;

Importing country's specification available;

Temperature probes and moisture meters calibrated and dated;

Robust records, i.e., they clearly detail what information is recorded, who put it in, at what date and time, and any resultant action required;

Kiln operators are trained and are on a competency register.

For those who may still be unsure exactly how to set up the necessary procedures for documentation and calibration, there are independent verification agencies available (Verified Timber Ltd, Independent Verification Services Ltd, Asure Quality). Procedures may be verified with inserted probes or by documented proof that the drying or steaming schedules ensure the core temperature requirements are met. Scion Drying Model runs are acceptable for the latter and often prove a cost-effective solution. Figure 1 on p.2 shows that wood core temperatures are often reached sooner than commonly thought.

So, as Stephen clearly emphasised:

- Mills are gaining approval to the new Biosecurity NZ standard,
- Equipment calibration is achievable and maintainable.

And remember, calibration is about accuracy, and verification is about facts not faults.

Each issue we will delve into our files and give answers to frequently asked drying questions, trying to add to our general understanding of the technical issues behind the art of Wood Drying

WHAT IS THE FILLET AIR VELOCITY IN MY KILN WHEN I CHANGE BOARD OR FILLET THICKNESS?

Steve Riley

In most kilns the air velocity is measured for a given board and fillet thickness. When board or fillet thickness is changed in a drying stack, you may want to know what is the new airflow, in order to get some idea of the new drying time.

There is no simple answer to this, because when you change these stack dimensions, as well as changing the amount of area available in the stack where the delivered volume of air can flow, you are also changing the aerodynamic resistance of the stack. This affects the amount of volume delivered through the stack. Thus you cannot simply adjust the air velocity by the ratio of airflow space.

We showed in Newsletter No.38 that air bypassing the stack significantly affects performance and in Newsletter No.37 we showed that volume delivery of a fan in a kiln can be determined by the intersection of a system pressure-volume (PV) curve, and a fan PV curve. We now show (in Boxes A and B) how assuming a typical heat-exchanger type kiln (where the stack resistance is a small part of the overall resistance) these two results can be combined to get an expression to estimate new stack air velocity (v_2) for a new stack dimension, assuming we know the air velocity (v_1) for the original stack. Combining Equations A and B we get:

$$\frac{v_2}{v_1} = \frac{(1 + B_1)}{(1 + B_1 \left[\frac{S_1}{S_2}\right] \sqrt{\frac{R_{S2}}{R_{S1}}})} \left[\frac{S_1}{S_2}\right]$$

where R_s = stack aerodynamic resistance, and B (bypass ratio) and S (airspace ratio) are defined in Fig. 1.

The change in air space ratio (S_1/S_2) is known, but the stack resistance (R_{s1}/R_{s2}) and the original bypass (B_1) values are often not known. However, from this we can develop a rule of thumb in order to avoid having to always plug values into it.

- Firstly, note that if the original bypass value is zero then $v_2/v_1 = S_1/S_2$.
- Secondly, we have plotted the values of v_2 for a typical case, for range of board or fillet size changes (starting with 5 m/s for a 40 mm board and 20 mm fillet) in Figure 2. Note:
  - For kilns with 30–50 % bypass (the most common situation, see Newsletter No.38) the change in velocity is slightly more than half what it would be if the bypass was zero;
  - For kilns with a very high original bypass, the change in velocity is small.
- Thirdly, if we are not within our assumptions (i.e., there ***is*** a significant change in volume delivered with the change in stack) it can be seen in Box A, Figure 4, that changes will tend to be smaller than given in the expression. For example, if board thickness increases, pressure rises, volume decreases, and velocity gets smaller.

Thus we can formulate a rule of thumb:

To calculate a new stack air velocity v_2 when changing fillet size or board size in a timber drying kiln use:

$$v_2 = v_1 + a\left[\frac{S_1}{S_2} - 1\right]v_1$$

In the typical heat-exchanger kiln case where stack resistance is a small part of the overall resistance (i.e., single/double track plus the kiln has heat exchanger, etc.) and the board and fillet size changes are not extreme:

- If bypass is spectacularly low (B<10%), $a \cong 1$;
- If "normal bypass" (B is 30–50%), $a \cong 0.5$
- If bypass is high, a is small. Say $a \cong 0.2$

Conversely, if the stack resistance is a large part of the overall resistance (multiple stacks, no heat exchanger, and/or board and fillet size changes are extreme), a is likely to be small $\cong 0.2$) but you should consider using use fan and system PV curves.

In all cases if the exact value is important to you, you'll have to resort to fan and system PV curves (arrgh!!)

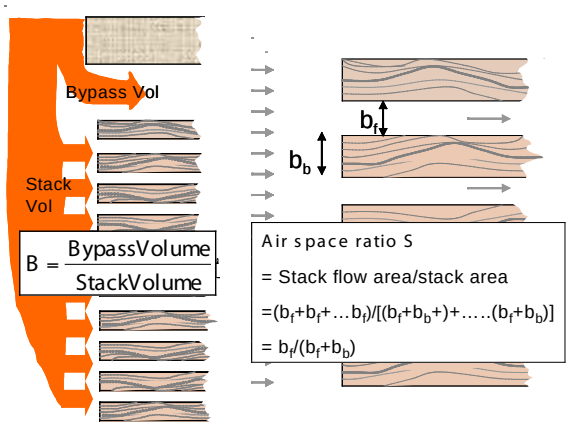

Figure 1. Bypass and air space ratios

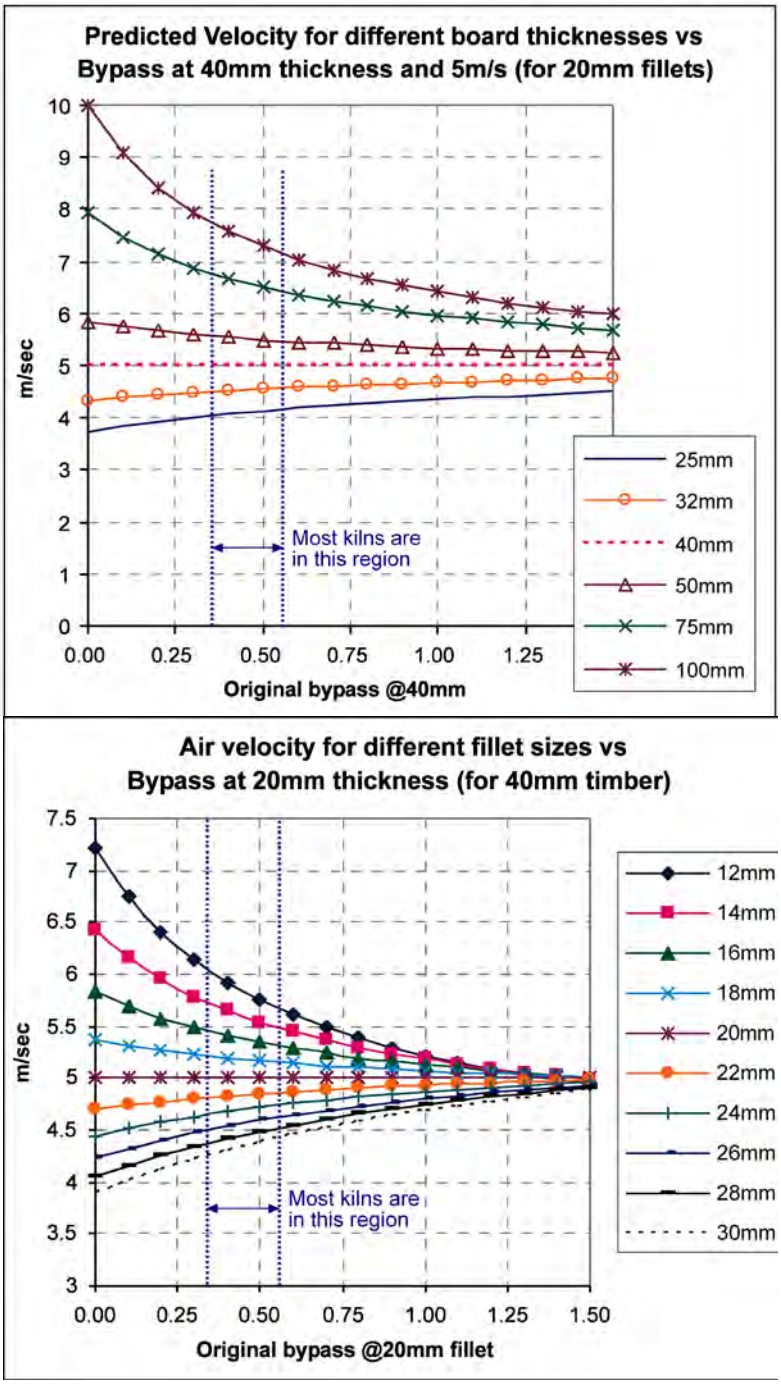

Figure 2. Typical results from the main equation, for base case of 5 m/s with 20 mm fillets, 40 mm boards, and 2.4-m stack.

Box A

Volume delivered by the fan when the stack dimensions are changed

If in a kiln the fans deliver a certain volume for one stack configuration, to find the new volume delivered, a new system curve intersection should be found with the fan curve. However, stack pressure drop is usually not the largest component, with pressure drops across the heat exchanger and fan orifice much higher.

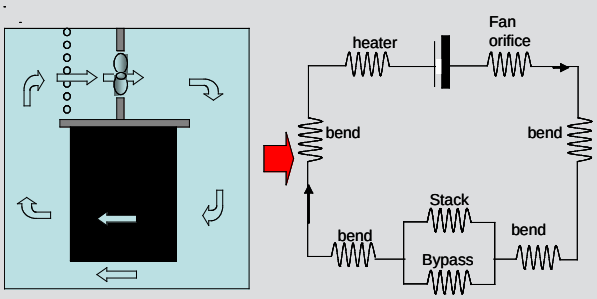

Figure 3. Stack air resistance is just one component

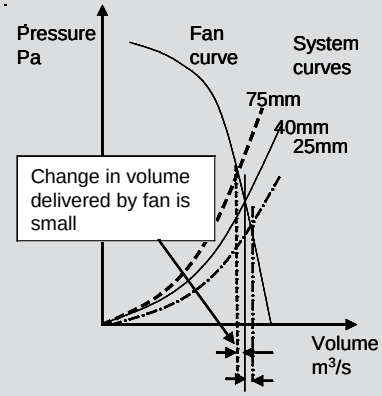

Figure 4. Volume delivered by fans determined from PV curves

Calculations of most common single and double track kilns with a heat exchanger, show surprisingly little change in total volume delivered when fillet thickness changes from a 40 mm base case to 25 or 75 mm. In most cases, the slope of the fan PV curve is steep, and maximum difference in volume delivery is ~3%. Thus we could simply assume when changing board thickness from 40 mm to 25–75 mm, that the volume (m^3/s) delivered by the fan is constant. If we compare a new situation (denoted by subscript 2) to a known situation (subscript 1),

remembering $B = \frac{BypassVolume}{StackVolume}$ we can say

$(1 + B_2)StackVol_2 = (1 + B_1)StackVol_1$. Since $\frac{v_2}{v_1} = \frac{StackVol_2}{As_2} \Big/ \frac{StackVol_1}{As_1}$ and stack flow area As

is proportional to $\frac{b_f}{(b_f + b_b)}$, we can write $\frac{v_2}{v_1} = \frac{(1 + B_1)}{(1 + B_2)} \left[\frac{\frac{b_{f1}}{(b_{f1} + b_{b1})}}{\frac{b_{f2}}{(b_{f2} + b_{b2})}} \right]$ Equation A

In cases where there are multiple stacks, no heat exchanger resistance, or extreme size changes or the slope of the fan PV is low, this assumption would need revisiting. We now need to deal with values for bypass (B). This is done in Box B.

Box B

Estimating bypass when stack dimensions are changed

In Newsletter No.38 we showed that air bypassing the stack significantly affects performance. By considering the airflow path as a collection of flow paths in series and parallel (Fig. 1), we could express bypass B as

$$B = \frac{BypassVolume}{StackVolume} = \frac{A_B}{A_S}\sqrt{\frac{R_S}{R_B}}$$ where A = flow area and R = aerodynamic resistance.

If we compare a new situation (denoted by subscript 2) to a known situation (subscript 1), we can compare bypass in two cases with

$$\frac{B_2}{B_1} = \frac{\frac{A_{B2}}{A_{S2}}\sqrt{\frac{R_{S2}}{R_{B2}}}}{\frac{A_{B1}}{A_{S1}}\sqrt{\frac{R_{S1}}{R_{B1}}}}$$ If the kiln stacks in case 1 and 2 have the same profile within the kiln, we can assume the bypass zones will have the same area and shape and thus $A_{B1} = A_{B2}$ and $R_{B1} \cong R_{B2}$. Since stack flow area is proportional to

$S = \frac{b_f}{b_f + b_b}$, we combine all the above into a simplified expression which will have terms that we have values for:-

$$\frac{B_2}{B_1} = \frac{\frac{b_{f1}}{(b_{f1} + b_{b1})}}{\frac{b_{f2}}{(b_{f2} + b_{b2})}}\sqrt{\frac{R_{S2}}{R_{S1}}}$$ Equation B

Thus if we know the base case bypass value and have values for stack resistance, we can get the new bypass value.